

**EFFECT OF NITROGEN LEVELS AND SPACING ON  
PRODUCTIVITY AND QUALITY OF INBRED AND  
HYBRID AROMATIC RICE**

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**DIVISION OF AGRONOMY  
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PRODUCTIVITY AND QUALITY OF INBRED AND HYBRID  
AROMATIC RICE**

By

**ANAND KUMAR GAUTAM**

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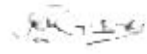
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*This is to certify that the thesis entitled, "Effect of nitrogen levels and spacing on productivity and quality of inbred and hybrid aromatic rice", submitted to the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirements for the degree of Doctor of Philosophy IN AGRONOMY embodies the results of bona fide research work carried out by Mr. Anand Kumar Gautam (Roll No.8767), under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.*

*The assistance and help received during the course of investigation have been duly acknowledged.*

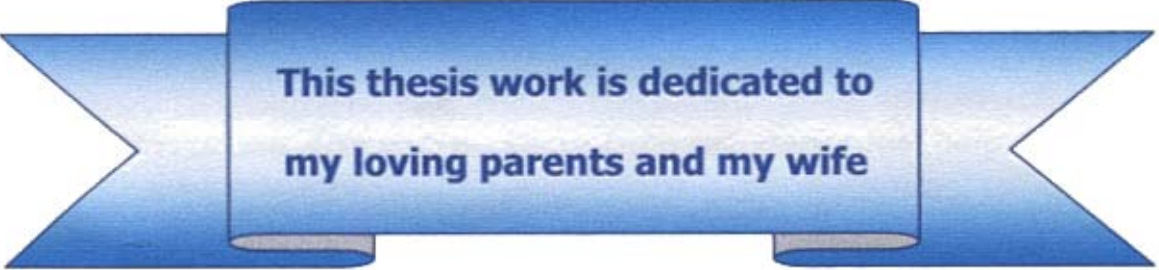
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**This thesis work is dedicated to  
my loving parents and my wife**

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## CHAPTER I

# INTRODUCTION

# INTRODUCTION

Aromatic rices occupy a pivotal position in India because of their high quality. Due to their excellent quality characters, they are popular in international market. India is one of the major producer and exporter of Basmati rice in the international market. Such rices are cultivated on an area of 0.7 million ha with annual production of 0.8 million tonnes of milled rice (Singh, 2000 and Dahiphale *et al.*, 2002). These areas are confined mainly to Punjab, Haryana, western U.P. and parts of Rajasthan in Trans-Indo-Gangetic plains (Anonymous, 2003). Among agricultural commodities, the share of Basmati/aromatic rices in total foreign exchange through export is about 24%, whereas the quantity is only 18% of total exported agricultural products (Sinha *et al.*, 2003). During the year 2001-2002, 6.67 lakh tonnes (30.2% of total rice export) of Basmati rice was exported from India, bringing Rs. 1842 crores as foreign exchange to the country (FAI, 2003). Thus, aromatic rices, particularly Basmati types, are the premium commodity for earning foreign exchange.

Out of many aromatic rice varieties cultivated in India, traditional tall varieties of Basmati constitute a sizable proportion of export, but their productivity is very low compared to non-aromatic rice varieties (Raju *et al.*, 1990 and Gangaiah and Prasad, 1999). Efforts are needed to increase the yield of aromatic rices for enhancing the quantum of exports for foreign exchange reserves. In this regard, a number of Basmati rice varieties have been developed through systematic genetic improvement programme. The release of aromatic rices of Basmati type viz. Pusa Sugandh 3 (inbred) and PRH 10 (hybrid) is expected to increase production and thus export of high quality rice. These

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varieties with attractive grain quality are input-responsive and early in maturity. They have the potential to produce 11 to 17% more grain yield than the previously developed Basmati rice varieties like Pusa Basmati 1 (IARI, 2002).

Agronomic practices for rice hybrid are different from inbred rices because of its genetic variability. In order to tap yield potential of newly-developed rice varieties either hybrid or inbred, appropriate agronomic practices needs to be developed. Among these practices, establishing an optimum plant density and application of nitrogen are the important factors to achieve higher yield from different rice varieties (Kumar *et al.*, 2002a). Because of high vigour and profuse tillering ability the rice hybrids may be transplanted wider as compared to conventional high-yielding varieties (Zhende, 1988).

It is an established fact that higher amount of major nutrients, specially nitrogen, is required to exploit the full yield potential of high yielding rice cultivars. Hybrids of any crop in general require higher doses of nitrogen. Meena *et al.* (2003) recorded highest grain yield of rice hybrid with the application 200 kg N ha<sup>-1</sup>, whereas inbred non-aromatic rice varieties responded only up to 120 kg N ha<sup>-1</sup> (Ram *et al.*, 2002). However, the information on nitrogen requirement and spacing for optimum yield of newly-released inbred and hybrid rice varieties is limited.

With the increasing scope of export, the feasibility of cultivation of newly-released inbred and hybrid aromatic rices in the traditional Basmati rice areas has to be explored. Full exploitation of yield potential cannot be realized unless a location specific agronomic practices are developed. Further, research results of crop management practices obtained

at a particular place cannot be generalized for other locations. It needs evaluation over years before recommendation.

Research results cannot be evaluated at each location over many years through field experiments because they are labour and time-consuming and expensive. Now-a-days, dynamic crop growth simulation models are available as tool to reduce the time required for field studies (Ramasamy, 2000). Crop models are increasingly being used for technology transfer and resource management (Whisler *et al.*, 1986) and estimating potential productivity (Aggarwal *et al.*, 2000 and Haefele *et al.*, 2003). They can also determine the suitable area for adoption of any agricultural technology by synthesizing and evaluating the research findings. The crop models are used for various purposes, such as, to find out optimum sowing dates and plant population, specific variety for location, and input requirement as well as their combination for attaining maximum productivity. Therefore, this tool can be used very well to describe variety x environment x crop management interactions, and their effect on growth and yield of rice (Probert *et al.*, 1998). As crop model can synthesize and evaluate the research results, modeling approach has been attempted to extrapolate the research findings for different rice growing areas of Indo-Gangetic plains of India.

Keeping above facts in view, the present investigation entitled **“Effect of nitrogen levels and spacing on productivity and quality of inbred and hybrid aromatic rice”**: was undertaken with the following objectives:

- i) To find out the appropriate plant spacing and nitrogen requirement for inbred and hybrid aromatic rice,

- ii) To evaluate the influence of spacing and nitrogen on growth, yield, N uptake and quality of aromatic rice,
- iii) To calibrate and validate the crop model by simulating the effect of spacing and N levels on aromatic rice, and
- iv) To simulate the effect of nitrogen and spacing on productivity of aromatic rices at different locations of Indo-Gangetic plains of India.

## **CHAPTER II**

# **REVIEW OF LITERATURE**

# REVIEW OF LITERATURE

In this chapter an attempt has been made to review the recent literature under different sub-heads pertaining to the present study. However, due to paucity of experimental evidences on some aspects of inbred and hybrid aromatic rice, similar related work on non-aromatic rice has also been reviewed and presented. The evidences of crop simulation modelling on rice along with other crops are also being cited.

## 2.1 Inbred and hybrid rice

The exploitation of heterosis in hybrid rice is comparatively a recent phenomenon. Among the extent of heterosis, standard heterosis i.e. superiority of  $F_1$  over best check is more reliable for the right index for all the practical purpose (Manuel and Prasad, 1992).

### 2.1.1 Growth characters

Several research workers have reported positive heterosis in hybrid rice for growth parameters. Singh *et al.* (1992) observed significantly negative heterosis for plant height (-22.94%) and days to maturity (-16.26%) in IR 46830A x Madhuri than the inbred variety Sarjoo-52. The negative heterosis on these traits is preferable because of their association with stem stiffness and early maturity, respectively. Hybrid rice possesses higher physiological efficiency due to its vigorous root system, greater sink size, larger leaf area index (LAI) during grain filling and wider adaptability to varied environment with 10 to 15% yield advantage as compared to inbred varieties (Yang *et al.*, 1999).

Sahai and Chaudhary (1986) reported the superiority of hybrids in root growth over their parents which helped in utilizing the applied nitrogenous fertilizer more efficiently.

Under drought condition, hybrids had longer root length at tillering and at harvest (Souframanien *et al.*, 1998) and thus reduces the adverse effect of drought.

Growth analysis of six hybrids showed up to 115.5% higher heterosis for crop growth rate at vegetative stage with 3.5 – 23.8% higher leaf area index than the inbred variety Chaitanya (Madhuri *et al.*, 2001). Similarly, Srinivasulu *et al.* (1992) found significantly better growth performance of rice hybrids than conventional varieties, particularly at early growth stages with higher LAI, CGR and RGR.

The results of Chandrasekhar *et al.* (2001) revealed that hybrid rice TNRH-6 recorded higher values of CGR ( $29.2 \text{ g m}^{-2}\text{day}^{-1}$ ), LAI (3.93), LAD ( $100 \text{ dm}^2$ ), dry matter production ( $23.41 \text{ g plant}^{-1}$ ), tillers  $\text{plant}^{-1}$  (8.5), leaf area ( $241 \text{ cm}^2 \text{ plant}^{-1}$ ) and SLW ( $0.5 \text{ g m}^{-2}$ ) compared to pure line variety NLR 33358. Kumar and Subbaiah (2001) observed 10% and 17% higher tillers  $\text{m}^{-2}$  and DM ( $\text{g m}^{-2}$ ) at panicle initiation, respectively, in hybrid rice PAC-803 than the variety Ajaya. Padmavathi (1997) and Singh (2002) have also reported higher tiller no.  $\text{hill}^{-1}$ , more leaf area index and higher dry matter in hybrid rice as compared to inbred rice variety.

Lin and Liang (1997) found that *indica* hybrid Shanyou 63 showed heterobeltiosis for dry matter production due to higher tillers  $\text{plant}^{-1}$  and grains  $\text{panicle}^{-1}$  compared to Minhui 63. According to Yang *et al.* (2001) *Japonica-indica* hybrid rice accumulated 59% and 105% higher dry matter during grain filling than the average of parents and *indica-indica* hybrid Shanyou 63, respectively, which was attributed to the large leaf area index at heading and high photosynthetic potential from heading to harvest.

### 2.1.2 Yield attributes

Heterosis for yield in hybrid rice come mostly from vegetative growth (Yan, 1988) and also from simultaneous heterosis for number of productive tillers, panicle length and weight, fertile spikelets panicle<sup>-1</sup> and harvest index (Lokaprakash *et al.*, 1992; Shrivastava and Tripathi, 1999; Salgotra, 2000), 1000-grain weight and filled grains panicle<sup>-1</sup> (Vanniarajan, 1996), panicles per unit area and filled grains percentage (Balasubramanian and Ilyas, 1998).

Niu *et al.* (2001) reported more panicles plant<sup>-1</sup>, longer panicle, more number of grains panicle<sup>-1</sup> and higher test weight in hybrid rice as compared to high yielding inbred variety Liyou 57.

Paramasivan and Rangasamy (1990) have noticed negative heterosis (33-49%) for spikelet sterility, whereas Singh and Maurya (1999) observed 10 to 24% negative heterosis for spikelet fertility in eleven hybrids than Sarjoo-52 rice variety. Sarkar *et al.* (2001) also reported negative spikelet fertility (3-7%) in non-basmati hybrid but 15 and 17% positive heterosis in basmati rices PRH-12 and PRH-22, respectively, compared to Pusa Basmati-1. They also noted positive heterosis for productive tillers in both basmati and non-basmati hybrids at various locations in India.

Negative standard heterosis has been observed for test weight in hybrids by various researchers (Reddy *et al.*, 1984; Singh and Maurya, 1999; Setharamaiah *et al.*, 1999 and Chandrasekhar *et al.*, 2001). But they advocated higher heterosis for panicle length, total spikelets panicle<sup>-1</sup>, filled grains panicle<sup>-1</sup> and harvest index.

Padmavathi (1997) observed that rice hybrid NDHR-2 produced longer and heavier panicles, more sterile and total spikelets per panicle and higher 1000-grain weight than Pusa 834. On the other hand Pusa 834, an inbred rice, produced more panicles  $m^{-2}$  and significantly lesser sterile spikelets per panicle than rice hybrid NDHR-2. While panicle length, panicle weight, fertility per cent and test weight were higher in PRH-16 as compared to PA-6201. A non-scented hybrid rice Pusa RH-6 recorded significantly longer panicle, more number and weight of grains per panicle, higher fertility percentage and test weight than the scented hybrid rice RH-10 (Kumar *et al.*, 2002a).

Studies made by Bhanumathy *et al.* (2003) indicated that high yielding hybrids manifest positive heterosis for long panicles, filled grains, spikelet fertility and high standard heterosis for productive tillers and 1000-grain weight.

The results of Patil *et al.* (2003) indicated that two-line rice hybrids TGMS18 x CO and Pei'ai 64 x CO2 showed heterotic effect for profused tillering ability, panicle length and grains per panicle over three line rice hybrids CORH-2 and ADTRH-1.

### 2.1.3 Yield

In general, rice hybrids have yield advantage of 1 to 1.5  $t\ ha^{-1}$  over inbred high yielding rice varieties yielding 5 to 6  $t\ ha^{-1}$  in India (Virmani, 2002). Hybrid ORI 161 resulted 17% increase in grain yield ( $7.6\ t\ ha^{-1}$ ) over the best available pure line genotypes along with higher harvest index (Om, 1996).

Studies of Rangaswamy *et al.* (1999) at Tamil Nadu, revealed that the mean grain yield of medium duration semi-dwarf hybrid CORH-2 was 20% higher ( $6.1\ t\ ha^{-1}$ ) as compared to high yielding variety ADT-39 ( $5.0\ t\ ha^{-1}$ ) after multi-year multi-location 93

research trials. Similarly, ADTRH-1 released in 1998 for cultivation showed 26.9% and 24.5% higher yield over CORH-1 and ASH-18, respectively, with an average yield of 6.6 t ha<sup>-1</sup> (Kirubakaran *et al.*, 2001).

After evaluating under diverse agroclimatic zone of Andhra Pradesh, Vijaykumar *et al.* (1999) noticed the mean grain yield of hybrid rice between a range of 0.8 to 1.6 t ha<sup>-1</sup> higher than conventional rice variety IR 64. Prasad *et al.* (1998) reported that hybrid rice Pusa HR 3 produced significantly more grain yield (5.6 t ha<sup>-1</sup>) as compared to inbred rice Pusa 834 (3.3 t ha<sup>-1</sup>). Maity and Mishra (2001) found 8 and 17% more grain yield and harvest index, respectively, in hybrid PRH-16 over PA-6201 but less straw yield. At moderate level of 60 kg N ha<sup>-1</sup>, Baig *et al.* (1999) recorded higher positive heterosis for grain yield and harvest index. Srinivasulu *et al.* (1999) observed that the rice hybrid APHR-1 produced significantly higher (6.25 t ha<sup>-1</sup>) grain yield than conventional variety Chaitanya (5.97 t ha<sup>-1</sup>).

Singh *et al.* (2000) found that IASH Basmati hybrid-1 had an yield advantage of 1.3 t and 3.7 t ha<sup>-1</sup> over Basmati varieties CB-II (4.7 t ha<sup>-1</sup>) and Basmati-1 (3.75 t ha<sup>-1</sup>) at Rajasthan and Uttar Pradesh, respectively. The same hybrid showed a clear advantage of about 1.5 t ha<sup>-1</sup> over Pusa Basmati-1 at Hyderabad and Bangalore. In Uttar Pradesh it yielded as high as 8.0 t ha<sup>-1</sup> as compared to best check non-aromatic variety Sarjoo-52 (2.5 – 3.8 t ha<sup>-1</sup>).

The results of Reddy *et al.* (2001) indicated that rice hybrid KRH-2 gave 37% and 22% higher grain yield and harvest index than inbred variety IR 60, respectively. Similar superiority of hybrids over high yield conventional varieties has been reported by several

researchers (Mahendra Kumar *et al.*, 2001, Om *et al.*, 2001, Rigor *et al.*, 2001, George *et al.*, 2002 and Rao and Moorthy, 2002).

After multilocation testing, Guha Sarkar *et al.* (2001) found that Basmati hybrids (PRH 22, PRH 12, PRH 10 and PRH 9 ) and non-Basmati hybrids (PRH 3, PRH 6, PRH 16 and PRH 21) had significantly positive heterosis for grain yield per plant ranging from 27% to 154% and 15% to 57% over Pusa Basmati-1 and Jaya, respectively.

#### **2.1.4 Nitrogen uptake**

Hybrid rice had higher affinity in absorbing nitrate nitrogen than conventional cultivars especially at reproductive growth stages (Luo *et al.*, 1993). Yang *et al.* (1999) observed higher nitrate nitrogen concentration in hybrid rice than those of the inbred variety at most growth stages and suggested that nitrate accumulation and nutrient might be associated with high grain yield of hybrid rice. Padmavathi (1997) reported that during the initial (30 DAT) stages of crop growth, rice hybrid NDHR-2 recorded higher N content and uptake than Pusa 834. Maity (1998) found similar nitrogen uptake pattern before mid-tillering, heading and at grain filling stages in hybrids PA 6201 and PRH-6. But noticed higher uptake in strains by PA 6201 than PRH 6.

Srinivasulu *et al.* (1999) observed that rice hybrid APHR-1 had significantly higher N-uptake (138.3 kg ha<sup>-1</sup>) than the conventional variety Chaitanya (131.9 kg ha<sup>-1</sup>) irrespective of non-significant nitrogen content in grain and straw. Baig *et al.* (1999) revealed that nitrogen uptake by hybrids was significantly higher at harvesting than restorer lines and conventional variety but non-significant during flowering than variety Swarnprabha.

Kumar *et al.* (2002b) reported 15.95 and 11.25 per cent higher N-uptake in non-scented Hybrid Pusa RH-6 than in scented Hybrid Pusa RH-10 during two years of study, respectively. Singh (2002) found that nitrogen uptake by aromatic rice hybrid was 60% higher than Pusa Basmati-1.

### 2.1.5 Quality characteristics

Different cytoplasm has genetic effect on the quality parameters of rice. Hybrids developed from cytoplasmic male sterile lines thus varies in their grain quality. Cytoplasmic effects were observed significant for fat content, protein content, brown rice rate and amylose content (Yi and Chen, 1992).

Maity (1998) noticed higher hulling, milling and head rice recovery, head rice yield and protein content in rice hybrid PA-6201 as compared to PRH-16. Whereas Kumar (2001) found that rice kernel length after cooking and protein content values were higher in aromatic rice hybrid Pusa RH-10 than non-aromatic rice hybrid Pusa RH-6. However, no noticeable change was observed between these two hybrids in other quality characters except head rice recovery and breadth of rice kernel before cooking.

Singh *et al.* (2001b) has reported varietal differences in quality parameters of Basmati type aromatic rice varieties. The variety Pusa 1121 exhibited maximum kernel length (8 mm), L:B ratio (4.74), head rice recovery (54.5%) and kernel elongation ratio (2.70), while Taraori Basmati recorded maximum hulling (78.8%) and Basmati 370 with highest milling (72.5%).

In an experiment, Kirubakaran *et al.* (2001) observed higher physical and cooking quality characteristics of rice hybrid ADTRH-1 compared to inbred variety ASD 18. Salgotra

*et al.* (2002) reported that hybrids exhibited significant positive heterosis for protein content and negative heterosis for L:B ratio under both normal and high fertility level.

## 2.2 Spacing

Plant spacing due to variation in plant population affects growth parameters, yield attributes and yield.

### 2.2.1 Growth characters

Many researchers (Nigam *et al.*, 1988; Krishnan *et al.*, 1994; Rajesh and Thanunathan, 2003) reported an increase in rate of tillering with an increase in plant spacing. However, tillers  $m^{-2}$  decreased with increase in plant spacing which may be due to the less number of hills per unit area (Gulati *et al.*, 1987; Sharma, 1994a; Kanungo and Roul, 1994).

Padmajarao (1995) reported substantial increase in LAI, number of tillers and dry matter  $m^{-2}$  at a closer spacing (20 x 10 cm) over wider spacings (20 x 15 and 20 x 20 cm) of the scented rice varieties. Padmavathi (1997) and Kumar (2001) observed that closer spacing tended to produce taller plant and more dry matter as compared to wider spacing.

Nigam *et al.* (1988) found higher LAI, TDM  $plant^{-1}$  and leaf area duration in dense population than in sparse population. From their study, Shrirame *et al.* (2000) noticed that wider spacing of 20 x 15 cm recorded significantly higher number of functional leaves, leaf area, number of total tillers and dry matter accumulation  $hill^{-1}$  as compared to closer spacing of 20 x 10 cm.

### 2.2.2 Yield attributes

In their experiments Sharma and Singh (1992) and Singh *et al.* (2001c) observed a significant increase in number of panicles  $m^{-2}$  with decrease in spacing. Contrary to this, Krishnan *et al.* (1994) observed more productive tillers  $m^{-2}$  with wider spacing of 20 x 10 cm than 15 x 10 cm spacing. Whereas, Verma *et al.* (2002) noticed significantly more number of effective tillers  $m^{-2}$  in 20 x 20 cm and 20 x 15 cm spacings than 20 x 10 cm, but reported former two spacings at par. In contrast, Venugopal and Singh (1985) recorded no significant effect of plant spacing on number of panicles  $m^{-2}$ .

Kanungo and Roul (1994) reported significantly higher test weight at a spacing of 15 x 15 cm over 15 x 10 cm spacing with non-significant effect in panicle length and unfilled grains per panicle.

Padmavathi (1997) reported higher yield parameters such as number of panicles  $m^{-2}$ , panicle weight, panicle length and test weight with closer spacing (15 x 10 cm) than wider spacing (20 x 20 cm). While, Kumar *et al.* (2002a) observed higher values of number and weight of grains per panicle, length of panicle, 1000-grain weight and fertility percentage at plant density of 25 plants  $m^{-2}$  over a density of 33 and 50 plants  $m^{-2}$ . The study of Verma and Mani (2000) indicated longer panicle length and more grains per panicle at closer spacing (20 x 15 cm) than at wider spacing (20 x 20 cm) with no difference in 1000-grain weight.

Satyavathi *et al.* (2001) noticed substantial increase in number of grains  $panicle^{-1}$  and 1000-grain weight from 20 x 10 cm to 20 x 15 cm and 20 x 20 cm spacing, but marginal decrease in panicle length and spikelet sterility. While, Singh *et al.* (2001c)

reported no significant difference in panicle length, grain weight, number of grains per panicle and 1000-seed weight when rice transplanted at 20 x 10 cm and 15 x 10 cm spacings.

Regarding spikelet sterility, transplanting rice at closer spacing of 20 x 10 cm produced more spikelet sterility (30.5%) than wider spacing (21.6%) of 20 x 20 cm (Verma *et al.*, 2002). Saktivel and Subramanian (2002) also reported that higher population density (88 hills m<sup>-2</sup>) exhibited more degree of spikelet sterility over lower density (60 hills m<sup>-2</sup>).

### 2.2.3 Yield

Padmavathi (1997) and Singh *et al.* (2001c) reported significantly higher grain and straw yield with 15 x 10 cm spacing as compared to 20 x 10 cm spacing which was mainly due to more number of panicles m<sup>-2</sup>. Gangaiah and Rao (2000) observed that scented rice cultivar produced 7.7% and 8.2% more grain and straw yield, respectively, at a spacing of 15 x 10 cm than 15 x 15 cm. Contrary to this, Venugopal and Singh (1985) and Krishnan *et al.* (1994) found higher grain and straw yield of non-scented rice variety with increase in plant spacing.

The grain yield of Basmati-370 decreased with the increase in spacing from 20 x 10 cm to 20 x 20 cm (Padmajarao, 1995). But, Verma and Mani (2000) and Satyavathi *et al.* (2001) observed increase in grain yield per plant from 20 x 10 cm to 20 x 20 cm spacing.

Contrary to the above findings, some researchers (Raju *et al.*, 1989; Kanungo and Roul, 1994; Shrirame *et al.*, 2000; Sharma and Bali, 2001) have also reported no significant difference in grain and straw yields of rice with different spacings.

Grain yield of Pusa Basmati-1 was found to be higher at a spacing of 20 x 15 cm than when planted at a spacing of 15 x 15 cm (Jadhav *et al.*, 2002). Nayak *et al.* (2002) observed that straw yield was significantly more under closer spacings of 15 x 15 cm and 20 x 10 cm than wider spacing of 20 x 15 cm.

Kumar *et al.* (2002b) reported a density of 25 plants m<sup>-2</sup> registered 9.0 and 6.1% higher grain yield over a density of 33 plants m<sup>-2</sup> and 21.5 and 13.5% higher over a density of 50 plants m<sup>-2</sup> during 1998 and 1999, respectively along with significantly higher harvest index. However, higher plant density produced more straw yield than lower plant density. Verma *et al.* (2002) also observed similar results.

Rajesh and Thanunathan (2003) noticed significantly higher grain and straw yield of a traditional rice variety Kambanchamba at a wider spacing of 20 x 15 cm than a closer spacing of 20 x 10 cm.

#### **2.2.4 Nitrogen uptake**

Thorat and Patil (1987) observed significantly higher uptake of nitrogen at a spacing of 15 x 10 cm than 15 x 15 cm and 15 x 20 cm at maximum tillering, flowering and harvesting stages of rice. However, maximum N uptake was at flowering stage.

Srinivasulu *et al.* (1999) reported that the nitrogen uptake by grains and straw of rice was non-significant with normal and skip row planting. Padmavathi (1997) also obtained similar results, however, nitrogen uptake was more with 15 cm spacing than the 20 cm spacing at early crop growth stages.

Gangaiah and Rao (2000) also confirmed that the total nitrogen uptake by rice transplanted at a spacing of 15 x 10 cm was 8.2% higher than planted at a spacing of 15 x

15 cm. In contrast, Kumar *et al.* (2001b) reported that nitrogen uptake by grains and total nitrogen uptake was enhanced significantly with a density of 25 plants m<sup>-2</sup> over 33 and 50 plants m<sup>-2</sup>, where as reverse trend was noticed on nitrogen uptake by straw.

### **2.2.5 Quality characteristics**

Chandra *et al.* (1997) reported that quality parameters like head-rice recovery (%), kernel elongation (mm) and L:B ratio were not significantly altered due to plant spacings. But, Satyavathi *et al.* (2001) observed higher amylose and protein content and volume expansion ratio in wider spacing (20 x 20 cm) than in narrower spacing (20 x 15 cm and 20 x 10 cm). However, kernel elongation ratio and L:B ratio were unaffected. Kumar (2001) noticed that lower plant density (25 plants m<sup>-2</sup>) significantly influenced the hulling and milling percentage and head rice recovery as well as rice length and breadth before and after cooking towards higher value.

## **2.3 Nitrogen**

Nitrogen is a constituent of all protein and non-protein components in rice. It is associated with green colour of leaves, photosynthetic activity, vegetative growth and regulates rice productivity. Nitrogen normally limits rice production because crop removes large amount of nitrogen and also it is easily lost from soil (Prasad, 1996). It is required in adequate amount for maximizing the rice productivity. Response to fertilizer nitrogen differs among rice varieties affecting their growth, yield attributes, yield and quality. In this regard, though enormous informations on the effect of fertilizer nitrogen is available, but here the review is restricted to only pertinent literatures.

### 2.3.1 Effect of N on growth attributes

Generally increased application of N significantly increased the growth parameters such as plant height (Singh *et al.*, 1995; Maske *et al.*, 1997; Singh *et al.*, 1998; Jaiswal and Singh, 2001), tiller number per hill (Om *et al.*, 1999; Maske *et al.*, 1997; Kalia and Kumar, 2002), dry matter production (Om *et al.*, 1998; Singh and Singh, 2000), leaf area index (Jaiswal and Singh, 2000; Baig *et al.*, 1999; Somasundaram *et al.*, 2002b), crop growth rate and number of tillers  $\text{m}^{-2}$  (Lawal and Lawal, 2002). Contrary to these findings, Paraye and Kandalkar (1994) reported that increasing nitrogen level from 50 to 150  $\text{kg ha}^{-1}$  did not affect the plant height and effective tillers  $\text{m}^{-2}$  in conventional rice varieties.

Aromatic rices showed significant increase in plant height and dry matter production with each successive increment of N from 0 to 180  $\text{kg ha}^{-1}$  (Gangaiah and Prasad, 1999). Chopra and Chopra (2000) observed significant increase in plant height and total biomass with increase in N levels in aromatic rice variety Pusa Basmati-1. Yadav *et al.* (2002) observed that plant height, panicle length and dry matter production of rice cultivars increased successively from 0 to 120  $\text{kg N ha}^{-1}$ .

From their study Reinke *et al.* (1994) observed significant increase in anthesis and harvest biomass with each increment of nitrogen. Growth analysis of different rice varieties revealed that the application of high level of nutrient manifested significantly higher tiller production, plant stature, leaf area index, leaf area ratio, crop growth rate, biomass production; whereas specific leaf weight, relative growth rate and per cent of pre-anthesis and post-anthesis dry matter production decreased drastically (Singh and Jain, 2000).

### 2.3.2 Effect of N on yield attributes

Singh *et al.* (2001a) and Singh *et al.* (2003a) observed significant improvement in the yield attributing characters with successive increase in the level of nitrogen. Dar *et al.* (2000) and Singh and Singh (2000) noticed significant increase in number of panicles  $m^{-2}$ , panicle length and grains panicle $^{-1}$  with increasing level of nitrogen. Dhurandar *et al.* (2000) and Brinda *et al.* (2001) reported significant increase in number of panicles  $m^{-2}$  and filled grains panicle $^{-1}$  up to 90 kg N  $ha^{-1}$  in aromatic basmati and non-aromatic rice cultivar, respectively. Prakash (2002) observed that number of panicles  $m^{-2}$  and panicle weight of basmati rice were at par with the application of 90 and 120 kg N  $ha^{-1}$  in Rajasthan.

In hybrid rice, the panicles  $m^{-2}$  and panicle weight significantly increased up to the application of 150 kg N  $ha^{-1}$  and at par with the application of 200 kg N  $ha^{-1}$  (Subbiah *et al.*, 2001). But, Balasubramanian (2002) reported that number of grains panicle $^{-1}$ , 1000-grain weight, panicle length and weight were significantly increased with the increments of nitrogen from 0 to 200 kg  $ha^{-1}$ .

An increase in test weight (1000-grain weight) with increasing level of fertilizer nitrogen was reported by several workers (Behera, 1998; Chopra and Chopra, 2000; Pal *et al.*, 2001). However, Rajarathinam and Balasubramanian (1999), Om *et al.* (2001) and Ram *et al.* (2002) found no change in test weight with the application of increasing level of fertilizer nitrogen. In contrast, Kalia and Kumar (2002) reported significant increase in 1000-grain weight along with panicle weight of aromatic rice varieties up to the application of 90 kg N  $ha^{-1}$  and then decrease at 135 kg N  $ha^{-1}$ .

Om *et al.* (1998), Balasubramanian (2002) and Dhurandhar and Tripathi (1999) reported heavier panicles with increased application of fertilizer nitrogen. Singh (2002) noticed an improvement in the yield attributes with successive increase in the level of N.

### 2.3.2 Yield

Increase in grain yield with an increase in the level of nitrogen have been reported by many workers from different parts of the world (Wani *et al.*, 1999; Dar *et al.*, 2000; Paikaray *et al.*, 2002). Raju *et al.* (1990), Singh and Shreedevi (1997), Behera (1998), Jadhav and Sahane (1998) and Singh and Pillai (1996) reported linear increase in grain yield of scented rice up to 90 kg N ha<sup>-1</sup> and then marginal increase thereafter. Whereas, Pal *et al.* (2001) observed that grain and straw yield at 60 and 90 kg N ha<sup>-1</sup> were at par on clay-loam slightly acid soil of Ranchi.

From Pakistan, Asif *et al.* (1997) reported highest grain yield of variety Basmati 385 with 130 kg N ha<sup>-1</sup>. Gangaiah and Prasad (1999) observed significantly higher grain and straw yield of aromatic rice at 180 kg N ha<sup>-1</sup> over 120 kg N ha<sup>-1</sup>. Shukla *et al.* (1993) reported that increasing level of nitrogen from 0 to 150 kg ha<sup>-1</sup> led to linear increase in grain and straw yield of high yielding semi-dwarf rice variety IR-36. Whereas, Krishnan *et al.* (1994) noticed no significant difference in grain and straw yield at the application of 180 and 240 kg N ha<sup>-1</sup> at Coimbatore.

Shrivastava and Tripathi (1999) reported that the application of 120 kg N ha<sup>-1</sup> significantly increased the grain yield of hybrid and inbred rice varieties as compared to lower (60 kg N ha<sup>-1</sup>) and higher doses (180 kg N ha<sup>-1</sup>). They observed that increase in nitrogen dose beyond 120 kg N ha<sup>-1</sup>, though increased the straw yield but decreased the

grain yield by about 8.19% at higher dose of nitrogen. Maity and Mishra (2001) reported 48 and 26% higher grain yield of hybrid rice at 160 kg N ha<sup>-1</sup> over zero and 80 kg N ha<sup>-1</sup> followed by 17.5% decline at 240 kg N ha<sup>-1</sup>. Om *et al.* (1999), Om *et al.* (2000) and Meena *et al.* (2003) reported that application of fertilizer nitrogen up to 200 kg ha<sup>-1</sup> increased the grain and straw yield of rice hybrids.

The national advanced varietal trials conducted in India during 2002-2003 revealed varied response of basmati and hybrid rice to N levels in different regions. Basmati rice varieties responded up to 60 kg N ha<sup>-1</sup> at Kaul and up to 120 kg N ha<sup>-1</sup> at Nagina. At Kapurthala, yield differences were not significant at different levels of applied fertilizer nitrogen. The grain yield response of hybrid rice to nitrogen was reported to be significant up to 100 kg N ha<sup>-1</sup> at Parbhani and Mandya, 120 kg N ha<sup>-1</sup> at Aduthurai, 120 kg N ha<sup>-1</sup> at Kapurthala and Kanpur, 150 kg N ha<sup>-1</sup> at Karjat and 180 kg N ha<sup>-1</sup> at Pantnagar (DRR, 2004).

### 2.3.3 Nitrogen uptake

Increase in N content (%) and N uptake (kg ha<sup>-1</sup>) with increase in the application of fertilizer nitrogen up to 120 kg ha<sup>-1</sup> has been reported by several researchers (Dubey and Bisen, 1989; Pradeep *et al.*, 1994; Wani *et al.*, 1999; Dar *et al.*, 2000; Velu and Ramanathan, 2000; Paikaray *et al.*, 2002; Sudhakar *et al.*, 2003; Budhar and Tamilselvan, 2003).

Meena *et al.* (2002) and Balasubramanian (2002) noticed increased total uptake of nitrogen by rice hybrid with an increase in N levels up to 200 kg ha<sup>-1</sup>. Rapid uptake of nitrogen between early tillering and rapid tillering was reported by Himissa *et al.* (1989)

whereas Maity (1998) observed maximum N uptake between mid-tillering to heading at all levels of application from 80 to 240 kg N ha<sup>-1</sup>.

Successive increase in rates of nitrogen application increased the N concentration (Hatwar *et al.*, 1992; Mahajan and Tripathi, 1992) and the uptake of nitrogen (Somasundaram *et al.*, 2002b) at all crop growth stages of rice. From their study, Geetha and Thiyagarajan (2003) concluded that allocation of applied fertilizer nitrogen to different plant parts varied with crop stage and depends on rate and time of N application.

#### **2.3.4 Quality**

Several researchers (Moorthy *et al.*, 1988; Rao *et al.*, 1993; Chander and Pandey, 1996; Singh *et al.*, 2001a; Adhikari, 2003) reported that the quality traits like hulling, milling, head rice recovery, kernel length and breadth and L:B ratio of aromatic rice varieties were not influenced by the application of fertilizer nitrogen. Chutiwat *et al.* (1996) observed no change in physical and chemical quality of rice grains due to nitrogen rates, except protein content.

Singh *et al.* (1997) noticed that N fertilization to scented rice resulted in significant increase in rice recovery, protein content in grain, length and breadth of kernel with increase in N dose up to 100 kg per hectare. Maity (1998) reported higher hulling, milling, head rice recovery, head rice yield and protein content at higher level of nitrogen in rice hybrid PA-6201 as compared to PRH-16. Hemlatha *et al.* (1999), Singh (2002) and Kalia and Kumar (2002) also found that protein content of aromatic rice increased significantly with increasing level of nitrogen.

## **2.4 Interaction effects**

### **2.4.1 Inbred/Hybrid Rice x Spacing**

Yan (1988) from China recommended more spacing for hybrid rice (15-25 kg seeds ha<sup>-1</sup>) compared to conventional rice (110-180 kg seeds ha<sup>-1</sup>) under direct seeded condition. He concluded that hybrid rice require more space as compared to conventional rice.

Miller *et al.* (1991) observed significant interaction effect of plant population on grain weight. Shrirame (2000) reported that hybrid rice TNRH 18 produced higher grain yield and dry matter hill<sup>-1</sup> at wider spacing (20 x 15 cm) than closer spacing (20 x 10 cm); whereas both spacings had non-significant effect on other hybrids and variety.

Kumar *et al.* (2002b) noticed significantly higher grain yield of non-scented rice hybrid at wider plant density of 25 plants m<sup>-2</sup> than closer density (33 and 50 plants m<sup>-2</sup>). But, grain yield of scented hybrid was comparable at closer plant densities.

### **2.4.2 Inbred/Hybrid Rice x Nitrogen**

Differences in varietal response to fertilizer nitrogen have been reported by various research workers. Zhende (1988) reported that the response to nitrogen by conventional rice varieties ranged from 85 to 140 kg N ha<sup>-1</sup> whereas the hybrids showed the response up to 400 kg N ha<sup>-1</sup>. Maskina *et al.* (1992) noticed varietal differences in the response to applied fertilizer nitrogen. They observed that cultivar PR 106 responded significantly in terms of grain yield to N application up to 150 kg ha<sup>-1</sup> whereas PR 108 responded only up to 120 kg N ha<sup>-1</sup>.

Tripathi *et al.* (1998) observed significant increase in grain yield with increasing levels of N up to 120 kg N ha<sup>-1</sup> with Kasturi, up to 90 kg N ha<sup>-1</sup> with HKR 228, Pusa Basmati 1 and NDR-625 and up to 60 kg N ha<sup>-1</sup> with traditional variety Kalanamak.

In a study, Subbiah *et al.* (2001) found that Pro Agro 6201 recorded significantly higher yield at 200 kg N ha<sup>-1</sup> (76.5 q ha<sup>-1</sup>) over 150 kg N ha<sup>-1</sup>, while in DRRH 1 and ADHR 2 hybrids the increase of nitrogen level over 150 kg N ha<sup>-1</sup> did not increase the grain yield significantly. They also observed significant interaction effect on yield attributes. In another study, rice hybrid CORH 2 produced maximum grain yield of 58.1 q ha<sup>-1</sup> at 175 kg N ha<sup>-1</sup> in sandy clay loam sodic soil (Somasundaram *et al.*, 2002a).

Dubey and Bisen (1989) reported the interaction of nitrogen levels and varieties for total nitrogen uptake at harvest.

## **2.5 Crop simulation modelling**

Various simulation models have been developed to simulate growth of crop, behaviour of fertilizer in soil-plant and water, and nitrogen transformation and transport. They are used for various purposes such as to optimize planting date and plant population, to identify suitable variety for location and to identify input requirement as well as input combination to achieve maximum productivity (Mathews *et al.*, 2002). But, crop growth models should be calibrated for cultivar's behaviour through crop coefficients and subsequently utilized for application (Kalwe *et al.*, 2002).

In Punjab, Jand *et al.* (1994) used CERES-Rice model to evaluate the date of transplanting for rice. Results showed that though model under-estimated the grain yield by 10.9-8.34 per cent of the observed yield, it was within the acceptance range. Optimum

transplanting was June 13 for high yield as simulated and observed. Similar result was obtained by Hundal and Kaur (1999). Earlier transplanted (June 1) rice may perform better if seedling age is reduced from 40 to 30 days and increasing the plant population increased rice yield (Hundal and Kaur, 1999). They also concluded that crop models can be used as agronomic tool in evaluation of various alternative treatments.

Under rainfed conditions of Kerala, Saseendran *et al.* (1998) using CERES-Rice V3 model suggested that the optimum planting dates were from the 23<sup>rd</sup> to 26<sup>th</sup> week for multiple cropping in a year, and from the 26<sup>th</sup> to 32<sup>nd</sup> week for a monocrop. In northern India, Aggarwal and Kalra (1994) used the WTGROWS model and showed that a delay in planting date decreased the wheat yield, in part by subjecting to warmer temperature during grain filling.

Zhu *et al.* (2001) accounted that the simulated values of attainable growth of leaf, stem, root, panicle dry weight, tiller population and final grain yield of rice were close to observed value.

According to Singh *et al.* (2003b), validated results revealed that simulated pre-anthesis duration and leaf area index of rice over the time for combination of transplanting dates and nitrogen levels matched well with observed values, whereas grain and biomass yield slightly varied. They opined that the grain yield could be predicted fairly well with a validated model. They also suggested that highest grain yield of rice can be obtained by 35 days old seedlings at normal planting (15 June) with 200 kg N ha<sup>-1</sup> in Kashmir as simulated by model.

Density of planting, water regime and nutrient management are the areas that has been investigated with crop models. Crop models have been used to develop and confirm the relationship between them to overall yield and yield attributes in different crops. Lansigan *et al.* (1997) used the ORYZA-W model to generate probability distributions of rainfed lowland rice yield for different planting densities, seedling ages at transplanting and water management. Thiyagarajan *et al.* (1997) used ORYZA-O model to classify some irrigated rice soils in India and generated fertilizer N recommendation curves that identified different optimal timing of N application for the different soil N supply regimes. In a study, Martin (1999) advocated that, with adequate calibration and initialization, ORYZA 1N and CERES-RICE models were capable of simulating the effect of climatic parameter, varieties and agronomic management on rice satisfactorily. He concluded that simulated grain yield, crop N and biomass at maturity was very close to the measured values.

Singh and Thorton (1992), using CERES-RICE model in Thailand, found a significant decline in rice yields when 50 kg N ha<sup>-1</sup> was applied compared with 100 kg N ha<sup>-1</sup> as urea in a clay soil.

The effect of plant population, water and nitrogen on corn yields were simulated for semiarid areas of Kenya using CERES-Maize (Keating *et al.*, 19990) and for semiarid area of western Nebraska under no-till condition (Lyon *et al.*, 2003).

Kalwe (1998) observed that under intermediate levels of irrigation and nitrogen predicted values of wheat growth and yield parameters by model WTGROWS were closer to observed values.

Crop simulation models are used to understand the G x E interactions to evaluate the performance of varieties, to predict potential yield and to extrapolate results using long-term weather data (Manuel *et al.*, 1999). Simulated potential rice grain yield across India revealed little impact for longitudinal position, but latitude and elevation had distinct impact on the growth, duration and grain yield of rice (Ramasamy, 2000). He stated that model's simulated potential grain yield of rice varied from 9.34 to 13.98 t ha<sup>-1</sup> between 9°08' and 31°25'N latitude and increased with increasing latitudes and elevation (0 to 900 m MSL). Aggarwal *et al.* (2000) observed the climatic potential yield of rice-wheat system between 12.0 and 19.5 t ha<sup>-1</sup> in most parts of the Indo-Gangetic plains of India. They opined that higher potential yield in the north-western regions compared to the eastern regions was related to temperatures and solar radiation during crop season. Simulated yield trend analysis for last fifteen years revealed that the grain yield of rice is declining in some parts of Trans-Indo-Gangetic Plains of India at a rate of 0.26 t ha<sup>-1</sup> with the application of fertilizer nitrogen (Banerjee, 2003).

Since there is variation in between the model's simulated and experimental measured yield which is due to inability to address the spatial and temporal variability inherent in the soils, climate, management practices and crop responses to stress (McMaster *et al.*, 2003). However, an acceptance interval of  $\pm 10\%$  of the observed grain yield has been defined to assess simulated yield outputs (Zhu *et al.*, 2001; Andales *et al.*, 2003).

## **CHAPTER III**

# **MATERIALS & METHODS**

# MATERIALS AND METHODS

The experiment entitled “**Effect of nitrogen levels and spacing on productivity and quality of inbred and hybrid aromatic rice**” was conducted under field conditions during *kharif* seasons of 2002 and 2003. The details of the materials used and methods adopted during the course of investigation are presented in this chapter.

## 3.1 Location

The experiment was conducted in the main block 14-C at the research farm of Indian Agricultural Research Institute (IARI), New Delhi, situated at 77°12' E and 28°40' N and at an altitude of 228 m above mean sea level.

## 3.2 Climate and weather conditions

Delhi region comes under agro-climatic zone “Trans-gangetic plains” with sub-tropical and semi-arid type of climate characterized by hot and dry summer and cold winter. May and June are the hottest months with maximum temperature ranging from 41°C to 46°C. January is the coldest month of the year with a minimum temperature ranging between 5°C to 7°C. The mean annual rainfall is about 710 mm, most of which (about 84%) is received between July and September. The annual pan evaporation is about 850 mm.

The weather data during crop growing seasons recorded at the meteorological observatory of Indian Agricultural Research Institute, New Delhi, are given in Appendix I and Appendix II and also depicted in Fig. 1.

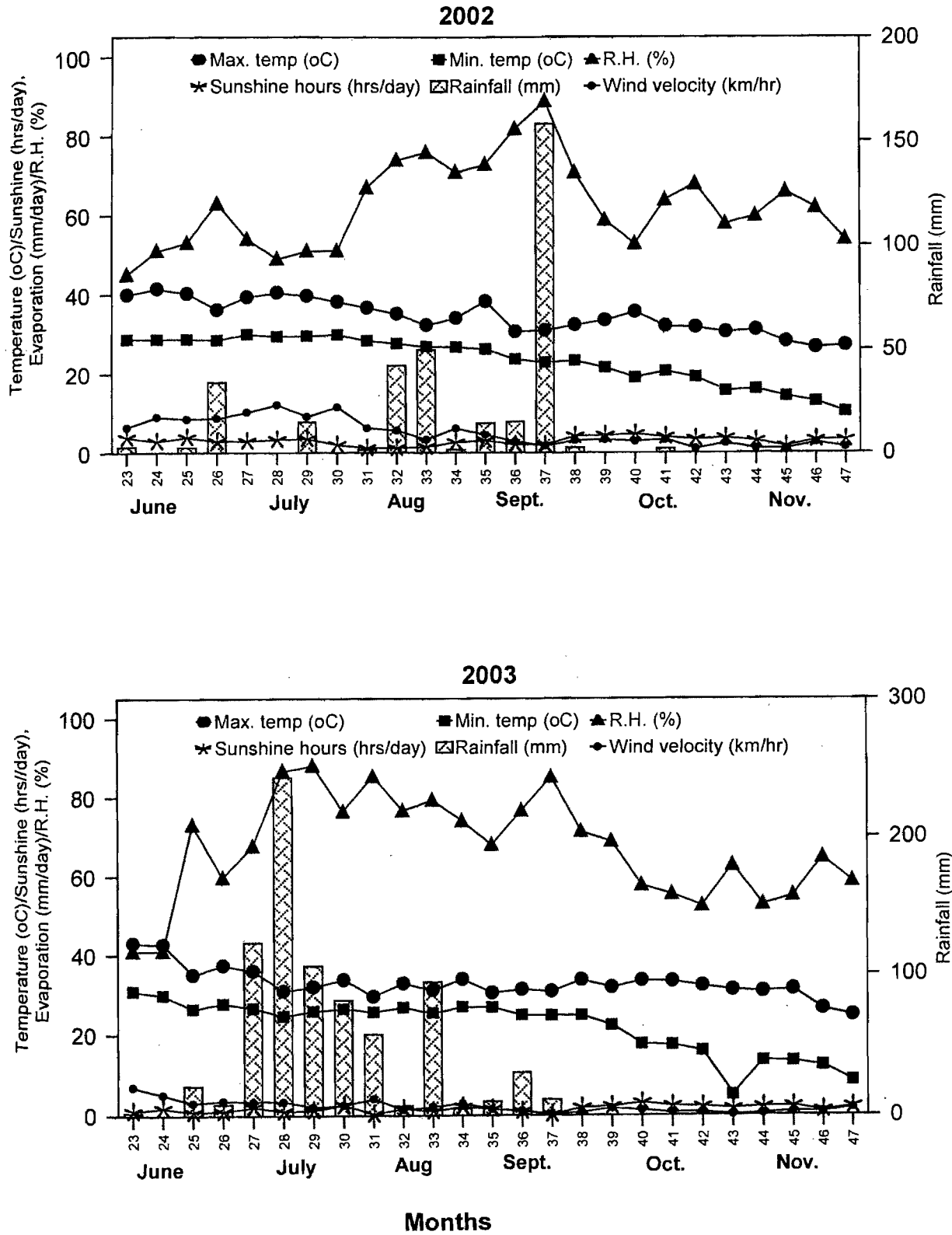


Fig. 1. Mean weekly meteorological variables during *kharif* 2002 and 2003

**Table 1. Physio-chemical characteristics of the soil**

Particulars	2002		2003	
	0-15cm	15-30 cm	0-15 cm	15-30 cm
<b>A. Physical characteristics</b>				
<b>Mechanical composition</b>				
<b>(Hydrometer method, Bouyoucos, 1962)</b>				
Sand (%)	52.6	52.9	51.4	52.4
Silt (%)	21.7	20.9	22.1	20.7
Clay (%)	25.7	26.2	26.5	26.9
Texture class	← Sandy clay loam →			
Saturated soil water (%) (Richards and Weever, 1948)	27.65	26.86	27.80	26.97
Moisture at field capacity (%) (Richards and Weever, 1948)	18.35	18.14	18.64	18.39
Moisture at wilting point (%) (Richards and Weever, 1948)	8.56	7.60	8.78	7.96
Bulk density ( g cm <sup>-3</sup> )	1.47	1.55	1.49	1.59
<b>B. Chemical characteristics</b>				
Organic carbon (%) (Walkley and Black method, Jackson, 1973)	0.495	0.317	0.483	0.326
Total Nitrogen (%) (Kjeldhal method, Jackson 1973)	0.053	0.036	0.052	0.039
Available phosphorus (P <sub>2</sub> O <sub>5</sub> kg ha <sup>-1</sup> ) (Olsen's method, Jackson, 1973)	22.50	19.32	21.62	18.10
Available potassium (K <sub>2</sub> O kg ha <sup>-1</sup> ) (Flame photometer method, Jackson, 1973)	241.7	220.7	236.2	217.6
Soil pH (1:2.5 soil water) (Elico pH meter, Piper, 1950)	7.7	7.9	7.8	8.1
NH <sub>4</sub> <sup>+</sup> - N (ppm)	20.72	16.10	20.32	15.76
NH <sub>3</sub> - N (ppm)	16.32	13.20	15.95	12.91

### 3.3 Cropping history of the experimental field

Rice in *kharif* followed by wheat in *rabi* was continuously grown in the field for the last seven years.

### 3.4 Physico-chemical characteristics of the soil

A composite soil sample at 0-15 cm and 15-30 cm depth from randomly selected ten sites of the experimental field was collected and analysed for physico-chemical characteristics. The important soil characteristics are given in Table 1. The soil was sandy clay-loam in texture with moderate water holding capacity, medium in organic carbon, low in total nitrogen, medium in available phosphorus and high in available potassium content.

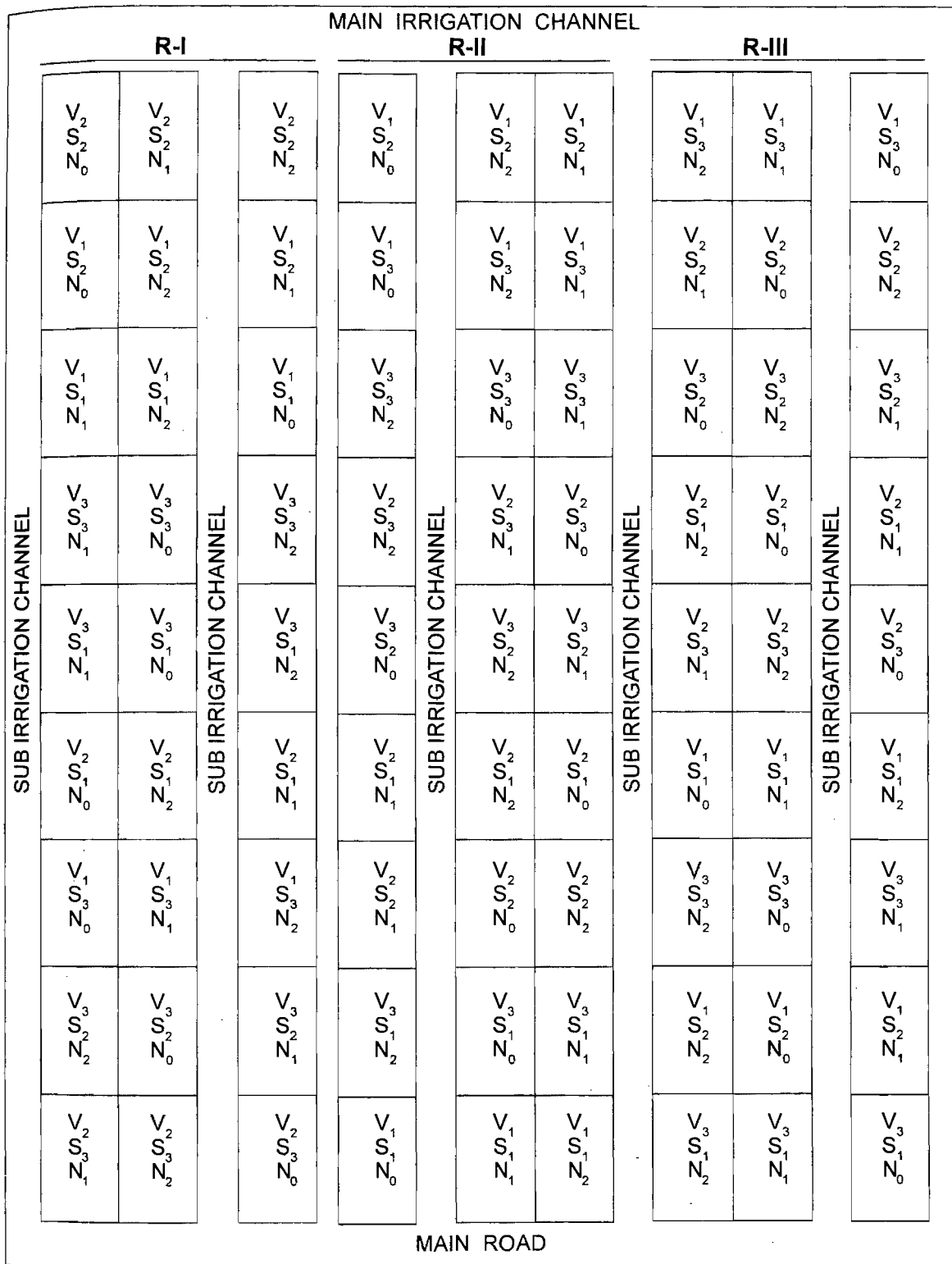
### 3.5 Experimental details

The experiment was laid out in a split plot design with three replications. The allocation of treatment combinations to different plots was done by using Fisher and Yates random table (Fisher and Yates, 1963).

#### 3.5.1 Layout

The plan of layout is presented in Fig. 2 and details are given below.

Crop	:	Rice
Season	:	<i>Kharif</i> , 2002 and 2003
Experimental design	:	Split plot design (Varieties x spacing in main plots and levels of N in sub-plots)
Replications	:	3
Gross plot size	:	7.2 m x 2.4 m
Net plot size	:	6 m x 1.6 m



**EXPERIMENTAL DETAILS**

$V_1$  = PRH 10

$V_2$  = Pusa Sugandh 3

$V_3$  = Pusa Basmati 1

$S_1$  = 20 x 10 cm

$S_2$  = 20 x 15 cm

$S_3$  = 20 x 20 cm

$N_0$  = 0 kg N ha<sup>-1</sup>

$N_1$  = 80 kg N ha<sup>-1</sup>

$N_2$  = 160 kg N ha<sup>-1</sup>

**Fig. 2. LAYOUT PLAN OF EXPERIMENTAL FIELD**

### 3.5.2 Treatments

#### Varieties

V<sub>1</sub> : Pusa Rice Hybrid 10 (PRH-10)

V<sub>2</sub> : Pusa Sugandh-3 (PS-3)

V<sub>3</sub> : Pusa Basmati-1 (PB-1)

#### Spacing

S<sub>1</sub> : 20 cm x 10 cm (50 hills m<sup>-2</sup>)

S<sub>2</sub> : 20 cm x 15 cm (33.3 hills m<sup>-2</sup>)

S<sub>3</sub> : 20 cm x 20 cm (25 hills m<sup>-2</sup>)

#### Levels of nitrogen

N<sub>0</sub> = 0 kg N ha<sup>-1</sup>

N<sub>1</sub> = 80 kg N ha<sup>-1</sup>

N<sub>2</sub> = 160 kg N ha<sup>-1</sup>

Total number of treatments : 3 x 3 x 3 = 27

Total number of plots : 27 x 3 = 81

### 3.5.3 Characteristics of the rice varieties

#### Pusa Rice Hybrid-10

This is a superfine aromatic rice hybrid with basmati quality developed at IARI, New Delhi in 1998 from the cross of Pusa 6A x PRR-78. It has 15-20% superiority in yield over high yielding rice variety Pusa Basmati-1. The grains are medium long and fine with a test weight of 20-22 g. It possesses an attractive aroma. This hybrid was released in July 2001 for commercial cultivation in Uttaranchal, western U.P., Delhi and Haryana. It is a medium-

duration variety and matures 15-20 days earlier as compared to Pusa Basmati-1. Thus saves at least one to two irrigation(s) and may be fitted well in a rice-based cropping system.

### **Pusa Sugandh-3**

This is a semi-dwarf, high yielding aromatic inbred rice variety possessing typical basmati quality with an average yield of 50 q/ha. This variety was also released in July 2001 for commercial cultivation in the North-Western Plain zone of the country. Due to its earliness (120-125 days), high yield, relative tolerance to major insect-pests and diseases and desirable grain and cooking quality traits, it is likely to provide a potential alternative to commercially grown basmati rice varieties in the traditional basmati growing areas.

### **Pusa Basmati-1**

It is also an aromatic, inbred, non-lodging, semi dwarf and high yielding rice variety developed at IARI, New Delhi and released in 1989 for commercial cultivation. This variety is medium in height (90-100 cm) and in maturity (130-135 days) with average yield of 50 q ha<sup>-1</sup>. It also possesses an attractive aroma with test weight of 20-21 g.

#### **3.5.4 Details of cultural operations**

The schedule of cultural operations performed in the experimental field are given in Table 2 and the main operations are described below:

##### **3.5.4.1 Raising of rice nursery**

For each variety, the rice nursery was grown separately on puddled raised beds of 10 m x 2 m with a half meter wide irrigation-cum-drainage channel all around the beds. A fertilizer dose of 500 g urea + 600 g of single super phosphate + 200 g muriate of potash

was applied to each bed. Pre-sprouted seeds of each variety were broadcasted uniformly at the rate of 500 g seeds per bed of 20 m<sup>2</sup>. Then the seeds were covered with a thin layer of FYM to prevent the seed from bird damage. The beds were irrigated as and when it was felt necessary. Nitrogen was top-dressed as urea at the rate of 500 g per bed on seventh day of sowing after removing the weeds.

### **3.5.4.2 Major field operations**

#### **Preparatory cultivation**

The experimental field was prepared by harrowing, discing and leveling by a tractor drawn implement. The field was puddled thrice using victory and country plough and properly levelled. The bunds and channels were made as per experimental layout.

#### **Transplanting**

Three seedlings of 27 days old as per treatment were transplanted per hill in the 2-3 cm standing water.

#### **Gap filling**

To maintain the uniform plant population, gap filling was done one week after transplanting in plots wherever it was felt necessary.

#### **Irrigation**

The irrigations were given to maintain 4-5 cm standing water throughout the crop growing period. However, plots were drained out about 24 hours before nitrogen application and 15 days before harvesting of the crop.

**Table 2. Schedule of cultural operations in the experimental field**

Operations	Dates	
	2002	2003
Nursery preparation	June 5	June 4
Sowing of rice seed in nursery	June 12	June 12
Discing, cultivating and leveling of experimental field	June 29	June 27
Puddling	July 6	July 7
Layout and bunding	July 7	July 8
Transplanting	July 9	July 9
Basal application of fertilizers (SSP, MOP and Zn SO <sub>4</sub> )	July 6	July 7
N – top dressing (1st)	July 16	July 16
<b>N – top dressing (2<sup>nd</sup>)</b>		
PRH – 10	August 12	August 14
Pusa Sugandh – 3	August 16	August 17
Pusa Basmati – 1	August 24	August 27
<b>N top dressing (3<sup>rd</sup>)</b>		
Pusa Rice Hybrid 10	September 12	September 15
Pusa Sugandh 3	September 16	September 19
Pusa Basmati 1	September 24	September 28
Hand weeding (1st)	July 24	July 25
Herbicide application	July 12	July 13
Insecticide application	August 12	August 14
Harvesting and drying	Oct.14-30	Oct.17-31
Threshing, cleaning, drying and weighing	Nov. 2-10	Nov. 3-12

### **Fertilizer application**

Nitrogen was applied in three split doses through urea. As per treatment, 50% of N was applied 7 days after transplanting (DAT), 25% N at panicle initiation (PI) and remaining 25% N at heading stage of the crop. A basal and uniform dose of 60 kg P<sub>2</sub>O<sub>5</sub> and 40 kg K<sub>2</sub>O ha<sup>-1</sup> were applied in the form of single super phosphate and muriate of potash, respectively along with 25 kg zinc sulphate ha<sup>-1</sup> during both the years.

### **Weed control**

Butachlor @ 1.5 kg a.i. ha<sup>-1</sup> as pre-emergence was applied 3-4 DAT to control the weeds. Also, one hand weeding at 45 DAT was done to keep the field weed free throughout the crop growth period.

### **Plant protection measures**

To control the common insect pests in rice crop, phorate a systemic insecticide was applied at the rate of 1.0 kg a.i. ha<sup>-1</sup> at 45 DAT during both the years of experimentation.

### **Harvesting and threshing**

After removing the border rows, the net plots were harvested, tied, tagged and left on the bund of the field to dry for one week. Threshing was done manually after recording the weight of the total produce of an individual plot. After proper cleaning and winnowing the grain weight of each plot at 14% moisture content was recorded.

## **3.6 Details of data collection**

### **3.6.1 Soil sampling**

Initial soil samples were taken from 0-15 and 15-30 cm depth from four locations in each replications using an auger one day before the start of the experiment.

### **3.6.2 Soil chemical analysis**

Initial soil samples were analysed for physico-chemical characteristics of soil by standard methods as given in Table 1.

### **3.6.3 Plant sampling**

Dates of panicle initiation, 50% flowering and maturity of rice varieties in each plot were recorded and converted to days accordingly. Five plants in each plot from second row were randomly selected and tagged for recording field observations.

#### **Plant height**

Plant height of the rice varieties was measured from the base of the plant to the tip of the tallest leaf/panicle at PI, flowering and harvesting stages.

#### **Tiller number**

Tiller number was recorded by counting from the sampling unit. It was done at PI, flowering and at harvest stage of the crop.

#### **Dry matter accumulation**

Five plants from each plot were cut from the ground level from the either side of the second row. The plant samples were collected at PI, flowering and at harvest stage of the crop. The leaves, stems and panicles were detached from plant sample at PI and flowering stages. First of all, these samples were dried in sun and then in hot air oven at 60°C till a constant weight was obtained. The dried plant samples were weighed and dry matter yield of leaves, stem and panicles were computed.

### **Leaf area index**

Green leaves of the plant samples used for dry matter computation were used to measure the leaf area by leaf area meter (Model 3100).

### **3.6.4 Yield attributes**

#### **Number of panicles m<sup>-2</sup>**

Number of panicles m<sup>-2</sup> at harvest was counted from randomly selected ten hills and computed into number of panicles m<sup>-2</sup>.

#### **Length and weight of panicle**

Ten panicles were randomly selected at the time of harvest and dried to a constant weight at 60°C in hot air oven. Then length was measured from the neck to the tip of the panicle and the mean panicle length was computed. The mean panicle weight was computed by weighing the selected panicles.

#### **Number of grains/panicle and fertility percentage**

Both filled and unfilled grains were counted separately from randomly selected ten panicles and were added to get total number of grains per panicle. Then the mean total number of grains per panicle were computed. Fertility percentage was calculated by using the following expression:

$$\text{Fertility percentage} = \frac{\text{Number of filled grains}}{\text{Total number of grains}} \times 100$$

#### **Test weight:**

From each plot thousand filled grains were counted using electronic numigral seed counter and then weight was recorded in gram using electronic balance.

### 3.6.5 Grain and straw yield

The total biomass yield of each net plot was recorded after cutting and removing the border and sample zone. The grains from individual plots were cleaned, sun-dried and weighed. The grain yield was computed at 14 per cent moisture. The straw yields were computed by deducting the grain yields from the dry weight of total biomass (grain plus straw).

### 3.6.6 Harvest index (HI)

Harvest index was calculated by using the following expression (Singh and Staskoff, 1971).

$$\begin{aligned} \text{Harvest index} &= \frac{\text{Economic yield}}{\text{Biological yield}} \times 100 \\ &= \frac{\text{Grain yield}}{\text{Grain yield} + \text{Straw yield}} \times 100 \end{aligned}$$

### 3.6.7 Grain quality character

Rough paddy samples from each plots were used to study the following physico-chemical and quality parameters, which were scored using standard procedure as per the details given below.

#### Hulling percentage:

Well dried rough rice samples from each plot weighing 100 g were hulled in a mini "Satake Rice Medium" and weight of brown rice was recorded. Hulling percentage was worked out as:

$$\text{Hulling (\%)} = \frac{\text{Weight of brown rice (g)}}{\text{Weight of rough rice (g)}} \times 100$$

**Milling percentage:**

The hulled brown rice samples were milled in a “Satake Rice Whitening and Caking Machine” for 5 minutes. The polished rice was weighed and milling percentage was calculated as:

$$\text{Milling (\%)} = \frac{\text{Weight of milled rice (g)}}{\text{Weight of rough rice(g)}} \times 100$$

**Head rice recovery percentage:**

Head rice yield was determined by separating whole grains and  $\frac{3}{4}$  grains manually and percentage was expressed as:

$$\text{Head rice recovery (\%)} = \frac{\text{Weight of whole milled rice}}{\text{Weight of rough rice}} \times 100$$

**Kernel length and breadth before cooking (KLBC and KBBC)**

Ten milled kernels from each plot were taken at random and measured on graph paper for their length and breadth using a ‘Photo Enlarger’ with a magnification of 3X. The mean length and breadth were expressed in mm.

**Kernel length and breadth after cooking (KLAC and KBAC)**

Ten individual kernels were placed separately in a labelled test tubes and presoaked in 5 ml of tap water for 30 minutes. The tubes were placed in boiling water for 8 minutes. Then the tubes were cooled under running water for a minute. Excess water was removed with the help of blotting paper. Length and breadth of cooked kernel were measured in mm as mentioned above.

**Protein content (%):**

Protein content in grain was obtained by multiplying N content in per cent with a factor 5.95 (Juliano *et al.*, 1973).

**3.6.8 Plant chemical analysis**

The plant samples collected at different growth stages of rice for dry matter studies, were again dried in hot air oven at 60°C for 6 hours. The oven dry samples of plant and air dried samples of grains were ground to pass through 40 mesh sieve in macro-wiley mill. From each sample of grain and straw, 0.5 gram was weighed separately for chemical analysis to determine nitrogen content.

**Determination of nitrogen content:**

The nitrogen content in rice grain and straw samples were determined by modified Kjeldahl method (Jackson, 1973).

**Nitrogen uptake:**

Nitrogen uptake by rice at different growth stages were calculated by multiplying dry matter production with corresponding values of their content and was expressed in kg ha<sup>-1</sup>.

**3.7 Model calibration, validation and application for yield simulation****The Model**

InfoCrop model developed by a network of scientists of Centre for Applications of Systems Simulation (CASS), IARI, New Delhi, India was used for the study. The model follows the daily step calculation scheme for the rate of dry matter production of the plant organs and the rate of phenological development. It is a decision support system based on MACROS, SUCROS and WTGROWS models. This model simulates the effects of weather,

soils, agronomic management, water and major pests on growth and yield. It is user-friendly and has been validated in major crop specific environments of India. It includes databases of Indian soils, weather and varieties of major crops. InfoCrop model deals with chickpea, cotton, groundnut, maize, mustard, pearl millet, pigeonpea, potato, rice, sorghum, wheat, soybean and sugarcane (Aggarwal *et al.*, 2003).

The basic crop model is written in Fortran Simulation Environment (FSE) programming language. The model is sensitive to physiology of crop varieties, different agronomic management practices (planting date, seed rates, amount and time of irrigation and fertilization), soil (pH, texture and fertility), environmental factors and pests. This model can be used to analyse and interpret the experimental data, estimation of yield potential and optimization of crop management.

### **Calibration of the model**

The InfoCrop model was calibrated with the data from 18 treatment combinations of 0 nitrogen, three plant populations and three rice varieties of two years study. The model can not account the plant spacing, therefore, plant population as hills  $m^{-2}$  was considered for each plant spacing. The soil and daily weather data of experimentation years 2002 and 2003 were used to calibrate the model. Separate input data files of soil, weather and crop management practices were created for 3 rice varieties as per model standard input format and file structure.

The procedure for determining the coefficients of each variety in the study initially involved running the model with values derived through field data set and expert judgement. Then the model was run using a range of value for coefficient, until simulated

and observed values of days to flowering, days to physiological maturity and grain yield were close to the acceptance range.

### **Validation of the model**

The performance of the calibrated model was tested against the independent data sets of 36 treatment combination i.e. 2 N-levels (80 and 160 kg ha<sup>-1</sup>), 3 plant population (25, 33.3 and 50 hills m<sup>-2</sup>), 3 varieties (PRH 10, PS 3 and PB 1) and 2 years of study (2002 and 2003), of field experiment. Soil, weather and agronomic management input data were the same that were used for calibration of the model. The model was validated for days to flowering, days to physiological maturity and grain yield. The accuracy to model predictions was estimated using the coefficient of determination ( $R^2$ ) between simulated and measured values. The root mean square error (RMSE) between the simulated and measured value was also used. 1:1 line was also drawn to study the closeness of simulated and measured values.

### **Application of the model**

The validated InfoCrop model was used to simulate long term trend (9-13 years) in rice yield with the following nitrogen levels and plant population at representative locations of Indo-Gangetic plain. One location from each transaction of Indo-Gangetic plain that lies in India was selected as follows.

<b>Location</b>	:	Ludhiana, Pantnagar, Patna and Barrakpore
<b>N levels</b>	:	0, 40, 80, 120, 160 and 200 kg ha <sup>-1</sup>
<b>Plant population</b>	:	25, 33.3, 50 and 66.6 hills m <sup>-2</sup>
<b>Varieties</b>	:	PRH 10, PS 3 and PB 1

Grain yield of rice was simulated for above locations using soil data (Appendix IV to VII) as well as long-term weather data. The yield of each rice variety for each location was simulated for 26<sup>th</sup> June of transplanting using 21 days old rice seedling with two split application of nitrogen (half at transplanting and remaining half at 21 DAT). Other agronomic practices were followed as standard.

### **3.8 Statistical analysis**

The data related to each parameter of field experiment were statistically analysed as per procedure of analysis of variance and significance was tested by 'F' test (Cochran and Cox, 1957). Standard error of means (SEm  $\pm$ ) and critical difference (CD) at 5% level of significance were worked out for each parameter. Simulated and measured parameters were compared through residual mean square error (RSME) and regression analysis.

## **CHAPTER IV**

# **EXPERIMENTAL RESULTS**

# EXPERIMENTAL RESULTS

The results obtained during the course of field and laboratory investigations entitled **"Effect of nitrogen levels and spacing on productivity and quality of inbred and hybrid aromatic rice"** have been statistically analysed and are presented in this chapter in a tabular form and are substantiated through figures wherever required. The data on recorded observations that showed statistical significance are described in detail.

## 4.1 Growth characters

Plant growth characters such as plant height, number of tillers per hill, leaf area index and dry matter accumulation were recorded and evaluated at various growth stages of the crop.

### 4.1.1 Plant height

The plant height recorded at PI, flowering and harvest stages are presented in Table 3. The results indicated that inbred aromatic rice Pusa Basmati 1 registered significantly higher plant height than PRH 10 and Pusa Sugandh 3 at PI and harvest stage in both the years of study. Whereas the differences in plant height between PRH 10 and Pusa Sugandh 3 at PI and flowering stages were found to be non-significant during both the years. However, Pusa Sugandh 3 recorded significantly taller plants at harvest compared to hybrid rice PRH 10.

Significantly taller plants of rice were recorded at all growth stages at a spacing of 20 x 10 cm as compared to 20 x 20 cm during both the years of study except at PI stage

**Table 3. Effect of plant spacing and levels of nitrogen on plant height (cm) of aromatic rice at various growth stages**

Treatments	Plant height (cm)					
	PI stage		Flowering stage		At harvest	
	2002	2003	2002	2003	2002	2003
<b>Rice varieties</b>						
PRH 10	68.9	72.3	95.5	100.8	100.9	106.1
Pusa Sugandh 3	67.9	70.9	96.9	102.2	103.4	108.7
Pusa Basmati 1	75.7	79.7	98.9	104.0	106.0	110.6
<b>SEm ±</b>	<b>1.24</b>	<b>1.04</b>	<b>0.85</b>	<b>0.70</b>	<b>0.68</b>	<b>0.61</b>
<b>CD (P=0.05)</b>	<b>3.75</b>	<b>3.11</b>	<b>2.56</b>	<b>2.13</b>	<b>2.03</b>	<b>1.85</b>
<b>Spacing (cm)</b>						
20 x 10	73.7	79.1	100.8	104.6	105.7	110.9
20 x 15	71.0	73.7	96.8	102.4	103.1	108.0
20 x 20	67.8	70.1	93.7	100.0	101.5	106.5
<b>SEm ±</b>	<b>1.24</b>	<b>1.04</b>	<b>0.85</b>	<b>0.70</b>	<b>0.68</b>	<b>0.61</b>
<b>CD (P=0.05)</b>	<b>3.75</b>	<b>3.11</b>	<b>2.56</b>	<b>2.13</b>	<b>2.03</b>	<b>1.85</b>
<b>N levels (kg ha<sup>-1</sup>)</b>						
0	66.4	69.9	92.6	98.5	99.1	104.3
80	70.4	73.9	96.4	102.6	103.5	109.5
160	75.7	79.1	102.3	105.9	107.7	111.6
<b>SEm ±</b>	<b>1.17</b>	<b>0.87</b>	<b>0.70</b>	<b>0.64</b>	<b>0.59</b>	<b>0.57</b>
<b>CD (P=0.05)</b>	<b>3.35</b>	<b>2.50</b>	<b>2.01</b>	<b>1.86</b>	<b>1.69</b>	<b>1.64</b>

during 2002 at 20 x 15 cm spacing. However, a spacing of 20 x 15 cm recorded significantly taller plants than that recorded with a spacing of 20 x 20 cm at PI and flowering stages during 2002 and at flowering stage during 2003.

Application of nitrogen resulted in significant increase in plant height at all the growth stages during both the years. Highest plant height (107.7 and 111.6 cm) at harvest stage during 2002 and 2003, respectively were recorded with the application of 180 kg N ha<sup>-1</sup>.

#### **4.1.2 Number of tillers/hill**

A decreasing trend in the number of tillers per hill of rice varieties as influenced by spacing and nitrogen levels (Table 4) was recorded with the advancement in the age of crop. At all growth stages during both the years of study hybrid rice PRH 10 registered significantly more number of tillers as compared to inbred rice varieties Pusa Sugandh 3 and Pusa Basmati 1. Whereas, at harvest, Pusa Sugandh 3 produced significantly more number of tillers than Pusa Basmati 1 during both the years.

It is also clear from the data that number of tillers per hill increased with the increase in the spacing for rice transplanting. Transplanting of rice at a wider spacing of 20 x 20 cm produced significantly higher number of tillers per hill as compared to closer spacings of 20 x 10 cm and 20 x 15 cm.

Nitrogen application had marked effect on the production of tillers. Successive increase in nitrogen levels significantly increased the tiller number at all the growth stages of the crop. Maximum tiller number (8.50 and 9.17) per hill at harvest was recorded during 2002 and 2003, respectively with the application of 160 kg N ha<sup>-1</sup>.

**Table 4. Effect of plant spacing and levels of nitrogen on number of tillers hill<sup>-1</sup> of aromatic rice at various growth stages**

Treatments	No. of tillers hill <sup>-1</sup>					
	PI stage		Flowering stage		At harvest	
	2002	2003	2002	2003	2002	2003
<b>Rice varieties</b>						
PRH 10	12.17	13.11	10.30	11.62	8.44	9.67
Pusa Sugandh 3	10.80	11.36	9.18	10.29	7.55	7.85
Pusa Basmati 1	10.40	10.92	8.69	9.86	6.88	7.10
<b>SEm ±</b>	<b>0.28</b>	<b>0.16</b>	<b>0.29</b>	<b>0.32</b>	<b>0.15</b>	<b>0.17</b>
<b>CD (P=0.05)</b>	<b>0.83</b>	<b>0.48</b>	<b>0.87</b>	<b>0.98</b>	<b>0.45</b>	<b>0.51</b>
<b>Spacing (cm)</b>						
20 x 10	8.84	10.46	7.58	9.34	5.42	6.32
20 x 15	11.58	11.67	9.85	10.54	7.63	7.83
20 x 20	12.95	13.27	10.74	11.89	9.82	10.47
<b>SEm ±</b>	<b>0.28</b>	<b>0.16</b>	<b>0.29</b>	<b>0.32</b>	<b>0.15</b>	<b>0.17</b>
<b>CD (P=0.05)</b>	<b>0.83</b>	<b>0.48</b>	<b>0.87</b>	<b>0.98</b>	<b>0.45</b>	<b>0.51</b>
<b>N levels (kg ha<sup>-1</sup>)</b>						
0	8.83	9.51	7.73	8.69	6.69	7.02
80	11.67	12.19	9.36	10.78	7.68	8.43
160	12.87	13.70	11.08	12.30	8.50	9.17
<b>SEm ±</b>	<b>0.26</b>	<b>0.17</b>	<b>0.27</b>	<b>0.27</b>	<b>0.13</b>	<b>0.15</b>
<b>CD (P=0.05)</b>	<b>0.75</b>	<b>0.49</b>	<b>0.77</b>	<b>0.79</b>	<b>0.37</b>	<b>0.43</b>

#### 4.1.3 Leaf area index (LAI)

The leaf area index measured at different growth stages (Table 5) indicated that rice hybrid PRH 10 had significantly higher leaf area than Pusa Sugandh 3 and Pusa Basmati 1 during both the years of investigation, except than Pusa Sugandh 3 at PI stage. However, all the varieties in the study measured higher LAI value during flowering stage. Whereas, at physiological maturity Pusa Basmati 1 registered lower value indicating thereby early leaf senescence.

Transplanting of rice at various spacings had significant influence on leaf area index except at physiological maturity during first year of the study. Plant spacing of 20 x 10 cm registered significantly higher LAI values as compared to 20 x 15 cm and 20 x 20 cm spacings. A decreasing trend in the LAI values was noticed with an increase in the plant spacing during both the years of study.

Irrespective of growth stages, each successive increase in the nitrogen level pushed up the LAI values and the maximum (2.11 and 2.62) was obtained with the application of 160 kg N ha<sup>-1</sup>. However, at physiological maturity, the leaf area index was at par with 80 and 160 kg N ha<sup>-1</sup>.

#### 4.1.4 Dry matter accumulation

The data pertaining to dry matter production at different growth stages and by various plant parts as affected by various treatments are presented in Table 6 and Table 7 and depicted in Fig. 3.

The data revealed that all the three varieties viz. PRH 10, Pusa Sugandh 3 and Pusa Basmati 1 at all the stages of growth exhibited significant difference with each other in

**Table 5. Effect of plant spacing and levels of nitrogen on leaf area index of aromatic rice at various growth stages**

Treatments	Leaf area index					
	PI stage		Flowering stage		At physiological maturity	
	2002	2003	2002	2003	2002	2003
<b>Rice varieties</b>						
PRH 10	2.93	3.38	4.28	4.67	2.26	2.73
Pusa Sugandh 3	2.90	3.09	3.78	4.32	2.07	2.50
Pusa Basmati 1	2.38	2.54	3.24	3.58	1.61	1.98
<b>SEm ±</b>	<b>0.08</b>	<b>0.10</b>	<b>0.11</b>	<b>0.09</b>	<b>0.05</b>	<b>0.06</b>
<b>CD (P=0.05)</b>	<b>0.24</b>	<b>0.30</b>	<b>0.34</b>	<b>0.27</b>	<b>0.16</b>	<b>0.18</b>
<b>Spacing (cm)</b>						
20 x 10	3.16	3.38	4.37	4.63	2.05	2.73
20 x 15	2.79	3.05	3.71	4.13	1.96	2.36
20 x 20	2.27	2.58	3.22	3.81	1.93	2.12
<b>SEm ±</b>	<b>0.08</b>	<b>0.10</b>	<b>0.11</b>	<b>0.09</b>	<b>0.05</b>	<b>0.06</b>
<b>CD (P=0.05)</b>	<b>0.24</b>	<b>0.30</b>	<b>0.34</b>	<b>0.27</b>	<b>NS</b>	<b>0.18</b>
<b>N levels (kg ha<sup>-1</sup>)</b>						
0	2.20	2.37	2.67	3.27	1.74	2.08
80	2.66	2.87	3.84	4.09	2.09	2.51
160	3.35	3.77	4.79	4.91	2.11	2.62
<b>SEm ±</b>	<b>0.05</b>	<b>0.07</b>	<b>0.08</b>	<b>0.08</b>	<b>0.04</b>	<b>0.04</b>
<b>CD (P=0.05)</b>	<b>0.15</b>	<b>0.21</b>	<b>0.23</b>	<b>0.22</b>	<b>0.12</b>	<b>0.12</b>

producing total dry matter production during both the years of experimentation. PRH 10 produced highest total dry matter than other two varieties. The dry matter production of green leaf at PI stage during 2002 and green leaf and panicle at flowering stage during 2002 and 2003 in between PRH 10 and Pusa Sugandh 3 were non-significant. Pusa Basmati 1 produced lowest dry matter of various plant parts as well as total dry matter at different growth stages.

Plant spacing also had significant effect on total dry matter production as well as production of various plant parts at all the period of observations. Significantly more green leaf, leaf sheath and total dry matter were recorded with the adoption of 20 x 10 cm spacing as compared to 20 x 15 cm and 20 x 20 cm spacing, except leaf sheath production during 2003 over 20 x 15 cm spacing. However, significant variation occurred between 20 x 15 and 20 x 20 cm spacings.

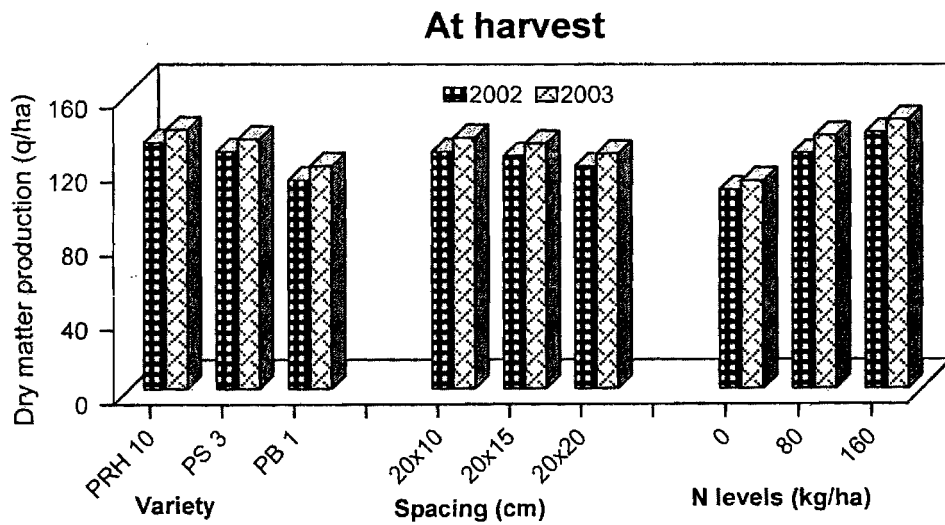
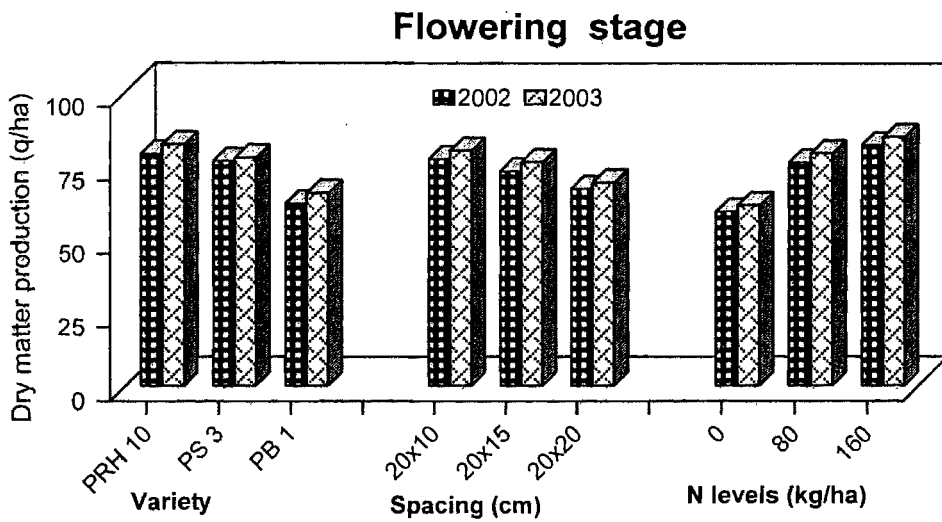
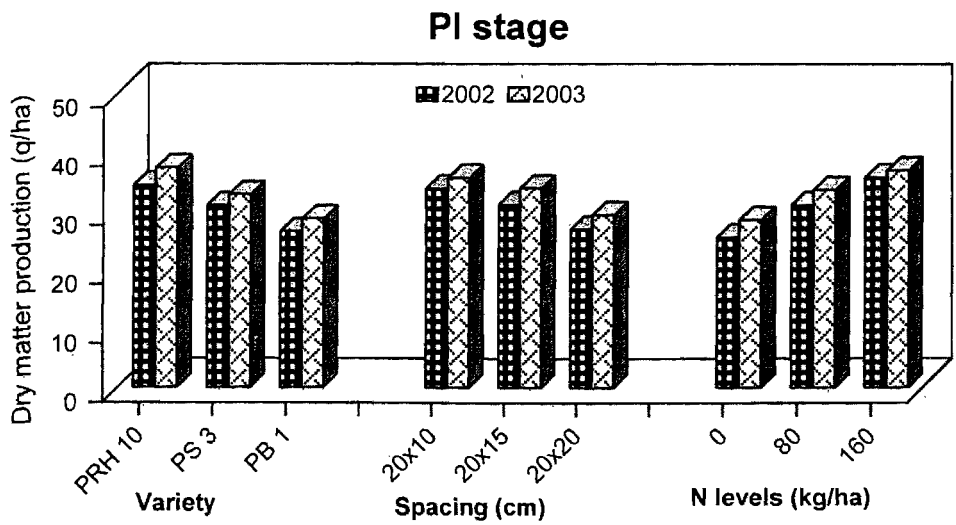
At flowering and harvest stage, similar trend of total leaf dry matter production was recorded among the adopted three spacings in both the years. Dry matter production of green leaf and panicle at flowering stage also statistically differed in all three spacings during both the years. At harvest, closer spacing of 20 x 10 cm produced 128.04 and 135.53 q ha<sup>-1</sup> of total dry matter during 2002 and 2003, respectively, which were significantly higher than that of produced from wider spacing of 20 x 20 cm.

Each successive increase in the level of nitrogen significantly pushed up the dry matter production of green leaf, leaf sheath and total dry matter production at PI stage during both the years of study. Similar trend was found at flowering stage too for the production of total dry matter as well as different plant parts. Application of 160 kg N ha<sup>-1</sup>

**Table 6. Effect of plant spacing and levels of nitrogen on dry matter production (q ha<sup>-1</sup>) of aromatic rice at panicle initiation stage**

Treatments	Dry matter production (q ha <sup>-1</sup> )					
	Green leaf		Leaf sheath		Total	
	2002	2003	2002	2003	2002	2003
<b>Rice varieties</b>						
PRH 10	13.45	14.26	20.84	22.94	34.28	37.21
Pusa Sugandh 3	13.42	13.05	17.40	19.62	30.82	32.67
Pusa Basmati 1	11.17	11.54	15.27	17.07	26.44	28.60
<b>SEm ±</b>	<b>0.30</b>	<b>0.26</b>	<b>0.45</b>	<b>0.54</b>	<b>0.68</b>	<b>0.87</b>
<b>CD (P=0.05)</b>	<b>0.90</b>	<b>0.78</b>	<b>1.35</b>	<b>1.64</b>	<b>2.07</b>	<b>2.65</b>
<b>Spacing (cm)</b>						
20 x 10	14.14	13.94	19.65	21.82	33.78	35.56
20 x 15	12.87	12.87	18.07	20.69	30.95	33.76
20 x 20	11.03	12.04	15.79	17.12	26.81	29.16
<b>SEm ±</b>	<b>0.30</b>	<b>0.26</b>	<b>0.45</b>	<b>0.55</b>	<b>0.68</b>	<b>0.87</b>
<b>CD (P=0.05)</b>	<b>0.90</b>	<b>0.78</b>	<b>1.35</b>	<b>1.64</b>	<b>2.07</b>	<b>2.65</b>
<b>N levels (kg ha<sup>-1</sup>)</b>						
0	10.23	10.43	15.14	16.28	25.37	28.30
80	12.66	13.29	18.21	20.13	30.86	33.42
160	15.15	15.12	20.16	23.22	35.61	36.76
<b>SEm ±</b>	<b>0.24</b>	<b>0.20</b>	<b>0.42</b>	<b>0.49</b>	<b>0.62</b>	<b>0.65</b>
<b>CD (P=0.05)</b>	<b>0.69</b>	<b>0.59</b>	<b>1.21</b>	<b>1.42</b>	<b>1.78</b>	<b>1.87</b>





**Fig. 3. Effect of plant spacing and levels of nitrogen on dry matter production ( $q\ ha^{-1}$ ) of aromatic rice at various growth stages**

produced 138.80 and 145.05 q ha<sup>-1</sup> of total dry matter production at harvest during 2002 and 2003, respectively.

## **4.2 Yield attributing characters**

### **4.2.1 Number of panicles per square meter**

The number of panicles per square meter as influenced by aromatic rice varieties, spacings and nitrogen levels are presented in Table 8 and Fig. 4.

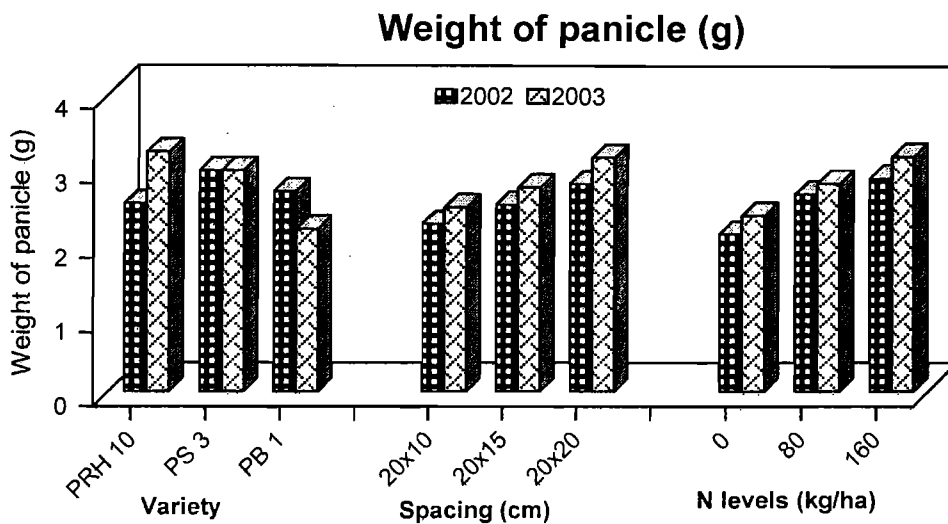
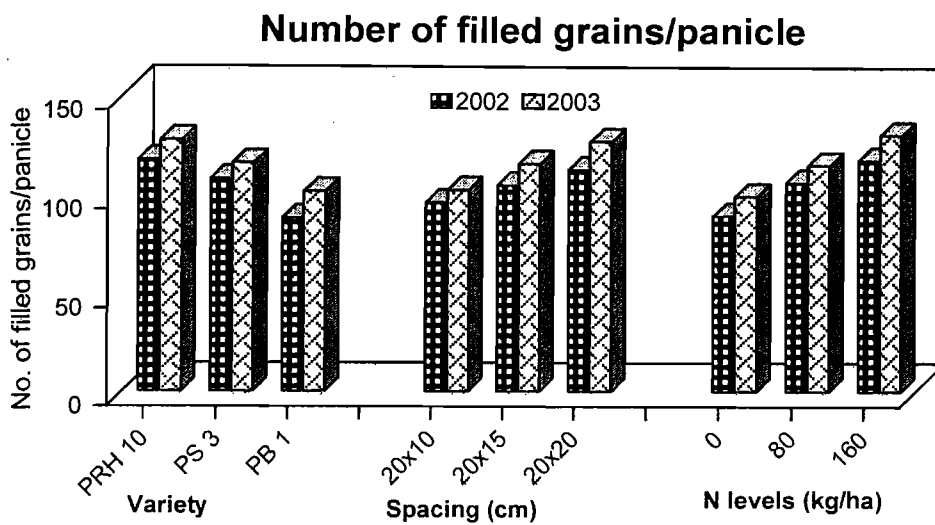
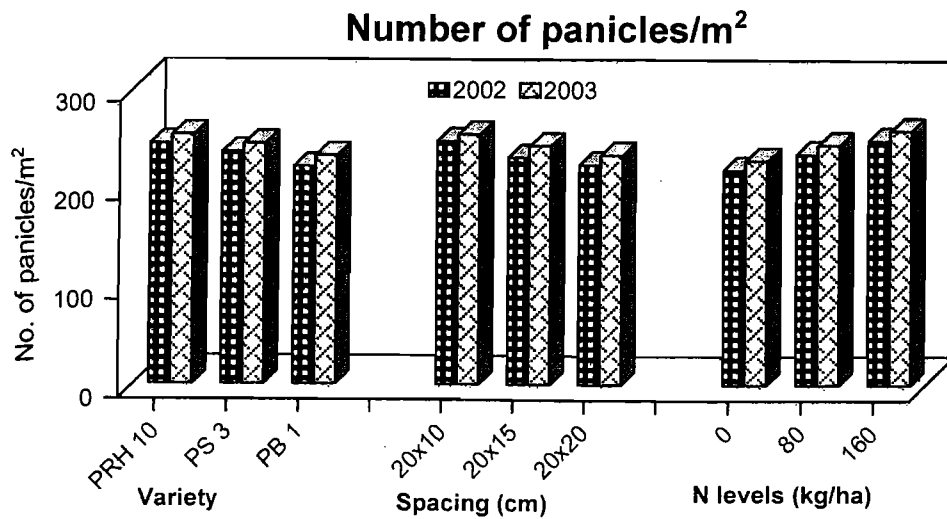
Rice hybrid PRH 10 produced significantly more number of panicles (243.4 in 2002 and 252.4 in 2003) over other two inbred rice varieties during both the years of investigations. Newly released Pusa Sugandh 3 was statistically superior to Pusa Basmati 1 in producing the panicles per unit area.

The results indicated that adoption of closer spacing of 20 x 10 cm resulted more number of panicles m<sup>-2</sup> as compared to wider spacing of 20 x 15 cm and 20 x 20 cm. However, significant difference was also noticed between the spacings of 20 x 15 cm and 20 x 20 cm during both the years of study.

Interaction effect of rice varieties and spacings on number of panicles per square meter was significant during both the years [Table 8(a) and Table 8(b)]. All rice varieties recorded maximum number of panicles m<sup>-2</sup> at a spacing of 20 x 10 cm which was significantly more than that of recorded with spacings of 20 x 15 cm and 20 x 20 cm. PRH 10 and Pusa Sugandh 3 were at par for recording panicles m<sup>-2</sup> at all spacings. The number of panicles m<sup>-2</sup> produced by Pusa Sugandh 3 and Pusa Basmati 1 were at par with 20 x 15 cm and 20 x 20 cm spacings during first and second years of the study. The number of

**Table 8. Effect of plant spacing and levels of nitrogen on yield attributing characters of aromatic rice**

Treatments	Number of panicles m <sup>-2</sup>		Number of filled grains panicle <sup>-1</sup>		Panicle weight (g)	
	2002	2003	2002	2003	2002	2003
<b>Rice varieties</b>						
PRH 10	243.4	252.4	117.3	127.3	2.97	3.22
Pusa Sugandh 3	235.1	243.3	107.8	115.7	2.69	2.97
Pusa Basmati 1	220.3	231.3	88.0	101.4	1.92	2.19
<b>SEm ±</b>	<b>1.93</b>	<b>1.57</b>	<b>1.06</b>	<b>1.43</b>	<b>0.04</b>	<b>0.03</b>
<b>CD (P=0.05)</b>	<b>5.8</b>	<b>4.7</b>	<b>3.2</b>	<b>4.3</b>	<b>0.12</b>	<b>0.09</b>
<b>Spacing (cm)</b>						
20 x 10	246.3	253.2	96.0	102.1	2.26	2.48
20 x 15	229.9	241.7	104.6	115.5	2.52	2.75
20 x 20	222.6	232.1	112.5	126.8	2.80	3.15
<b>SEm ±</b>	<b>1.93</b>	<b>1.57</b>	<b>1.06</b>	<b>1.43</b>	<b>0.04</b>	<b>0.03</b>
<b>CD (P=0.05)</b>	<b>5.8</b>	<b>4.7</b>	<b>3.2</b>	<b>4.3</b>	<b>0.12</b>	<b>0.09</b>
<b>N levels (kg ha<sup>-1</sup>)</b>						
0	217.4	226.7	89.4	99.1	2.13	2.38
80	233.7	242.8	106.3	114.9	2.57	2.81
160	247.7	257.5	117.6	130.0	2.88	3.17
<b>SEm ±</b>	<b>1.38</b>	<b>1.44</b>	<b>1.02</b>	<b>0.84</b>	<b>0.04</b>	<b>0.025</b>
<b>CD (P=0.05)</b>	<b>4.0</b>	<b>4.3</b>	<b>2.9</b>	<b>2.4</b>	<b>0.11</b>	<b>0.07</b>



**Fig. 4. Effect of plant spacing and levels of nitrogen on yield attributing characters of aromatic rice**

**Table 8(a). Interaction effect of aromatic rice and plant spacing on number of panicles m<sup>-2</sup> during 2002**

Varieties	Spacing (cm)		
	20x10	20x15	20x20
PRH 10	255.7	241.4	233.1
Pusa Sugandh 3	247.8	232.1	225.4
Pusa Basmati 1	235.3	216.1	209.4
<b>SEm ±</b>		<b>3.35</b>	
<b>CD (P=0.05)</b>		<b>10.1</b>	

**Table 8(b). Interaction effect of aromatic rice and plant spacing on number of panicles m<sup>-2</sup> during 2003**

Varieties	Spacing (cm)		
	20x10	20x15	20x20
PRH 10	263.8	252.4	241.1
Pusa Sugandh 3	254.0	242.9	233.0
Pusa Basmati 1	242.0	229.7	222.2
<b>SEm ±</b>		<b>3.58</b>	
<b>CD (P=0.05)</b>		<b>10.7</b>	

**Table 8(c). Interaction effect of aromatic rice and levels of nitrogen on number of panicles m<sup>-2</sup> during 2002**

Varieties	N levels (kg ha <sup>-1</sup> )		
	0	80	160
PRH 10	224.1	240.7	265.4
Pusa Sugandh 3	222.7	234.4	248.3
Pusa Basmati 1	205.6	226.1	229.2
<b>SEm ±</b>		<b>2.39</b>	
<b>CD (P=0.05)</b>		<b>6.8</b>	

**Table 8(d). Interaction effect of aromatic rice and levels of nitrogen on number of panicles m<sup>-2</sup> during 2003**

Varieties	N levels (kg ha <sup>-1</sup> )		
	0	80	160
PRH 10	233.2	249.4	274.7
Pusa Sugandh 3	231.4	242.9	255.6
Pusa Basmati 1	215.6	236.3	242.1
<b>SEm ±</b>		<b>2.50</b>	
<b>CD (P=0.05)</b>		<b>7.2</b>	

panicles  $m^{-2}$  produced by PRH 10 and Pusa Sugandh 3 with 20 x 20 cm spacing were at par with that of produced by Pusa Basmati 1 with 20 x 10 cm spacing.

Nitrogen application too, had significant influence in producing more number of panicles  $m^{-2}$ . Application of 80 kg N  $ha^{-1}$  resulted significantly higher number of panicles  $m^{-2}$  over control during both the years. However, maximum (247.7 and 257.5 during 2002 and 2003, respectively) number of panicles were recorded with application of 160 kg N  $ha^{-1}$  which was significantly superior over 0 and 60 kg N  $ha^{-1}$ . Interaction effect of rice varieties and nitrogen levels on number of panicles per unit area were also significant during both the years [Table 8(c) and Table 8(d)] of study. Significantly higher number of panicles per square meter were recorded with PRH 10 at the application of 160 kg N  $ha^{-1}$ , whereas at 0 and 80 kg of N  $ha^{-1}$ , the difference in number of panicles  $m^{-2}$  with PRH 10 and Pusa Sugandh 3 were found to be non significant. It was further noticed that number of panicles per square meter in Pusa Basmati 1 with 80 and 160 kg N  $ha^{-1}$  was non-significant. Almost similar trend was noticed during second year of the investigation.

#### **4.2.2 Number of filled grains per panicle**

The data on number of filled grains per panicle presented in Table 8 and Fig. 4 revealed that PRH 10 registered significantly more number of filled grains (117.3 and 127.3 during 2002 and 2003, respectively) as compared to Pusa Sugandh 3 and Pusa Basmati 1. Further, the difference in number of grains per panicle between Pusa Sugandh 3 and Pusa Basmati 1 was also significant. Transplanting of rice at different spacings resulted in significant variation in number of filled grains per panicle. The maximum number of filled

**Table 8(e). Interaction effect of aromatic rice and plant spacing on number of filled grains panicle<sup>-1</sup> during 2002**

Varieties	Spacing (cm)		
	20x10	20x15	20x20
PRH 10	105.3	114.2	132.4
Pusa Sugandh 3	100.3	109.6	113.4
Pusa Basmati 1	82.3	89.9	91.8
<b>SEm ± CD (P=0.05)</b>		<b>1.84 5.5</b>	

**Table 8(f). Interaction effect of aromatic rice and plant spacing on number of filled grains panicle<sup>-1</sup> during 2003**

Varieties	Spacing (cm)		
	20x10	20x15	20x20
PRH 10	114.6	120.9	146.3
Pusa Sugandh 3	108.3	117.2	121.6
Pusa Basmati 1	83.3	108.4	112.5
<b>SEm ± CD (P=0.05)</b>		<b>2.48 7.4</b>	

**Table 8(g). Interaction effect of aromatic rice and levels of nitrogen on number of filled grains panicle<sup>-1</sup> during 2002**

Varieties	N levels (kg ha <sup>-1</sup> )		
	0	80	160
PRH 10	97.1	114.7	140.7
Pusa Sugandh 3	93.8	111.3	118.2
Pusa Basmati 1	77.2	92.9	93.9
<b>SEm ±</b>		<b>1.8</b>	
<b>CD (P=0.05)</b>		<b>5.1</b>	

**Table 8(h). Interaction effect of aromatic rice and levels of nitrogen on number of filled grains panicle<sup>-1</sup> during 2003**

Varieties	N levels (kg ha <sup>-1</sup> )		
	0	80	160
PRH 10	107.6	121.7	152.7
Pusa Sugandh 3	102.4	117.3	127.3
Pusa Basmati 1	87.4	105.8	110.9
<b>SEm ±</b>		<b>2.2</b>	
<b>CD (P=0.05)</b>		<b>6.4</b>	

grains per panicle were recorded with wider spacing of 20 x 20 cm. Whereas, it was lowest at 20 x 10 cm spacing.

Interaction effect between rice varieties and plant spacing [Table 8(e) and Table 8(f)] revealed that PRH 10 registered highest number of filled grains per panicle at wider spacing of 20 x 20 cm during both the years. But, a non-significant difference existed between 20 x 10 and 20 x 15 cm spacing during 2003. Pusa Sugandh 3 and Pusa Basmati 1 transplanted at 20 x 15 cm and 20 x 20 cm spacing exhibited significantly higher number of grains per panicle than transplanting at 20 x 10 cm during 2002 and 2003, but at par between 20 x 15 cm and 20 x 20 cm, whereas PRH 10 registered non-significant effect in producing filled grains panicle<sup>-1</sup> at a spacing of 20 x 10 cm and 20 x 15 cm. PRH 10 and Pusa Sugandh 3 registered significantly more number of filled grains panicle<sup>-1</sup> with 20 x 10 cm spacing than Pusa Basmati 1 transplanted at 20 x 20 cm. Similar trend was observed in second year of the study.

Application of 80 or 120 kg N ha<sup>-1</sup> significantly produced more number of grains per panicle over control. The highest number of filled grains/panicle (117.6 and 130.0 during 2002 and 2003, respectively) were recorded with application of 160 kg N ha<sup>-1</sup>. Interaction effect indicated that PRH 10 and Pusa Sugandh 3 recorded increasing number of grains with each successive increment in nitrogen level [Table 8(g) and Table 8(h)]. But, they were at par with the application of 0 and 80 kg ha<sup>-1</sup>. The number of filled grains produced by PRH 10 and Pusa Sugandh 3 at 0 N application and by Pusa Sugandh 1 at 160 kg N ha<sup>-1</sup> were recorded non-significant.

**Table 8(i). Interaction effect of aromatic rice and plant spacing on panicle weight (g) at harvest during 2002**

Varieties	Spacing (cm)		
	20x10	20x15	20x20
PRH 10	2.60	2.78	3.43
Pusa Sugandh 3	2.49	2.75	2.84
Pusa Basmati 1	1.70	2.02	2.03
<b>SEm ± CD (P=0.05)</b>		<b>0.07 0.21</b>	

**Table 8(j). Interaction effect of aromatic rice and plant spacing on panicle weight (g) at harvest during 2003**

Varieties	Spacing (cm)		
	20x10	20x15	20x20
PRH 10	2.80	2.95	3.90
Pusa Sugandh 3	2.64	3.10	3.17
Pusa Basmati 1	2.00	2.21	2.34
<b>SEm ± CD (P=0.05)</b>		<b>0.06 0.18</b>	

**Table 8(k). Interaction effect of aromatic rice and levels of nitrogen on number of panicle weight (g) at harvest during 2002**

Varieties	N levels (kg ha <sup>-1</sup> )		
	0	80	160
PRH 10	2.47	2.90	3.54
Pusa Sugandh 3	2.30	2.75	3.03
Pusa Basmati 1	1.61	2.05	2.09
<b>SEm ±</b>		<b>0.07</b>	
<b>CD (P=0.05)</b>		<b>0.20</b>	

**Table 8(l). Interaction effect of aromatic rice and levels of nitrogen on number of panicle weight (g) at harvest during 2003**

Varieties	N levels (kg ha <sup>-1</sup> )		
	0	80	160
PRH 10	2.61	3.10	3.90
Pusa Sugandh 3	2.58	3.02	3.31
Pusa Basmati 1	1.96	2.30	2.30
<b>SEm ±</b>		<b>0.04</b>	
<b>CD (P=0.05)</b>		<b>0.12</b>	

### 4.2.3 Panicle weight

The data presented on panicle weight (Table 8 and Fig. 4) showed that like number of filled grains per panicle, weight of panicle was also significantly influenced by rice varieties, spacings and levels of nitrogen. Rice hybrid PRH 10 registered 2.97 and 3.22 g panicle weight during 2002 and 2003, respectively which was significantly heavier than that of recorded with Pusa Sugandh 3 and Pusa Basmati 1. Rice variety Pusa Sugandh 3 appeared significantly superior in recording more panicle weight as compared to Pusa Basmati 1.

Among the spacing treatments, significantly heavier panicle weight was recorded with a spacing of 20 x 20 cm over 20 x 10 cm and 20 x 15 cm spacing. However, spacing of 20 x 15 cm proved statistically superior over 20 x 10 cm spacing.

Interaction effect between rice varieties and plant spacing was significant during both the years [Table 8(i) and Table 8(j)]. PRH 10 registered maximum weight of panicle at a spacing of 20 x 20 cm which was significantly higher than that of recorded with the spacing of 20 x 10 cm and 20 x 15 cm during both the years of study. Pusa Sugandh 3 and Pusa Basmati 1 also recorded significantly heavier panicle at 20 x 20 cm spacing but non-significant in between 20 x 15 cm and 20 x 20 cm during both the years. Whereas, the weight of panicle of PRH 10 and Pusa Sugandh 3 was also non-significant when transplanted at the spacings of 20 x 10 cm and 20 x 15 cm during both the years. PRH 10 and Pusa Sugandh 3 produced significantly heavier panicle with 20 x 10 cm spacing than Pusa Basmati 1 transplanted at wider spacing of 20 x 20 cm during both the years of investigations.

**Table 9. Effect of plant spacing and levels of nitrogen on yield attributing characters of aromatic rice**

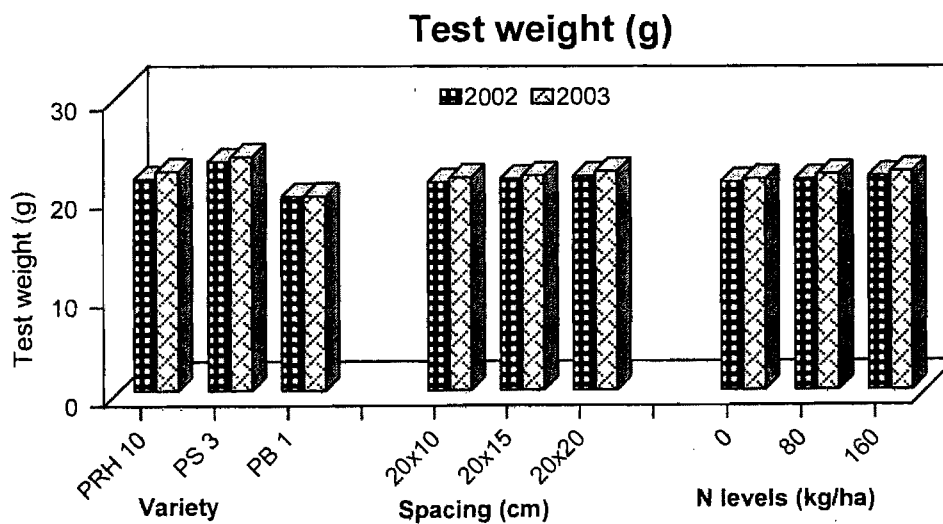
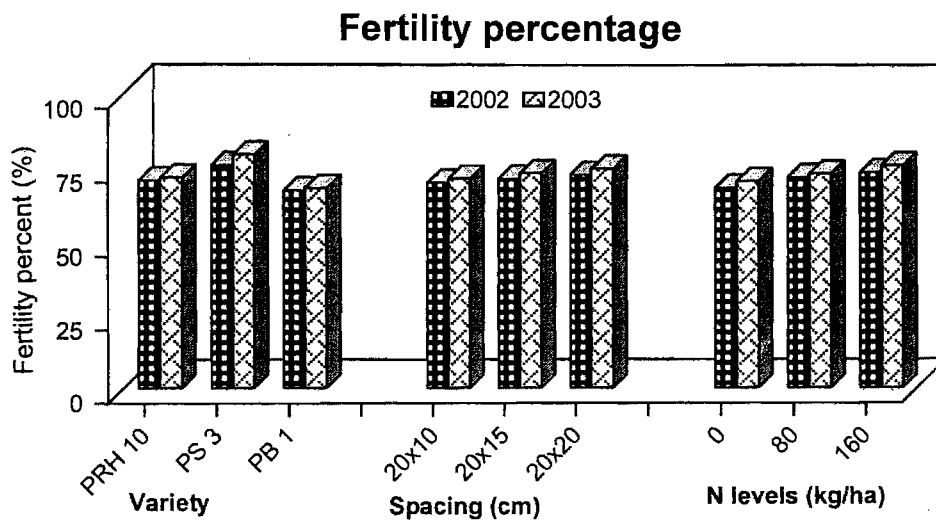
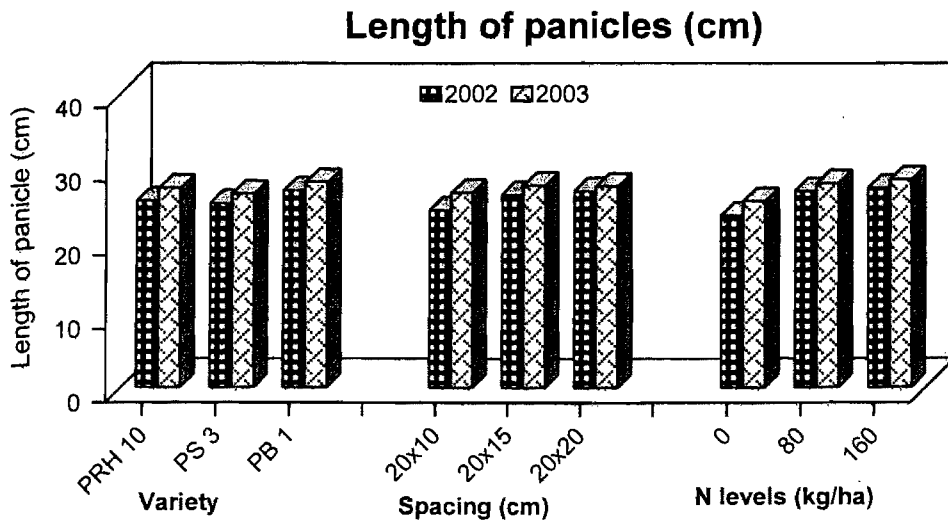
Treatments	Length of panicle (cm)		Fertility percentage		Test weight (g)	
	2002	2003	2002	2003	2002	2003
<b>Rice varieties</b>						
PRH 10	25.30	26.99	70.6	71.5	21.45	22.19
Pusa Sugandh 3	24.93	26.21	75.8	79.3	23.22	23.69
Pusa Basmati 1	26.29	27.83	67.2	68.0	19.65	19.69
<b>SEm ±</b>	<b>0.50</b>	<b>0.38</b>	<b>0.85</b>	<b>0.77</b>	<b>0.10</b>	<b>0.08</b>
<b>CD (P=0.05)</b>	<b>1.50</b>	<b>1.14</b>	<b>2.60</b>	<b>2.33</b>	<b>0.30</b>	<b>0.24</b>
<b>Spacing (cm)</b>						
20 x 10	24.12	26.43	69.9	71.2	21.12	21.57
20 x 15	26.16	27.38	71.2	73.0	21.46	21.77
20 x 20	26.64	27.22	72.5	74.6	21.74	22.23
<b>SEm ±</b>	<b>0.50</b>	<b>0.38</b>	<b>0.85</b>	<b>0.77</b>	<b>0.10</b>	<b>0.08</b>
<b>CD (P=0.05)</b>	<b>1.50</b>	<b>NS</b>	<b>NS</b>	<b>2.33</b>	<b>0.30</b>	<b>0.24</b>
<b>N levels (kg ha<sup>-1</sup>)</b>						
0	23.30	25.23	68.1	70.3	21.15	21.44
80	26.57	27.64	71.7	72.8	21.42	21.92
160	27.05	28.16	73.3	75.7	21.75	22.21
<b>SEm ±</b>	<b>0.37</b>	<b>0.34</b>	<b>0.76</b>	<b>0.85</b>	<b>0.08</b>	<b>0.07</b>
<b>CD (P=0.05)</b>	<b>1.06</b>	<b>0.98</b>	<b>2.18</b>	<b>2.46</b>	<b>0.23</b>	<b>0.20</b>

Application of either 80 or 160 kg N ha<sup>-1</sup> recorded significantly highest weight of panicle over control and the highest (2.88 and 3.17 g during 2002 and 2003, respectively) weight of panicle was recorded with application of 160 kg N ha<sup>-1</sup>. Interaction effect between rice varieties and panicle weight [Table 8(k) and Table 8(l)] was also significant during both the years of experimentation. The trend was similar to the interaction for filled grains per panicle. However, PRH 10 and Pusa Sugandh 3 produced significantly heavier panicle with the application of 160 kg N ha<sup>-1</sup> during 2002 and 2003. On the other hand, application of 160 kg N ha<sup>-1</sup> in Pusa Basmati 1 could not influence the weight of panicle over the application of 80 kg N ha<sup>-1</sup> during both the years of study. Significantly heavier panicle was produced by PRH 10 and Pusa Sugandh 3 at 0 kg N ha<sup>-1</sup> than Pusa Basmati 1 applied with 160 kg N ha<sup>-1</sup>.

#### **4.2.4 Length of panicle**

Data on length of panicle (Table 9 and Fig. 5) revealed that it was significantly influenced by rice varieties, spacings and levels of nitrogen. Pusa Basmati 1 recorded significantly longer panicle (26.29 cm and 27.83 cm) during first and second years of study. Transplanting of rice at a closer spacing of 20 x 10 cm produced significantly shorter panicle during first year of study than other two spacings. Whereas, during second year the plant spacing failed to influence the length of panicle.

Application of 80 or 160 kg N ha<sup>-1</sup> being statistically at par resulted significantly longer panicle over no nitrogen application.



**Fig. 5. Effect of plant spacing and levels of nitrogen on yield attributing characters of aromatic rice**

#### **4.2.5 Fertility percentage**

Data on fertility percentage presented in Table 9 and depicted in Fig. 5 indicated that during both the years, rice variety Pusa Sugandh 3 recorded significantly higher fertility percentage than PRH 10 and Pusa Basmati 1. Fertility percentage was unaltered due to spacings in the first year of experimentation, but was significantly higher at a spacing of 20 x 20 cm than that of a closer spacing of 20 x 10 cm during second year of the study.

It is also obvious from the table that the fertility percentage of aromatic rice varieties significantly increased with the application of 80 and 160 kg N ha<sup>-1</sup> over no nitrogen application during both the years of irrigation.

#### **4.2.6 Test weight**

The data on test weight presented in Table 9 and illustrated in Fig. 5 indicated that Pusa Sugandh 3 produced significantly heavier grain than PRH 10 and Pusa Basmati 1 during both the years of study. The data revealed that adoption of 20 x 20 cm spacing for rice transplanting resulted in heavier test weight than rice transplanting at closer spacing of 20 x 10 cm. A non-significant difference was observed between 20 x 15 cm and 20 x 20 cm spacing and between 20 x 10 and 20 x 15 cm spacing during first and second year of the study, respectively.

Application of either 80 or 160 kg N ha<sup>-1</sup> had significantly higher test weight over no nitrogen application. Whereas both levels of nitrogen application could not influence test weight in either of the year of study.

**Table 10. Effect of plant spacing and levels of nitrogen on grain and straw yield and harvest index of aromatic rice**

Treatments	Grain yield (q/ha)		Straw yield (q/ha)		Harvest index (%)	
	2002	2003	2002	2003	2002	2003
<b>Rice varieties</b>						
PRH 10	50.03	53.00	83.11	87.01	37.63	37.90
Pusa Sugandh 3	46.91	50.35	81.13	84.01	36.96	37.75
Pusa Basmati 1	36.79	40.82	75.92	79.31	32.85	34.11
<b>SEm ±</b>	<b>0.63</b>	<b>0.80</b>	<b>1.54</b>	<b>1.25</b>	<b>0.62</b>	<b>0.76</b>
<b>CD (P=0.05)</b>	<b>1.87</b>	<b>2.39</b>	<b>4.60</b>	<b>3.75</b>	<b>1.87</b>	<b>2.28</b>
<b>Spacing (cm)</b>						
20 x 10	41.13	44.14	86.90	91.39	32.00	32.52
20 x 15	44.84	48.63	80.78	83.71	35.74	36.86
20 x 20	47.76	51.40	72.48	75.63	39.70	40.38
<b>SEm ±</b>	<b>0.63</b>	<b>0.80</b>	<b>1.54</b>	<b>1.25</b>	<b>0.62</b>	<b>0.76</b>
<b>CD (P=0.05)</b>	<b>1.87</b>	<b>2.39</b>	<b>4.60</b>	<b>3.75</b>	<b>1.87</b>	<b>2.28</b>
<b>N levels (kg ha<sup>-1</sup>)</b>						
0	37.80	39.79	69.77	72.51	35.10	35.69
80	45.28	50.53	81.14	86.84	35.83	36.55
160	50.65	53.85	89.25	91.28	36.51	37.52
<b>SEm ±</b>	<b>0.61</b>	<b>0.74</b>	<b>1.35</b>	<b>0.95</b>	<b>0.53</b>	<b>0.69</b>
<b>CD (P=0.05)</b>	<b>1.76</b>	<b>2.12</b>	<b>3.88</b>	<b>2.73</b>	<b>NS</b>	<b>NS</b>

### 4.3 Grain and straw yield and harvest index

Data pertaining to grain and straw yield and harvest index as influenced by hybrid and inbred aromatic rice varieties, spacings and levels of nitrogen are presented in Table 10 and graphically illustrated in Fig. 6.

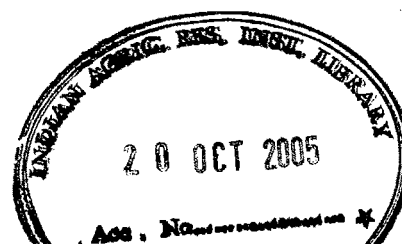
#### 4.3.1 Grain yield

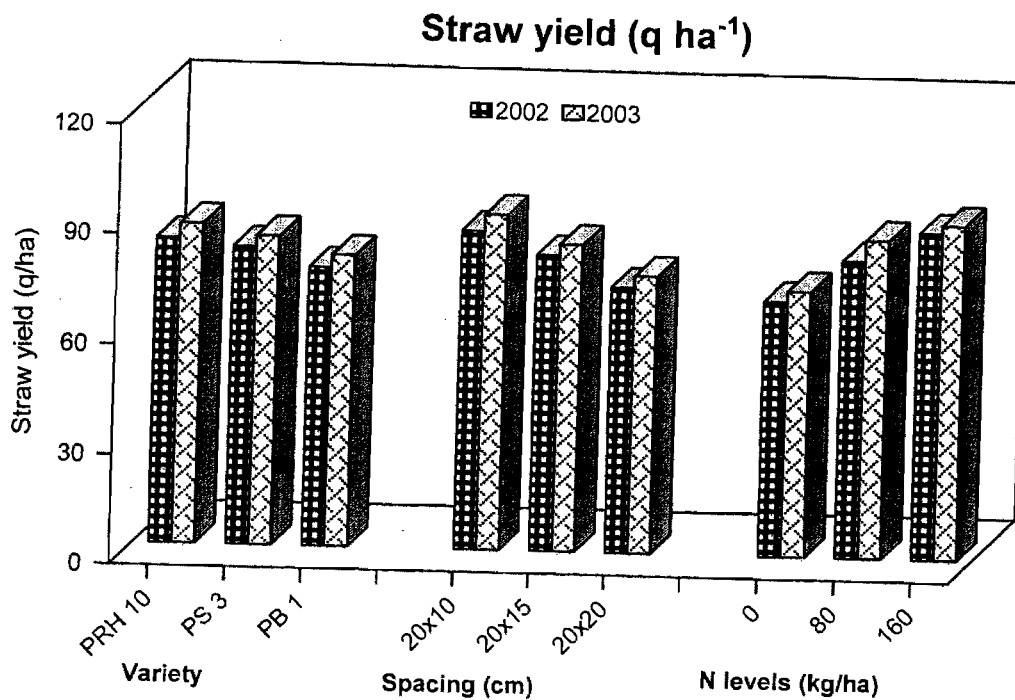
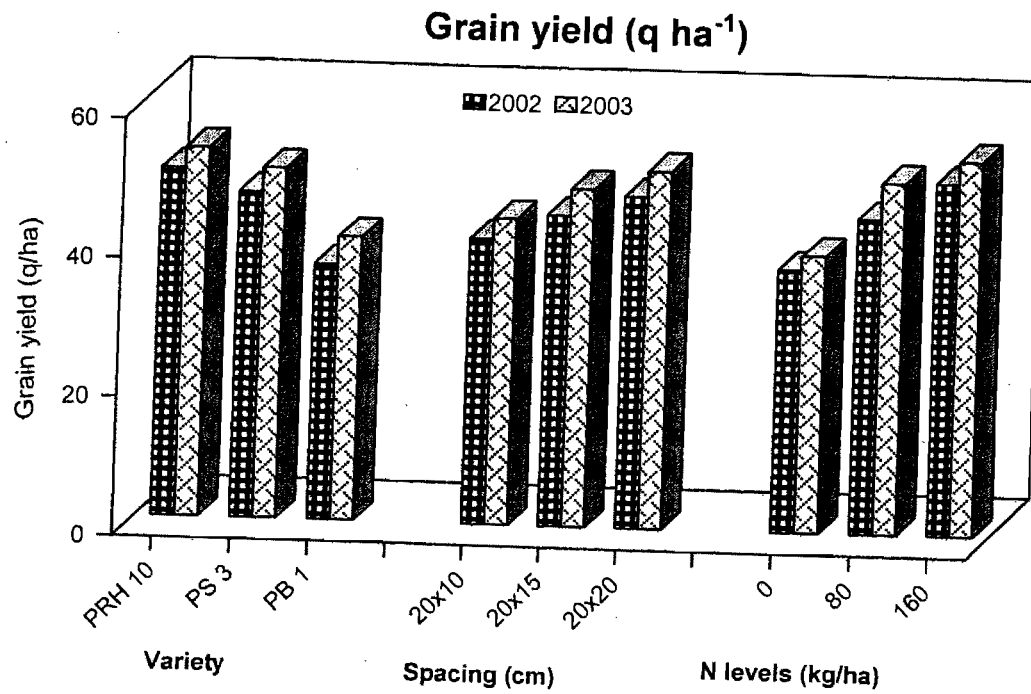
Perusal of the data on grain yield of rice indicated that rice hybrid PRH 10 outyielded 50.03 and 53.0 q ha<sup>-1</sup> during 2002 and 2003, respectively, which was significantly higher than that of inbred aromatic rice varieties Pusa Sugandh 3 and Pusa Basmati 1. Newly released inbred rice variety Pusa Sugandh 3 produced significantly 10.12 and 9.52 q ha<sup>-1</sup> more grain yields than Pusa Basmati 1 during 2002 and 2003, respectively. The increase in the grain yield of PRH 10 was 6.6 and 5.2 per cent higher than that of produced by Pusa Sugandh 3.

Different plant spacings adopted for transplanting also influenced the grain yield of rice. Transplanting of rice at a spacing of 20 x 20 cm proved significantly superior over the spacings of 20 x 10 and 20 x 15 cm. Medium spacing of 20 x 15 cm resulted significantly higher grain yield than closer spacing of 20 x 10 cm. The increases in the grain yield of rice due to wider spacing (20 x 20 cm) were 13.6 and 14.1 more over closer spacing (20 x 10 cm) and 5.6 and 5.3 per cent more over medium spacing (20 x 15 cm) during 2002 and 2003, respectively.

Application of 80 and 160 kg N ha<sup>-1</sup> significantly increased the grain yield of aromatic rice. Application of 160 kg N ha<sup>-1</sup> recorded 23.7 and 26.1 per cent more grain yield

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**Fig. 6. Effect of plant spacing and levels of nitrogen on grain and straw yield (q ha<sup>-1</sup>) of aromatic rice**

over no nitrogen application whereas it was 6.4 and 6.1 per cent more over 80 kg N ha<sup>-1</sup> respectively during first and second year of the experimentation.

The interaction effect of rice varieties and spacings were significant during both the years of study [Table 10(a) and Table 10(b)]. Rice hybrid PRH 10 produced significantly higher grain yield (53.91 and 57.40 q ha<sup>-1</sup> in 2002 and 2003, respectively) at wider spacing of 20 x 20 cm than transplanting at other spacings. However, the grain yield of hybrid was non-significant at 20 x 10 cm and 20 x 15 cm spacings during 2003. On the other hand both the inbred varieties Pusa Sugandh 3 and Pusa Basmati 1 being at par at 20 x 15 cm and 20 x 20 cm spacings yielded significantly higher than closer spacing of 20 x 10 cm. The performance of PRH 10 and Pusa Sugandh 3 were similar when transplanted at 20 x 10 cm and 20 x 15 cm spacings. These two varieties produced significantly more grain yield at closer (20 x 10 cm) spacing than produced by Pusa Basmati 1 at wider (20 x 20 cm) spacing.

Interaction effect of rice varieties and nitrogen application [Table 10(c) and Table 10(d)] revealed that PRH 10 and Pusa Sugandh 3 registered significantly more grain yield than Pusa Basmati 1 at all the levels of nitrogen application producing maximum at 160 kg N ha<sup>-1</sup> during both the years. But the grain yield at 0 and 80 kg N ha<sup>-1</sup> was at par between PRH 10 and Pusa Sugandh 3 in first and second year of experimentation. Application of 80 kg N ha<sup>-1</sup> in Pusa Basmati 1 produced significantly higher grain yield over no nitrogen application but was at par with the application of 160 kg N ha<sup>-1</sup>. Grain yield of PRH 10 and Pusa Sugandh 3 at 0 kg N ha<sup>-1</sup> and that of Pusa Basmati 1 at 160 kg N ha<sup>-1</sup> were registered

**Table 10(a). Interaction effect of aromatic rice and plant spacing on grain yield (q ha<sup>-1</sup>) during 2002**

Varieties	Spacings (cm)		
	20x10	20x15	20x20
PRH 10	46.17	50.00	53.91
Pusa Sugandh 3	43.56	47.00	50.15
Pusa Basmati 1	33.65	37.53	39.20
<b>SEm ± CD (P=0.05)</b>		<b>1.08 3.25</b>	

**Table 10(b). Interaction effect of aromatic rice and plant spacing on grain yield (q ha<sup>-1</sup>) during 2003**

Varieties	Spacings (cm)		
	20x10	20x15	20x20
PRH 10	49.62	51.94	57.40
Pusa Sugandh 3	46.32	52.69	52.05
Pusa Basmati 1	36.47	41.27	44.74
<b>SEm ± CD (P=0.05)</b>		<b>1.39 4.16</b>	

**Table 10(c). Interaction effect of aromatic rice and levels of nitrogen on grain yield (q ha<sup>-1</sup>) during 2002**

Varieties	N levels (kg ha <sup>-1</sup> )		
	0	80	160
PRH 10	42.09	50.30	57.70
Pusa Sugandh 3	40.41	47.31	53.01
Pusa Basmati 1	30.91	38.22	41.25
<b>S.E.m ± CD (P=0.05)</b>		<b>1.06 3.15</b>	

**Table 10(d). Interaction effect of aromatic rice and levels of nitrogen on grain yield (q ha<sup>-1</sup>) during 2003**

Varieties	N levels (kg ha <sup>-1</sup> )		
	0	80	160
PRH 10	43.41	54.56	61.00
Pusa Sugandh 3	42.36	51.61	57.09
Pusa Basmati 1	33.62	43.43	45.43
<b>S.E.m ± CD (P=0.05)</b>		<b>1.28 3.67</b>	

at par. In general, grain yield of rice during second year was higher than first year of the study.

#### **4.3.2 Straw yield**

Data pertaining to straw yield (Table 10) indicated that PRH 10 and Pusa Sugandh 3 being statistically at par produced significantly more straw yield than Pusa Basmati 1 during both the years of experimentation. Plant spacing had significant influence on straw yield. The production of straw significantly differed among three spacings during both the years of study. Higher straw yield (86.90 and 91.39 q/ha) was recorded with the adoption of 20 x 10 cm spacing.

Each successive increment in the level of nitrogen significantly increased the straw yield. Application of nitrogen @ 160 kg ha<sup>-1</sup> significantly enhanced the straw yield compared to 80 kg N ha<sup>-1</sup> application.

#### **4.3.3 Harvest index**

The harvest index was significantly influenced by rice varieties during both the years (Table 10). PRH 10 and Pusa Sugandh 3 being statistically at par recorded significantly higher harvest index than Pusa Basmati 1. All the spacing treatments in the study differed significantly in recording the values of harvest index. However, highest harvest index values (39.70% during 2002 and 40.38% during 2003) were recorded with a spacing of 20 x 20 cm which were significantly higher over the spacings of 20 x 10 cm and 20 x 15 cm. Application of nitrogen failed to influence the harvest index during both the years of study.

**Table 11. Effect of plant spacing and levels of nitrogen on hulling, milling and head rice recovery of aromatic rice**

Treatments	Hulling (%)		Milling (%)		Head rice recovery (%)	
	2002	2003	2002	2003	2002	2003
<b>Rice varieties</b>						
PRH 10	79.84	80.20	64.85	65.42	52.25	52.27
Pusa Sugandh 3	78.76	79.26	67.12	67.62	53.56	53.24
Pusa Basmati 1	77.85	77.90	66.04	66.84	51.37	51.93
<b>SEm ±</b>	<b>0.46</b>	<b>0.38</b>	<b>0.47</b>	<b>0.41</b>	<b>0.30</b>	<b>0.24</b>
<b>CD (P=0.05)</b>	<b>1.38</b>	<b>1.41</b>	<b>1.41</b>	<b>1.23</b>	<b>0.90</b>	<b>0.72</b>
<b>Spacing (cm)</b>						
20 x 10	78.10	78.37	64.78	65.75	51.36	51.86
20 x 15	78.65	79.30	66.13	66.79	52.13	52.42
20 x 20	79.70	79.69	67.10	67.34	53.69	53.16
<b>SEm ±</b>	<b>0.46</b>	<b>0.38</b>	<b>0.47</b>	<b>0.41</b>	<b>0.30</b>	<b>0.24</b>
<b>CD (P=0.05)</b>	<b>1.38</b>	<b>NS</b>	<b>1.41</b>	<b>1.23</b>	<b>0.90</b>	<b>0.72</b>
<b>N levels (kg ha<sup>-1</sup>)</b>						
0	77.44	78.15	65.22	65.42	51.37	51.75
80	78.94	79.21	66.23	66.61	52.31	52.43
160	80.07	80.00	66.56	67.85	53.49	53.16
<b>SEm ±</b>	<b>0.36</b>	<b>0.23</b>	<b>0.34</b>	<b>0.33</b>	<b>0.25</b>	<b>0.19</b>
<b>CD (P=0.05)</b>	<b>1.07</b>	<b>0.66</b>	<b>0.98</b>	<b>0.95</b>	<b>0.72</b>	<b>0.56</b>

#### **4.4 Grain quality characteristics**

Data on quality parameters of rice grain namely hulling and milling percentage, head rice recovery, length and breadth of rice kernel before and after cooking and protein content are presented in Table 11 and Table 12.

##### **4.4.1 Hulling percentage**

Rice hybrid PRH 10 exhibited significantly higher (79.84 and 80.20%) values of milling percentage than inbred rice variety Pusa Basmati 1 (Table 11). However, differences were non-significant in between PRH 10 and Pusa Sugandh 3, and Pusa Sugandh 3 and Pusa Basmati 1. Almost similar trend was noted during second year of the study.

Plant spacing caused a significant effect on hulling percentage only during 2002. The widest spacing of 20 x 20 cm registered significantly maximum hulling (79.70%) percentage over closer spacing of 20 x 10 cm, however, non-significant variation was noticed between 20 x 20 cm and 20 x 15 cm spacings. Nitrogen application also influenced the hulling percentage of rice and the highest (80%) was recorded with the application of 160 kg N ha<sup>-1</sup>.

##### **4.4.2 Milling percentage**

The data recorded on milling percentage of aromatic rice presented in Table 11 indicated that inbred rice varieties Pusa Sugandh 3 and Pusa Basmati 1 resulted significantly higher milling percentage than that of rice hybrid PRH 10. No significant difference was noticed between the two inbred aromatic rice varieties during either of the years of the study.

**Table 12. Effect of plant spacing and levels of nitrogen on kernel length and breadth before and after cooking and protein content in aromatic rice**

Treatments	Kernel length before cooking (mm)		Kernel length after cooking (mm)		Kernel breadth before cooking (mm)		Kernel breadth after cooking (mm)		Protein content (%)	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
<b>Rice varieties</b>										
PRH 10	6.74	6.89	11.54	11.73	1.71	1.71	2.16	2.10	7.91	7.96
Pusa Sugandh 3	7.43	7.50	13.34	13.36	1.80	1.82	2.53	2.57	7.70	7.73
Pusa Basmati 1	7.40	7.39	13.73	13.76	1.77	1.79	2.24	2.21	7.09	7.16
<b>SEM ±</b>	<b>0.05</b>	<b>0.05</b>	<b>0.08</b>	<b>0.12</b>	<b>0.02</b>	<b>0.02</b>	<b>0.02</b>	<b>0.02</b>	<b>0.06</b>	<b>0.06</b>
<b>CD (P=0.05)</b>	<b>0.16</b>	<b>0.15</b>	<b>0.24</b>	<b>0.36</b>	<b>0.07</b>	<b>0.05</b>	<b>0.07</b>	<b>0.07</b>	<b>0.19</b>	<b>0.18</b>
<b>Spacing (cm)</b>										
20 x 10	7.11	7.22	12.84	12.84	1.73	1.76	2.29	2.26	7.49	7.55
20 x 15	7.21	7.24	12.86	12.94	1.77	1.77	2.30	2.30	7.56	7.58
20 x 20	7.25	7.32	12.91	13.06	1.78	1.79	2.34	2.32	7.65	7.72
<b>SEM ±</b>	<b>0.05</b>	<b>0.05</b>	<b>0.08</b>	<b>0.12</b>	<b>0.02</b>	<b>0.02</b>	<b>0.02</b>	<b>0.02</b>	<b>0.06</b>	<b>0.06</b>
<b>CD (P=0.05)</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>
<b>N levels (kg ha<sup>-1</sup>)</b>										
0	7.14	7.22	12.75	12.80	1.74	1.77	2.28	2.27	6.93	7.00
80	7.20	7.26	12.92	12.95	1.75	1.77	2.32	2.28	7.83	7.85
160	7.23	7.30	12.95	13.10	1.79	1.78	2.33	2.33	7.94	8.00
<b>SEM ±</b>	<b>0.04</b>	<b>0.04</b>	<b>0.075</b>	<b>0.10</b>	<b>0.02</b>	<b>0.02</b>	<b>0.01</b>	<b>0.02</b>	<b>0.04</b>	<b>0.04</b>
<b>CD (P=0.05)</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>0.12</b>	<b>0.11</b>

Similar to the hulling percentage, milling percentage too was significantly highest (about 67%) under widest spacing of 20 x 20 cm over closer spacings.

Application of either of the dose of nitrogen registered significantly higher values of milling percentage than that of no nitrogen application during both the years of experimentation. Between the two doses of nitrogen application i.e. 80 and 160 kg ha<sup>-1</sup>, the significant difference for milling percentage was noticed during second year of the study.

#### **4.4.3 Head rice recovery**

Data presented in Table 11 revealed that rice cultivars, spacings and levels of nitrogen significantly influenced the head rice recovery. Among the three rice cultivars in the study, inbred aromatic rice Pusa Sugandh 3 had significantly highest (53.56 and 53.24% during 2002 and 2003, respectively) values of head rice recovery over PRH 10 and Pusa Basmati 1.

Head rice recovery did not differ with the transplanting of rice at 20 x 10 cm and 20 x 15 cm during either of the years of study, whereas widest spacing of 20 x 20 cm registered significantly maximum 53.69 value of head rice recovery during first year. Similar trend was noticed during second year of the study. Each increment of nitrogen significantly increased the head rice recovery and application of 160 kg N ha<sup>-1</sup> recorded the highest value of head rice recovery.

#### **4.4.4 Kernel length and breadth before cooking**

Inbred aromatic rice varieties Pusa Sugandh 3 and Pusa Basmati 1 registered significantly longer kernel (7.43 and 7.50 mm, and 7.40 and 7.39 mm during 2002 and 2003, respectively) before cooking than rice hybrid PRH 10 (6.74 and 6.89 mm) during both

the years of study (Table 12). Similar trend was noticed for kernel breadth before cooking of the rice cultivars included in the study.

Transplanting of rice at various spacings and application of levels of nitrogen could not bring a significant variation in the length and breadth of rice kernel before cooking during either of the year of experimentation.

#### **4.4.5 Kernel length and breadth after cooking**

The data on rice kernel length and breadth after cooking as influenced by rice cultivars, spacings and levels of nitrogen application are presented in Table 12.

Results indicated that all the three rice cultivars namely PRH 10, Pusa Sugandh 3 and Pusa Basmati 1 significantly varied with each other in length and breadth of rice kernel after cooking during both the years of study. Pusa Basmati 1 recorded significantly highest (13.73 and 13.76 mm during 2002 and 2003, respectively) value of kernel length after cooking, whereas Pusa Sugandh 3 registered significantly the highest (2.53 and 2.57 mm during 2002 and 2003, respectively) value of kernel breadth after cooking. Neither the plant spacings nor the levels of nitrogen application could remarkably influence the length and breadth of rice kernel after cooking during either of the years of investigation.

#### **4.4.6 Protein content**

Data on protein content (Table 12) of aromatic rice cultivars indicated that PRH 10 exhibited significantly highest (7.91 and 7.96%) than Pusa Sugandh 3 (7.70 and 7.73%) and Pusa Basmati 1 (7.09 and 7.16%) protein content during both the years of study. Protein content also significantly varied in between two inbred aromatic rices Pusa Sugandh 3 and Pusa Basmati 1.

**Table 13. Effect of plant spacing and nitrogen levels of on nitrogen uptake (kg ha<sup>-1</sup>) of aromatic rice at different growth stages**

Treatments	Nitrogen uptake (kg/ha)											
	Panicle initiation stage			Flowering stage			At harvest					
	2002	2003		2002	2003		Grain		Straw		Total	
<b>Rice varieties</b>												
PRH 10	78.00	85.05		95.44	100.38		67.91	72.60	43.62	46.54	111.53	119.14
Pusa Sugandh 3	69.20	73.70		89.71	92.81		61.82	66.93	40.87	43.42	102.69	110.35
Pusa Basmati 1	58.85	64.06		71.02	75.77		44.67	50.04	36.92	40.00	81.59	90.04
<b>SEm +</b>	<b>1.52</b>	<b>2.03</b>		<b>1.32</b>	<b>1.90</b>		<b>0.88</b>	<b>1.01</b>	<b>1.00</b>	<b>1.07</b>	<b>2.33</b>	<b>2.15</b>
<b>CD (P=0.05)</b>	<b>4.60</b>	<b>6.11</b>		<b>3.95</b>	<b>5.73</b>		<b>2.64</b>	<b>3.02</b>	<b>3.00</b>	<b>3.22</b>	<b>7.02</b>	<b>6.44</b>
<b>Spacing (cm)</b>												
20 x 10	75.56	80.22		90.22	94.78		53.71	57.37	43.14	46.55	96.31	103.92
20 x 15	69.49	75.73		86.09	90.76		58.21	63.75	40.73	43.30	98.85	107.05
20 x 20	61.00	66.86		79.86	83.42		63.02	68.45	37.54	40.11	100.55	108.56
<b>SEm +</b>	<b>1.52</b>	<b>2.03</b>		<b>1.32</b>	<b>1.90</b>		<b>0.88</b>	<b>1.01</b>	<b>1.00</b>	<b>1.07</b>	<b>2.33</b>	<b>2.15</b>
<b>CD (P=0.05)</b>	<b>4.60</b>	<b>6.11</b>		<b>3.95</b>	<b>5.73</b>		<b>2.64</b>	<b>3.62</b>	<b>3.00</b>	<b>3.22</b>	<b>NS</b>	<b>NS</b>
<b>N levels (kg ha<sup>-1</sup>)</b>												
0	50.60	53.55		66.96	69.95		44.55	47.40	31.20	33.30	75.75	80.71
80	72.20	78.50		89.45	94.07		60.50	67.17	42.30	46.16	102.81	113.33
160	83.25	90.26		99.77	104.94		69.35	75.00	47.91	50.50	117.25	125.48
<b>SEm +</b>	<b>1.32</b>	<b>1.56</b>		<b>1.14</b>	<b>1.89</b>		<b>0.83</b>	<b>0.75</b>	<b>0.80</b>	<b>0.72</b>	<b>1.97</b>	<b>1.82</b>
<b>CD (P=0.05)</b>	<b>3.78</b>	<b>4.48</b>		<b>3.27</b>	<b>5.43</b>		<b>2.40</b>	<b>2.16</b>	<b>2.30</b>	<b>2.07</b>	<b>5.66</b>	<b>5.23</b>

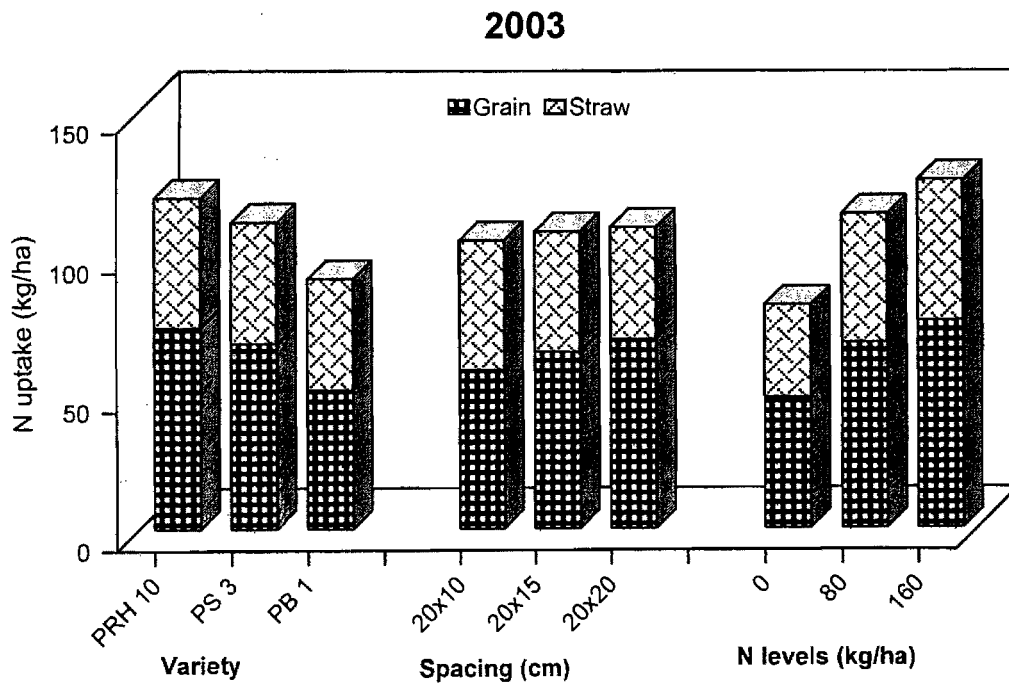
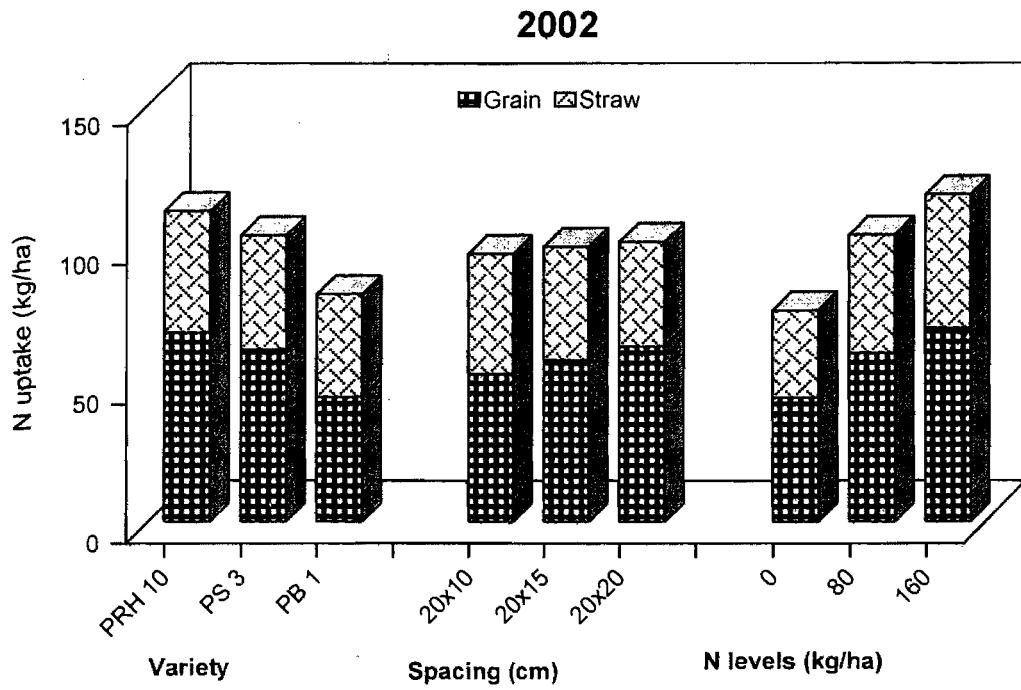
Transplanting of rice at different spacing could not influence the protein content. Each increment in nitrogen application significantly increased the protein content of milled rice during 2003. Application of 80 and 160 kg N ha<sup>-1</sup> did not affect the protein content of rice during 2002, but differed significantly over no nitrogen application.

#### **4.5 Nitrogen uptake**

The data on nitrogen uptake by rice at different growth stages and at harvest in grain and straw at harvest are presented in Table 13 and depicted in Fig. 7. Nitrogen content in plant parts are displayed in Appendix III.

The results on nitrogen uptake revealed that it was significantly influenced by rice cultivars, spacings and nitrogen levels. Rice hybrid PRH 10 recorded significantly higher nitrogen uptake at PI and flowering stages, and in grain and straw during both the years than Pusa Sugandh 3 and Pusa Basmati 1, except in straw than Pusa Sugandh 3. All the three rice cultivars in the study differ significantly in respect of total N uptake and the highest (111.53 and 119.14 kg ha<sup>-1</sup> during 2002 and 2003, respectively) total uptake was recorded by PRH 10.

Closer spacing of 20 x 10 cm registered significantly higher values of nitrogen uptake at PI and flowering stage during 2002 than the spacings of 20 x 15 cm and 20 x 20 cm, but was only significantly higher than widest spacing of 20 x 20 cm during 2003. On the other hand, widest spacing of 20 x 20 cm recorded significantly maximum nitrogen uptake (53.17 and 57.37 kg ha<sup>-1</sup> during 2002 and 2003, respectively) than those of recorded with the spacings of 20 x 10 cm and 20 x 15 cm. Contrary to this, significantly maximum nitrogen uptake values by straw was noticed in closer spacing of 20 x 10 cm than in a



**Fig. 7. Effect of plant spacing and levels of nitrogen on nitrogen uptake ( $\text{kg ha}^{-1}$ ) by grain and straw of aromatic rice**

spacing of 20 x 20 cm. However, all the spacings in both the years of study failed to influence the total nitrogen uptake.

Each increment of nitrogen application significantly increased the nitrogen uptake at PI and flowering stages and in rice grain and straw during both the years of experimentation. Total nitrogen uptake (117.25 and 125.48 kg ha<sup>-1</sup> during 2002 and 2003, respectively) at harvest was significantly higher with application of 160 kg N ha<sup>-1</sup>.

Interaction effect of rice cultivars and plant spacings on N uptake by grain was found significant during both the years [Table 13(a) and Table 13(b)]. Significantly higher N uptake by grain of PRH 10 was recorded at all the spacings as compared to both inbred rice varieties during both the years of study, except than Pusa Sugandh 3 at a spacing of 20 x 15 cm during 2003. Nitrogen uptake by Pusa Basmati 1 was noticed non-significant at the spacings of 20 x 15 cm and 20 x 20 cm during both the years of study but significantly higher than 20 x 10 cm. However, PRH 10 registered highest uptake of nitrogen in grain at widest spacing of 20 x 20 cm.

Interaction effect of rice cultivars and levels of nitrogen was significant [Table 13(c) and Table 13(d)]. The data revealed that nitrogen uptake by grain of PRH 10 and Pusa Sugandh 3 significantly increased with each increment in the level of nitrogen during 2002. Whereas, Pusa Basmati 1 registered significantly higher nitrogen uptake with the application of 80 and 160 kg N ha<sup>-1</sup> over no nitrogen, but at par in between the two levels of application. However, N uptake by PRH 10 and Pusa Sugandh 3 in grain was noticed to be non-significant at no nitrogen application. The same result was noticed during second year

**Table 13(a). Interaction effect of aromatic rice and plant spacing on nitrogen uptake (kg ha<sup>-1</sup>) by grain during 2002**

Varieties	Spacings (cm)		
	20x10	20x15	20x20
PRH 10	62.09	68.42	73.32
Pusa Sugandh 3	56.93	61.32	67.21
Pusa Basmati 1	40.49	45.40	48.11
<b>SEm ±</b>		<b>1.53</b>	
<b>CD (P=0.05)</b>		<b>4.59</b>	

**Table 13(b). Interaction effect of aromatic rice and plant spacing on nitrogen uptake (kg ha<sup>-1</sup>) by grain during 2002**

Varieties	Spacings (cm)		
	20x10	20x15	20x20
PRH 10	67.10	71.15	79.54
Pusa Sugandh 3	60.77	69.60	70.41
Pusa Basmati 1	44.23	50.49	55.39
<b>SEm ±</b>		<b>1.74</b>	
<b>CD (P=0.05)</b>		<b>5.22</b>	

**Table 13(c). Interaction effect of aromatic rice and levels of nitrogen on nitrogen uptake (kg ha<sup>-1</sup>) by grain during 2002**

Varieties	N levels (kg ha <sup>-1</sup> )		
	0	80	160
PRH 10	50.30	70.85	82.66
Pusa Sugandh 3	47.42	64.33	73.70
Pusa Basmati 1	35.94	46.83	51.24
<b>SEm ±</b>		<b>1.44</b>	
<b>CD (P=0.05)</b>		<b>4.13</b>	

**Table 13(d). Interaction effect of aromatic rice and levels of nitrogen on nitrogen uptake (kg ha<sup>-1</sup>) by grain during 2003**

Varieties	N levels (kg ha <sup>-1</sup> )		
	0	80	160
PRH 10	52.48	77.30	88.03
Pusa Sugandh 3	50.26	70.55	79.97
Pusa Basmati 1	39.47	53.65	56.98
<b>SEm ±</b>		<b>1.30</b>	
<b>CD (P=0.05)</b>		<b>3.74</b>	

of study. Nitrogen uptake at 0 kg N ha<sup>-1</sup> by these two varieties was at par with that of Pusa Basmati 1 at 160 kg N ha<sup>-1</sup> only during 2002.

## **4.6 Simulation modelling**

### **4.6.1 Varietal coefficients and calibration of the model**

Coefficients of the rice varieties in the study was generated by adjusting different variables and re-running the model such that the measured and simulated values of days to flowering, days to physiological maturity and grain yield of three rice varieties were close to the accepted values.

Table 14 shows the coefficients generated for three rice varieties after the calibration of the model. The results indicated that thermal degree-days for vegetative growth were 1450, 1500 and 1600°C for PRH 10, Pusa Sugandh 3 and Pusa Basmati 1, respectively, with corresponding grain filling values as 500, 480 and 400°C. Relative growth rate of leaf area, radiation use efficiency extinction coefficient of leaves at flowering and grain number coefficient (GNOCF) values were higher in hybrid rice PRH 10 than other two inbred varieties.

A comparison of the measured and simulated values (mean of the years 2002 and 2003) after calibration of the model regarding days to flowering, days to physiological maturity and grain yield of three rice varieties transplanted under three plant population and zero nitrogen application is presented in Table 15. The model simulated reasonably well for days to flowering and days to physiological maturity of all the rice varieties in the study. But, the model under estimated the grain yield of PRH 10, Pusa Sugandh 3 and Pusa Basmati 1 by 9.8, 10.1 and 7.2 per cent, respectively. Better closeness than this in between measured

**Table 14. Varietal coefficients of rice varieties for InfoCrop model**

Coefficients	Description	Rice varieties		
		PRH 10	Pusa Sugandh-3	Pusa Basmati-1
TTVG	Thermal time for vegetative growth (°C days)	1450	1500	1600
TTGF	Thermal time for grain filling (°C days)	500	480	400
RGRPOT	Relative growth rate of leaf area	0.0099	0.0090	0.0070
RUE	Radiation use efficiency (g MJ <sup>-1</sup> day <sup>-1</sup> )	2.3	2.3	2.2
SLAVAR	Specific leaf area of variety (dm <sup>2</sup> mg <sup>-1</sup> )	0.0024	0.0024	0.0022
GREENF	Index of greenness of leaves	0.90	0.90	0.70
KDF	Extinction coefficient of leaves at flowering (ha soil/ha leaf fraction)	0.60	0.50	0.40
GNOCF	Slope of grain no. m <sup>-2</sup> to dry matter during storage formation (No. of grain kg <sup>-1</sup> day <sup>-1</sup> )	58000	50000	48000
POTGWT	Potential grain weight (mg grain <sup>-1</sup> )	22	23	21

**Table 15. Calibrated results of three rice varieties**

Parameters	PRH 10		Pusa Sugandh 3		Pusa Basmati 1	
	Measured	Simulated	Measured	Simulated	Measured	Simulated
Days to flowering after seeding	90	89	95	95	107	108
Days to physiological maturity after seeding	117	116	122	122	134	136
Grain yield (q ha <sup>-1</sup> )	42.75	38.56 (-9.8)	41.38	37.18 (-10.1)	32.26	29.93 (-7.2)

Figures in parenthesis indicate per cent deviation of simulated from measured value

and simulated values of grain yield could not be achieved after repeated calibration of the model due to inability of the model in accounting the inherent fertility and productivity status of the soil.

#### **4.6.2 Validation of model**

The InfoCrop model was validated for three rice varieties in terms of days to flowering, days to maturity and grain yield using 36 treatments of the field experiments of the year 2002 and 2003. The result shows that the model slightly over and under estimated days to flowering and days to physiological maturity of variety PS 3 and PB 1, respectively (Fig. 8 and Fig. 9). However, there was close correspondence between simulated and observed number of days to flowering and to physiological maturity with residual mean square error (RMSE) of 1.5 and 2.0 days, respectively, across varieties, nitrogen levels and plant population. The simple regression indicated a slope closer to one and a reasonably significant regression coefficient.

The comparison of simulated grain yield with observed values as influenced by nitrogen are presented in Table 16 and depicted in Fig. 11. Simulated grain yield of PRH 10, Pusa Sugandh 3 and Pusa Basmati 1 over observed grain yield were higher by 1.2, 2.4 and 0.9 per cent at 80 kg N ha<sup>-1</sup> and by 0.4, 6.1 and 0.8 per cent at 160 kg N ha<sup>-1</sup>, respectively, irrespective of plant population. Mean simulated grain yield of PRH 10, Pusa Sugandh 3 and Pusa Basmati 1 were 0.8, 4.0 and 0.9 per cent higher than mean observed grain yield, respectively. Irrespective of the rice varieties, grain yields of rice were well simulated by model for 80 and 160 kg N ha<sup>-1</sup>.

**Table 16. Simulated and measured grain yield ( $q\ ha^{-1}$ ) of rice varieties as influenced by levels of nitrogen (mean of two years)**

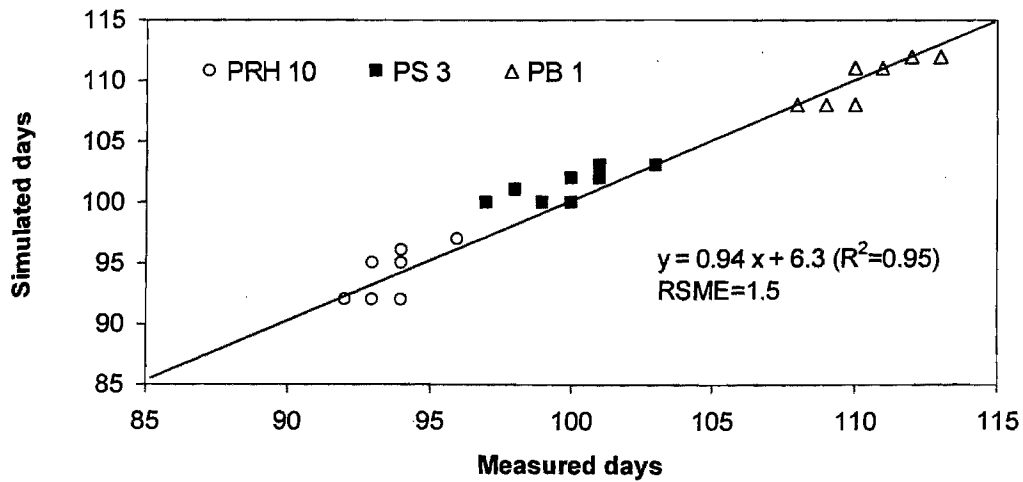
Rice varieties	Nitrogen levels ( $kg\ ha^{-1}$ )				Mean	
	80		160		Measured	Simulated
	Measured	Simulated	Measured	Simulated		
PRH 10	52.43	53.07 (+1.2)	59.35	59.60 (+0.4)	55.89	56.33 (+0.8)
Pusa Sugandh 3	49.46	50.66 (+2.4)	55.05	58.43 (+6.1)	52.43	54.54 (+4.0)
Pusa Basamati 1	40.83	41.20 (+0.9)	43.34	43.71 (+0.8)	42.08	42.45 (+0.9)
Mean	47.57	48.31 (+1.6)	52.58	53.91 (+2.5)		

Figures in parenthesis indicate per cent deviation of simulated from measured values

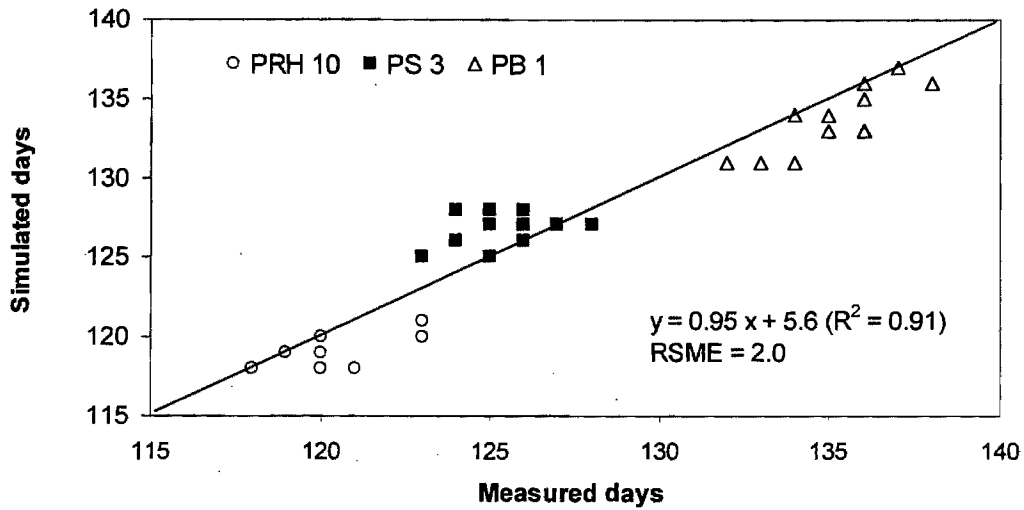
**Table 17. Simulated and measured grain yield ( $q\ ha^{-1}$ ) of rice varieties as influenced by plant population (mean of two years)**

Rice varieties	Plant population ( $hills\ m^{-2}$ )						Mean	
	50		33.3		25		Measured	Simulated
	Measured	Simulated	Measured	Simulated	Measured	Simulated		
PRH 10	51.93	54.93 (+5.8)	55.81	57.00 (+2.1)	59.91	57.09 (-4.7)	55.89	56.33 (+0.8)
Pusa Sugandh-3	48.49	50.57 (+4.3)	53.87	56.61 (+5.1)	54.40	56.88 (+4.6)	52.25	54.54 (+4.0)
Pusa Basamati-1	37.69	42.68 (+13.2)	42.60	42.62 (+0.2)	45.96	42.06 (-8.4)	42.08	42.45 (+0.9)
Mean	46.04	49.39 (+7.3)	50.76	52.07 (+2.6)	53.42	52.01 (-2.6)		

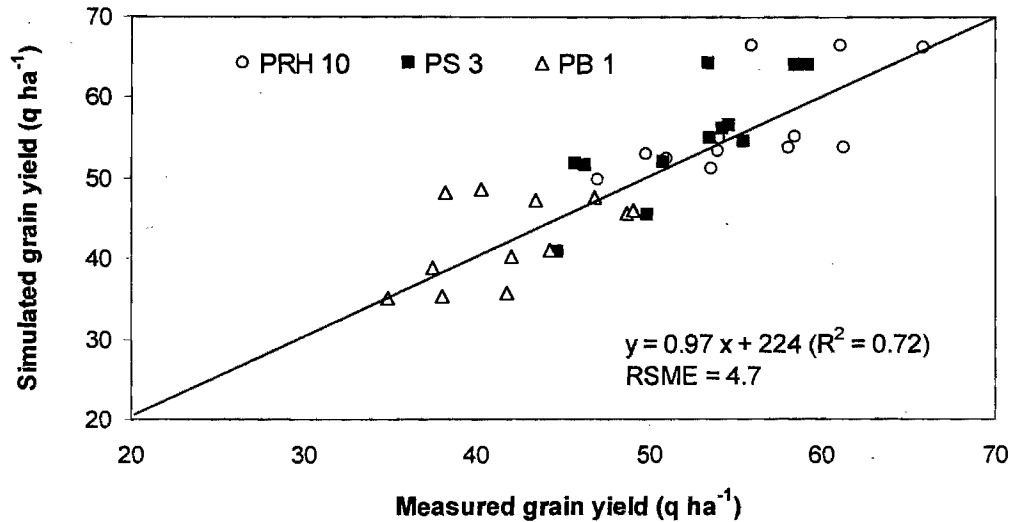
Figures in parenthesis indicate per cent deviation of simulated from measured values



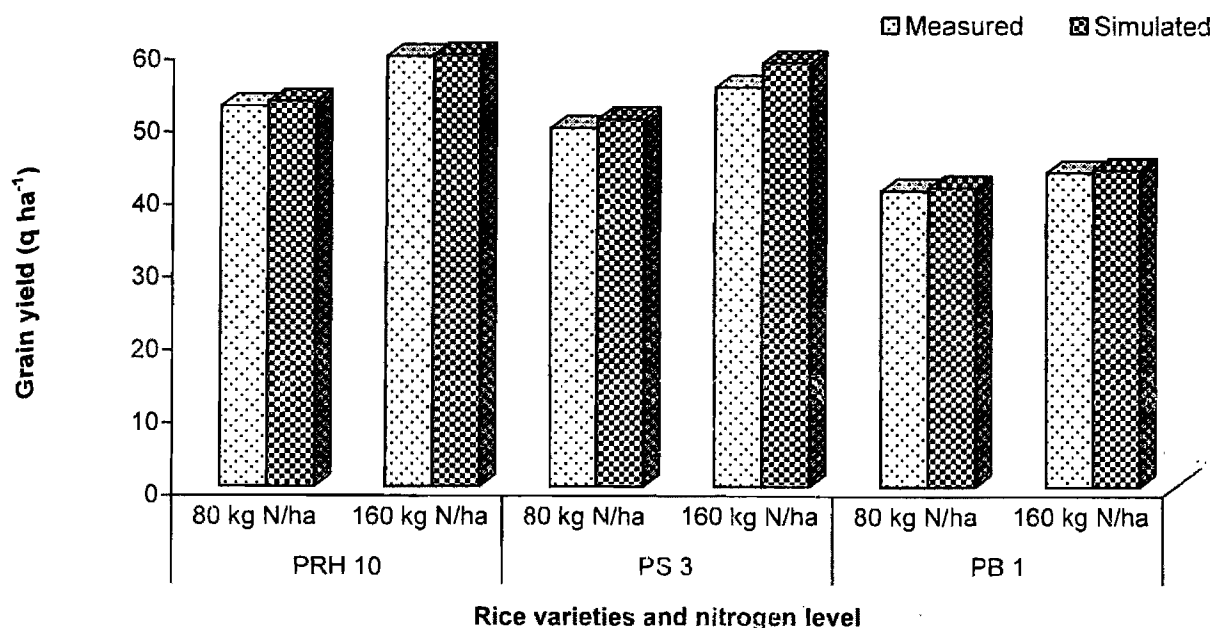
**Fig 8. Simulated and measured days to flowering of rice varieties after seeding**



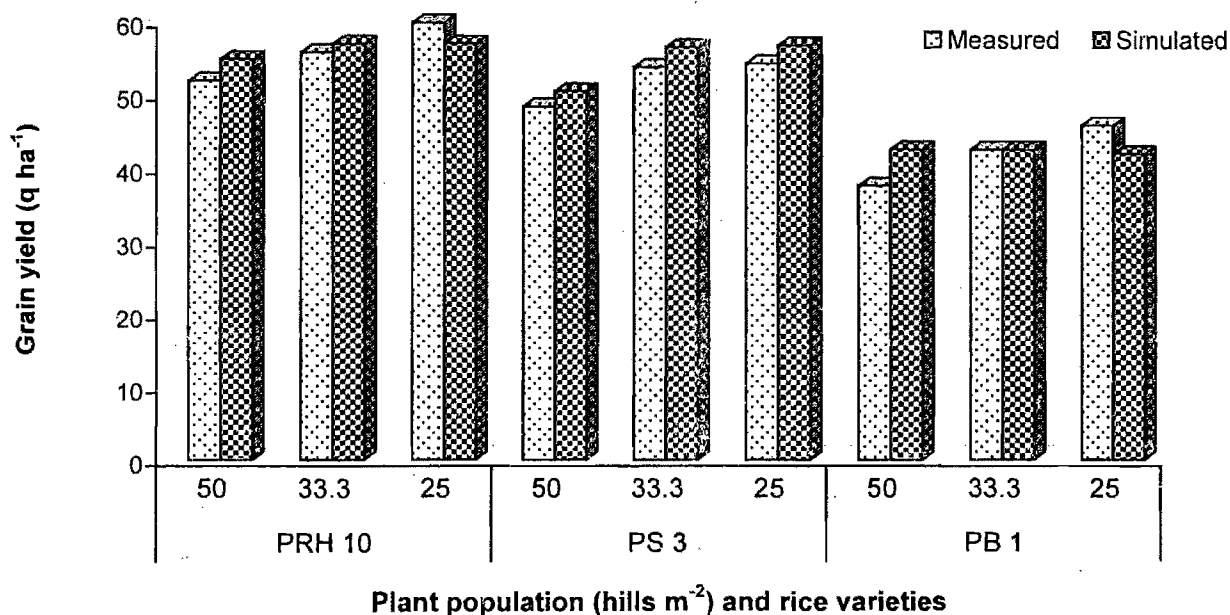
**Fig 9. Simulated and measured days to physiological maturity of rice varieties after seeding**



**Fig 10. Simulated and measured grain yield ( $q\ ha^{-1}$ ) of rice varieties for the years 2002 and 2003**



**Fig 11. Simulated and measured grain yield of rice varieties as influenced by nitrogen application (mean of two years)**



**Fig 12. Simulated and measured grain yield (q ha<sup>-1</sup>) of rice varieties as influenced by plant population (mean of two years)**

The model could not account the effect of plant population on grain yield up to satisfactory level (Table 17 and Fig. 12). The experimental results indicated increased grain yield of all varieties in the study with decrease in plant population i.e. increase in plant spacing, from 50 to 25 hills  $m^{-2}$ . Whereas, simulated grain yield of PRH 10 and Pusa Sugandh 3 was higher in 33.3 hills  $m^{-2}$  than in 50 hills  $m^{-2}$  and that of Pusa Basmati 1 remained same at all populations. However, irrespective of varieties, the model's prediction showed some increased trend of grain yield when plant population decreased from 50 to 33.3 hills  $m^{-2}$ . But, model's estimation for grain yield at 25 hills  $m^{-2}$  was remained similar to that estimated at 33.3 hills  $m^{-2}$ .

Fig. 10 illustrates the scatter of simulated and measured grain yield of three rice varieties around 1:1 line irrespective of nitrogen levels and plant population. The simple regression of simulated grain yield on observed had a slope of very close to one (0.98) and a regression coefficient of 0.72. The residual mean square error (RMSE) was calculated as 4.7  $q\ ha^{-1}$ , which was less than 10 per cent of the mean grain yield. At some data point, simulated grain yields were slightly over or underestimated relative to the observed grain yield. However, majority of data points were closer to the 1:1 line.

#### **4.6.3 Simulated grain yield at different sites in the Indo-Gangetic plains of India**

The validated InfoCrop model was used to simulate the grain yield of rice varieties over the period of 9 to 13 years at four representative locations of the Indo-Gangetic plains of India namely Ludhiana, Pantnagar, Patna and Barrackpore. The results are presented in Table 18 and 19 and depicted in Fig. 13-16.

**Table 18. Grain yield (q ha<sup>-1</sup>) of rice varieties estimated by model at different levels of nitrogen at four locations of Trans-Indo-Gangetic Plain of India**

Locations/ Varieties	Nitrogen levels (kg ha <sup>-1</sup> )						Mean
	0	40	80	120	160	200	
<b>Ludhiana (mean of 13 years)</b>							
PRH 10	15.36	33.93	53.93	70.73	79.39	82.79	56.00
Pusa Sugandh 3	12.80	28.25	42.49	55.44	65.71	69.68	45.63
Pusa Basmati 1	8.73	22.68	32.73	40.44	47.33	50.63	33.72
Mean	12.30	28.29	43.05	55.54	64.14	67.70	
<b>Pantnagar (mean of 13 years)</b>							
PRH 10	14.68	34.32	43.93	51.55	55.87	58.29	43.11
Pusa Sugandh 3	11.12	24.90	33.12	39.66	43.48	47.26	33.26
Pusa Basmati 1	7.71	16.65	21.88	25.38	26.93	28.09	21.11
Mean	11.17	25.29	32.98	38.86	42.09	44.55	
<b>Patna (mean of 9 years)</b>							
PRH 10	10.29	29.66	38.22	44.68	48.92	52.08	37.31
Pusa Sugandh 3	8.50	21.26	27.29	32.07	36.18	40.20	27.59
Pusa Basmati 1	5.67	13.59	16.55	19.04	21.25	22.38	16.42
Mean	8.15	21.50	27.35	31.93	35.45	38.22	
<b>Barrackpore (mean of 12 years)</b>							
PRH 10	8.29	23.72	30.44	35.35	39.13	41.27	29.70
Pusa Sugandh 3	6.55	17.55	23.52	27.72	30.70	33.31	23.23
Pusa Basmati 1	4.53	10.92	13.34	15.51	17.01	17.92	13.20
Mean	6.46	17.40	22.43	26.19	28.95	30.83	

**Table 19. Grain yield (q ha<sup>-1</sup>) of rice varieties estimated by model at different plant population at four locations of Trans-Indo-Gangetic Plain of India**

Locations/ Varieties	Plant population (hills m <sup>-2</sup> )				Mean
	25	33.3	50	66.7	
<b>Ludhiana (mean of 13 years)</b>					
PRH 10	55.80	56.00	56.10	56.10	56.00
Pusa Sugandh 3	45.61	45.55	45.70	45.70	45.63
Pusa Basmati 1	38.49	33.90	33.75	33.75	33.72
Mean	44.97	45.15	45.18	45.18	
<b>Pantnagar (mean of 13 years)</b>					
PRH 10	42.58	42.94	43.32	43.59	43.11
Pusa Sugandh 3	32.72	33.06	33.40	33.84	33.26
Pusa Basmati 1	20.57	20.96	21.33	21.58	21.11
Mean	31.96	33.32	32.68	33.00	
<b>Patna (mean of 9 years)</b>					
PRH 10	36.52	37.13	37.60	37.98	37.31
Pusa Sugandh 3	26.93	27.38	27.84	28.19	27.59
Pusa Basmati 1	16.07	16.20	16.56	16.83	16.42
Mean	26.51	26.90	27.33	27.66	
<b>Barrackpore (mean of 12 years)</b>					
PRH 10	28.94	29.55	29.95	30.36	29.70
Pusa Sugandh 3	22.72	23.00	23.5	23.74	23.23
Pusa Basmati 1	12.69	13.11	13.34	13.67	13.20
Mean	21.45	21.89	22.25	22.59	

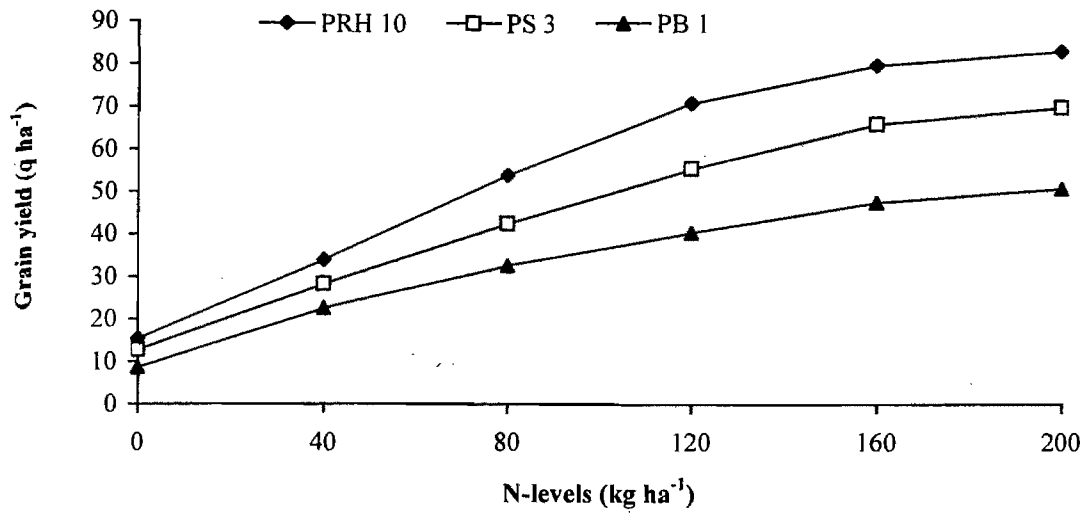
#### 4.6.3.1 Effect of nitrogen

The results of simulation grain yield revealed that each successive increase in nitrogen application increased the simulated grain yield of all rice varieties at all locations (Table 18).

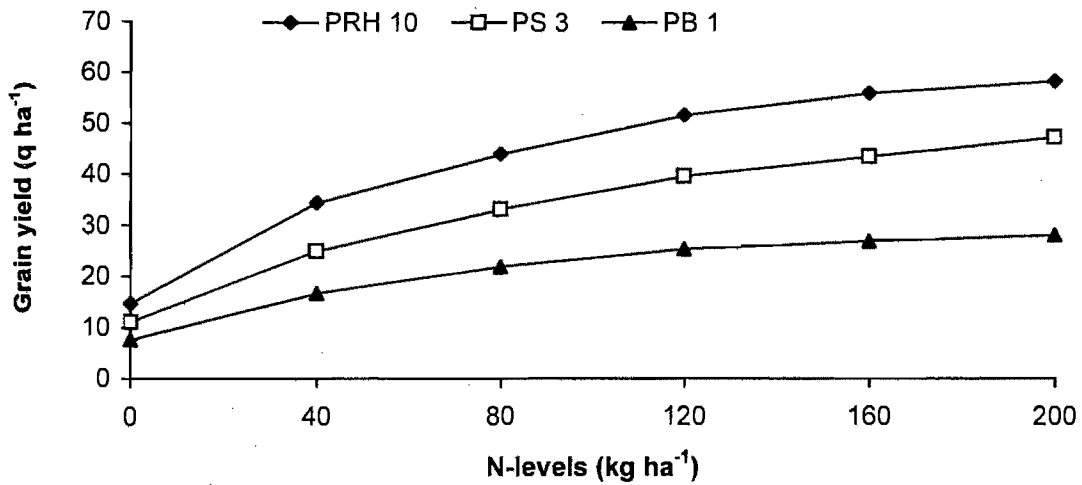
At Ludhiana, the response of nitrogen was up to 200 kg ha<sup>-1</sup> irrespective of variety yielding 67.7 q ha<sup>-1</sup>. There was marked increase in simulated grain yield of PRH 10, Pusa Sugandh 3 and Pusa Basmati 1 by 8.66, 10.27 and 6.89 q ha<sup>-1</sup> when nitrogen application was increased from 120 to 160 kg ha<sup>-1</sup> (Table 18 and Fig. 13), but the yield increase was comparatively less from 160 to 200 kg N ha<sup>-1</sup>.

At Pantnagar, the mean grain yield of 13 years revealed the similar results as in Ludhiana. Here, the grain yield of PRH 10 and Pusa Sugandh 3 increased up to 200 kg N ha<sup>-1</sup> yielding 58.29 and 47.26 q ha<sup>-1</sup>, respectively (Table 18 and Fig. 14). But the grain yield of Pusa Basmati 1 reasonably increased only up to the application of 120 kg N ha<sup>-1</sup> with the simulated grain yield of 25.38 q ha<sup>-1</sup>. When nitrogen was increased up to 160 kg ha<sup>-1</sup>, the yield increase of Pusa Basmati 1 was only 1.55 q ha<sup>-1</sup> as compared to 4.32 and 3.82 q ha<sup>-1</sup> increase in PRH 10 and Pusa Sugandh 3, respectively.

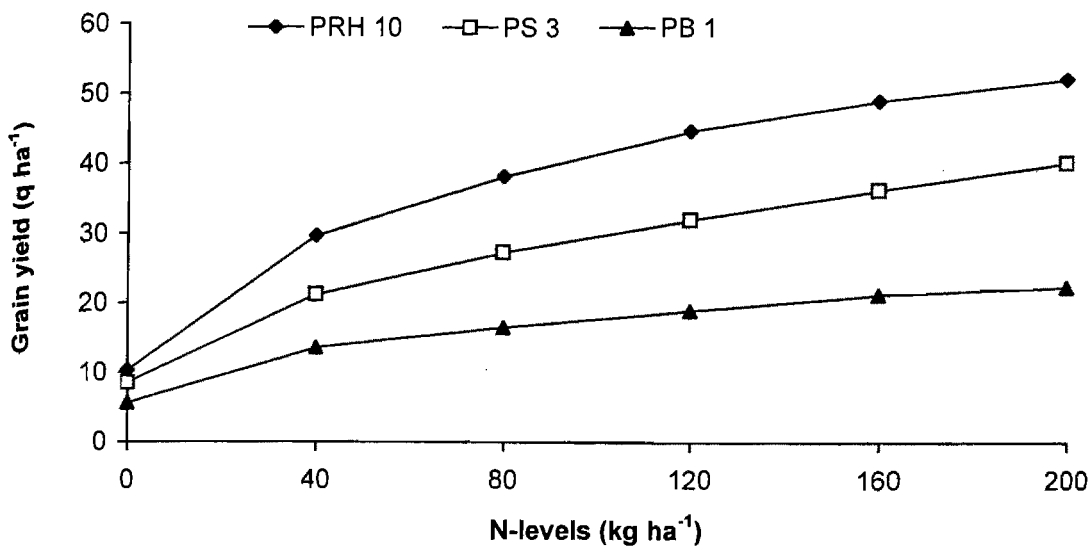
At Patna also, PRH 10 and Pusa Sugandh 3 gave reasonably highest grain yield (52.08 and 40.20 q ha<sup>-1</sup>, respectively) at 200 kg N ha<sup>-1</sup> (Table 18 and Fig. 15). But, the grain yield of Pusa Basmati 1 markedly increased only up to 120 kg N ha<sup>-1</sup>. Thereafter, the yield increase was marginal, though the highest simulated grain yield (22.38 q ha<sup>-1</sup>) was obtained at 200 kg N ha<sup>-1</sup>.



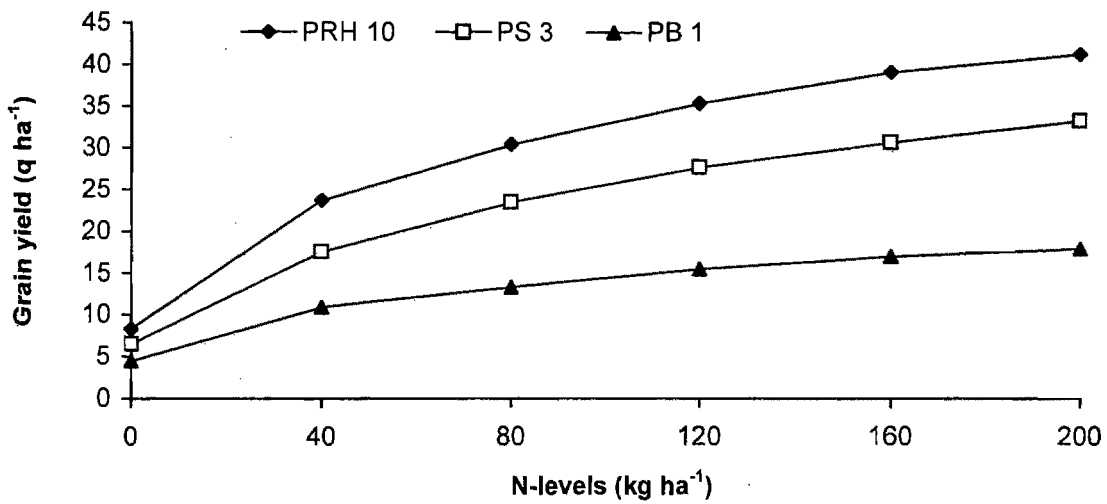
**Fig 13. Simulated grain yield (q ha<sup>-1</sup>) of rice varieties at different levels of nitrogen at Ludhiana ( mean of 13 years)**



**Fig 14. Simulated grain yield (q ha<sup>-1</sup>) of rice varieties at different levels of nitrogen at Pantnagar (mean of 13 years)**



**Fig 15. Simulated grain yield (q ha<sup>-1</sup>) of rice varieties at different levels of nitrogen at Patna (mean of 9 years)**



**Fig 16. Simulated grain yield (q ha<sup>-1</sup>) of rice varieties at different levels of nitrogen at Barrackpore**

At Barrackpore, the simulated grain yield of PRH 10 and Pusa Sugandh 3 marginally increased by 2.14 and 2.61 q ha<sup>-1</sup>, respectively, at 200 kg N ha<sup>-1</sup> over 160 kg N ha<sup>-1</sup> (Table 18 and Fig. 16). Whereas, Pusa Basmati 1 produced satisfactory yield only up to 120 kg N ha<sup>-1</sup>. Thereafter, yield increase was very marginal.

Irrespective of the varieties, the response to nitrogen application was up to 200 kg ha<sup>-1</sup> at Ludhiana as compared to other locations. However, at most of the locations, the simulated grain yield of PRH 10 at 40 kg N ha<sup>-1</sup> was higher than that of obtained from Pusa Basmati 1 at 160 kg N ha<sup>-1</sup> except at Ludhiana, where PRH 10 gave 3.3 q ha<sup>-1</sup> more grain yield at 80 kg N ha<sup>-1</sup> than that of Pusa Basmati 1 at 200 kg N ha<sup>-1</sup>. Comparing the PRH 10 and Pusa Sugandh 3, similar or higher grain yield from PRH 10 at 120 kg N ha<sup>-1</sup> by Pusa Sugandh 3 at 200 kg N ha<sup>-1</sup>.

#### **4.6.3.2 Effect of plant population**

Simulated grain yield at four locations as influenced by plant population is presented in Table 19. The result revealed that there was no marked effect of plant population on the simulated grain yields of any rice varieties at any location. The simulated grain yield increased by 0.21, 1.04, 1.15 and 1.14 q ha<sup>-1</sup> at Ludhiana, Pantnagar, Patna and Barrackpore, respectively, when plant population was increased from 25 to 66.7 hills m<sup>-2</sup>.

#### **4.6.3.3 Simulated grain yield trend of rice varieties**

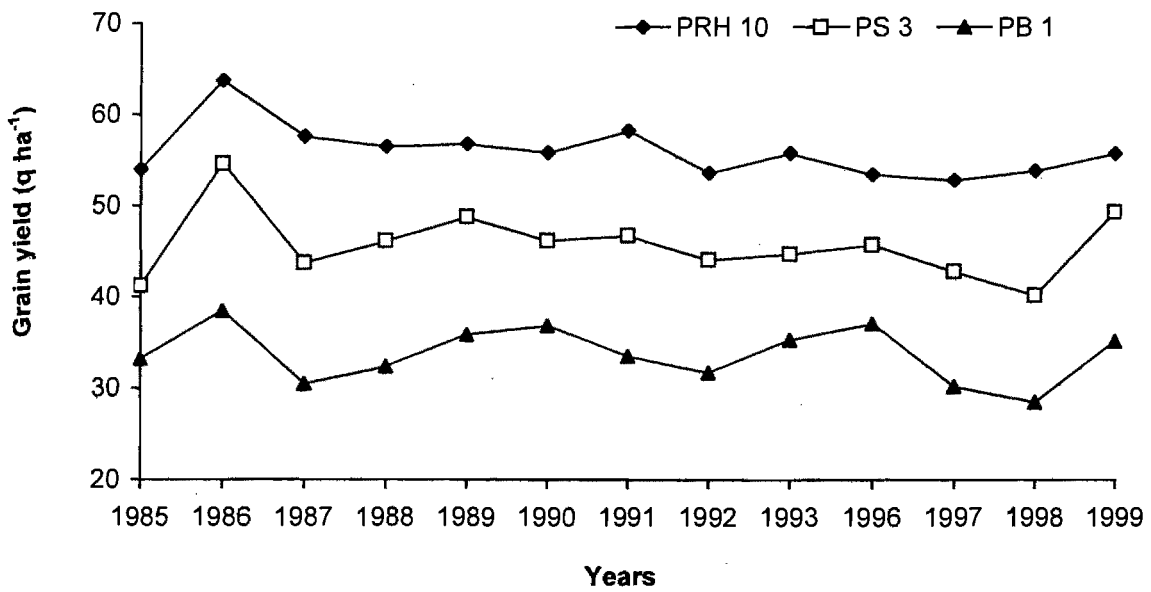
The results of simulated grain yield over multiple years at four locations of Indo-Gangetic plains of India are given in Table 20-23 and also depicted from Fig. 17-20.

**Table 20. Grain yield (q ha<sup>-1</sup>) of rice varieties at Ludhiana in different years as simulated by model**

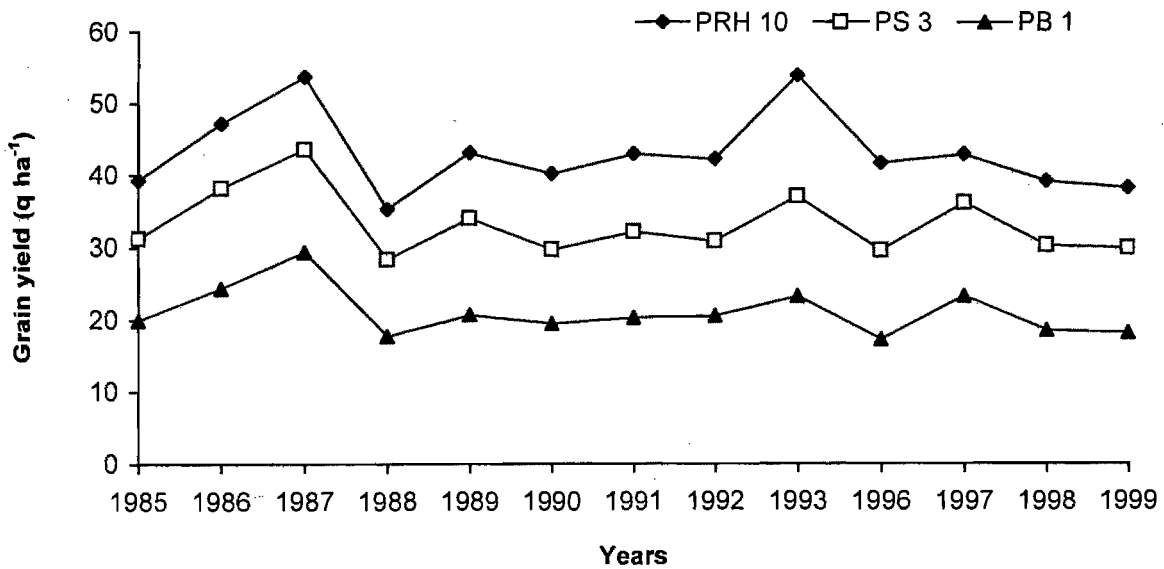
Years	Grain yield (q ha <sup>-1</sup> )			
	PRH 10	Pusa Sugandh 3	Pusa Basmati 1	Mean
1985	54.01	41.21	33.21	42.81
1986	63.71	54.63	38.47	52.27
1987	57.62	43.73	30.47	43.90
1988	56.55	46.17	32.39	45.00
1989	56.89	48.86	35.87	47.21
1990	55.94	46.27	36.90	46.37
1991	58.32	46.83	33.57	46.24
1992	53.66	44.14	31.76	43.19
1993	55.80	44.70	35.33	45.28
1996	53.42	45.71	37.06	45.40
1997	52.77	42.77	30.19	41.91
1998	53.85	40.14	28.50	40.76
1999	55.75	49.32	35.10	46.72
<b>SD (±)</b>	<b>2.89</b>	<b>3.78</b>	<b>3.02</b>	<b>2.89</b>
<b>CV (%)</b>	<b>5.2</b>	<b>8.2</b>	<b>8.9</b>	<b>6.40</b>

**Table 21. Grain yield (q ha<sup>-1</sup>) of rice varieties at Pantnagar in different years as simulated by model**

Years	Grain yield (q ha <sup>-1</sup> )			Mean
	PRH 10	Pusa Sugandh 3	Pusa Basmati 1	
1985	39.26	31.23	19.92	30.14
1986	47.14	38.19	24.38	36.57
1987	53.68	28.39	17.82	42.22
1988	35.28	28.39	17.82	27.16
1989	42.15	34.09	20.78	32.77
1990	40.29	29.81	19.57	29.89
1991	43.05	32.32	20.43	31.93
1992	42.32	31.04	20.69	31.35
1993	53.93	37.16	23.46	38.18
1996	41.73	29.74	17.40	29.62
1997	42.95	36.29	23.45	34.23
1998	39.24	30.44	18.70	29.46
1999	38.39	30.07	18.39	28.95
<b>SD (±)</b>	<b>5.54</b>	<b>4.39</b>	<b>3.33</b>	<b>4.27</b>
<b>CV (%)</b>	<b>12.8</b>	<b>13.2</b>	<b>15.8</b>	<b>13.1</b>



**Fig 17. Simulated grain yield (q ha<sup>-1</sup>) of rice varieties during different years at Ludhiana**



**Fig 18. Simulated grain yield (q ha<sup>-1</sup>) of rice varieties during different years at Pantnagar**

**Ludhiana:**

Simulated grain yield of rice varieties over 13 years showed year to year variations. The simulated grain yield of PRH 10, Pusa Sugandh 3 and Pusa Basmati 1 ranged from 52.77 (1997) to 63.71 (1986), from 40.14 (1998) to 54.62 (1986) and from 28.50 (1998) to 38.47 (1998) q ha<sup>-1</sup>, respectively (Table 20 and Fig. 17). The mean grain yield varied from 40.76 q ha<sup>-1</sup> in 1998 to 52.77 q ha<sup>-1</sup> in 1986. The highest yield of all the varieties was observed in 1986. Pusa Basmati 1 resulted 8.9% higher coefficient variation, whereas the lowest (5.2%) coefficient was recorded with PRH 10 for simulated grain yield.

**Pantnagar:**

At Pantnagar, the lowest simulated mean grain yield (28.95 q ha<sup>-1</sup>) was recorded in the year 1999, whereas highest grain yield (42.22 q ha<sup>-1</sup>) was obtained in the year 1987 (Table 21). The grain yield of PRH 10, Pusa Sugandh 3 and Pusa Basmati 1 varied from 38.89 to 53.93 q ha<sup>-1</sup>, from 28.39 to 43.57 q ha<sup>-1</sup> and from 17.40 to 29.42 q ha<sup>-1</sup>, respectively. Simulated grain yield of all the varieties was highest in 1987. PRH 10 with lowest (12.8%) coefficient of variation indicated less variation in the grain yield simulated over multiple years. Simulated grain yield of PRH 10 was highest in the year 1993, whereas Pusa Sugandh 3 and Pusa Basmati 1 produced highest yield in the year of 1987 (Fig. 18).

**Patna:**

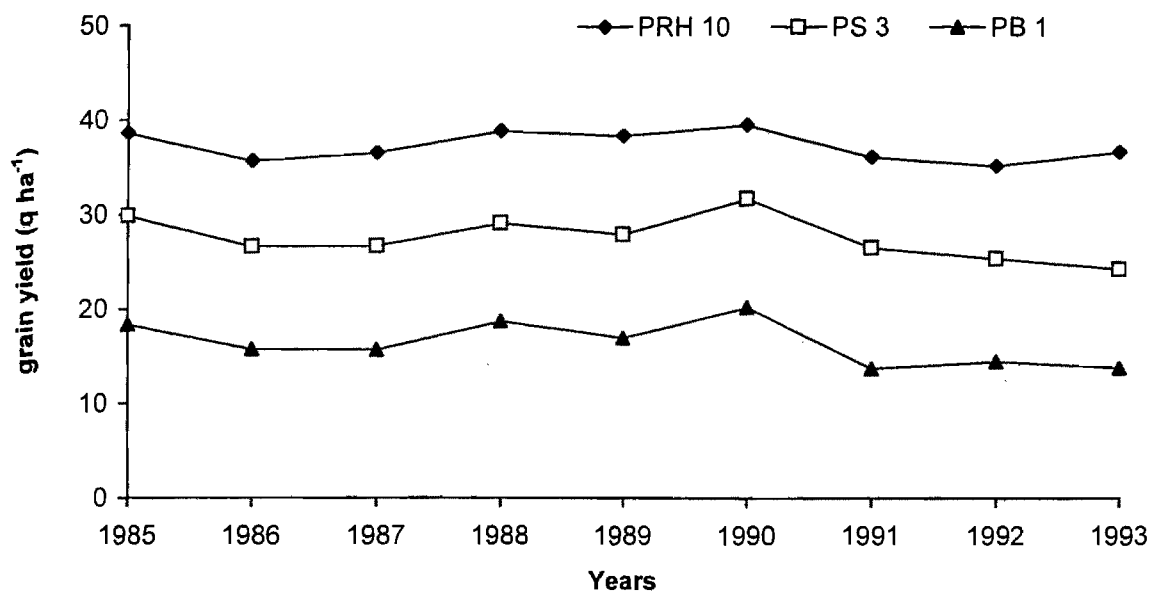
Mean simulated grain yield, at Patna, ranged from 24.90 q ha<sup>-1</sup> in 1993 to 30.53 q ha<sup>-1</sup> in 1990 (Table 22). The grain yield variation of PRH 10 ranged from 35.17 q ha<sup>-1</sup> in 1992 to 39.56 q ha<sup>-1</sup> in 1990, whereas in case of Pusa Sugandh 3 and Pusa Basmati 1, the yield ranged from 24.26 q ha<sup>-1</sup> in 1993 to 31.78 q ha<sup>-1</sup> in 1990 and from 13.73 q ha<sup>-1</sup> in 1991 to 20.26 q ha<sup>-1</sup> in 1990, respectively (Fig. 19). Pusa Basmati 1 had higher coefficient of variation (CV) of 14.2 per cent.

**Table 22. Grain yield (q ha<sup>-1</sup>) of rice varieties at Patna in different years as simulated by model**

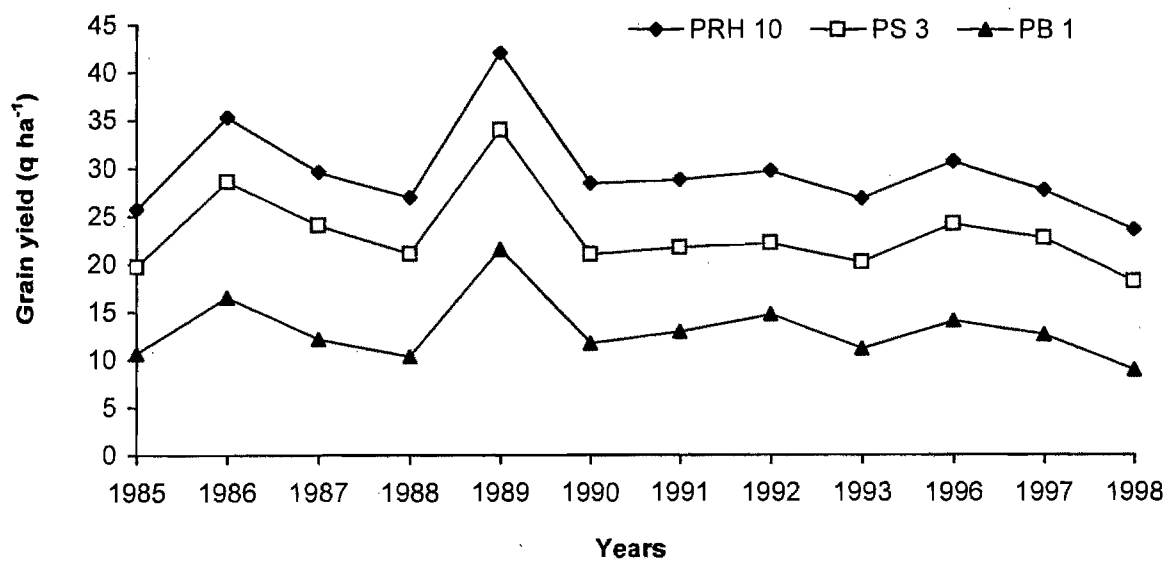
Years	Grain yield (q ha <sup>-1</sup> )			
	PRH 10	Pusa Sugandh 3	Pusa Basmati 1	Mean
1985	38.66	29.92	18.39	28.99
1986	35.71	26.66	15.75	26.04
1987	36.56	26.68	15.68	26.31
1988	38.90	29.13	18.73	28.92
1989	38.43	27.99	16.96	27.79
1990	39.56	31.78	20.26	30.53
1991	39.10	26.51	13.73	25.45
1992	35.17	25.34	14.44	24.98
1993	36.68	24.26	13.77	24.90
1996	41.73	29.74	17.40	29.62
<b>SD (±)</b>	<b>1.59</b>	<b>2.36</b>	<b>2.33</b>	<b>2.03</b>
<b>CV (%)</b>	<b>4.2</b>	<b>8.6</b>	<b>14.2</b>	<b>7.5</b>

**Table 23. Grain yield (q ha<sup>-1</sup>) of rice varieties at Barrackpore in different years as simulated by model**

Years	Grain yield (q ha <sup>-1</sup> )			
	PRH 10	Pusa Sugandh 3	Pusa Basmati 1	Mean
1985	25.72	19.72	10.67	18.70
1986	35.30	28.61	16.55	26.82
1987	29.63	24.08	12.23	22.98
1988	26.97	21.11	10.41	19.50
1989	42.11	34.06	21.60	32.59
1990	28.51	21.11	11.82	30.48
1991	28.92	21.86	13.04	21.28
1992	29.86	22.32	14.87	22.35
1993	26.99	20.34	11.29	19.54
1996	30.82	24.32	14.18	23.11
1997	27.85	22.85	12.77	21.15
1998	23.72	18.33	9.03	17.03
<b>SD (±)</b>	<b>4.85</b>	<b>4.31</b>	<b>3.35</b>	<b>4.14</b>
<b>CV (%)</b>	<b>16.3</b>	<b>18.6</b>	<b>25.3</b>	<b>24.3</b>



**Fig 19. Simulated grain yield (q ha<sup>-1</sup>) of rice varieties during different years at Patna**



**Fig 20. Simulated grain yield (q ha<sup>-1</sup>) of rice varieties during different years at Barrackpore**

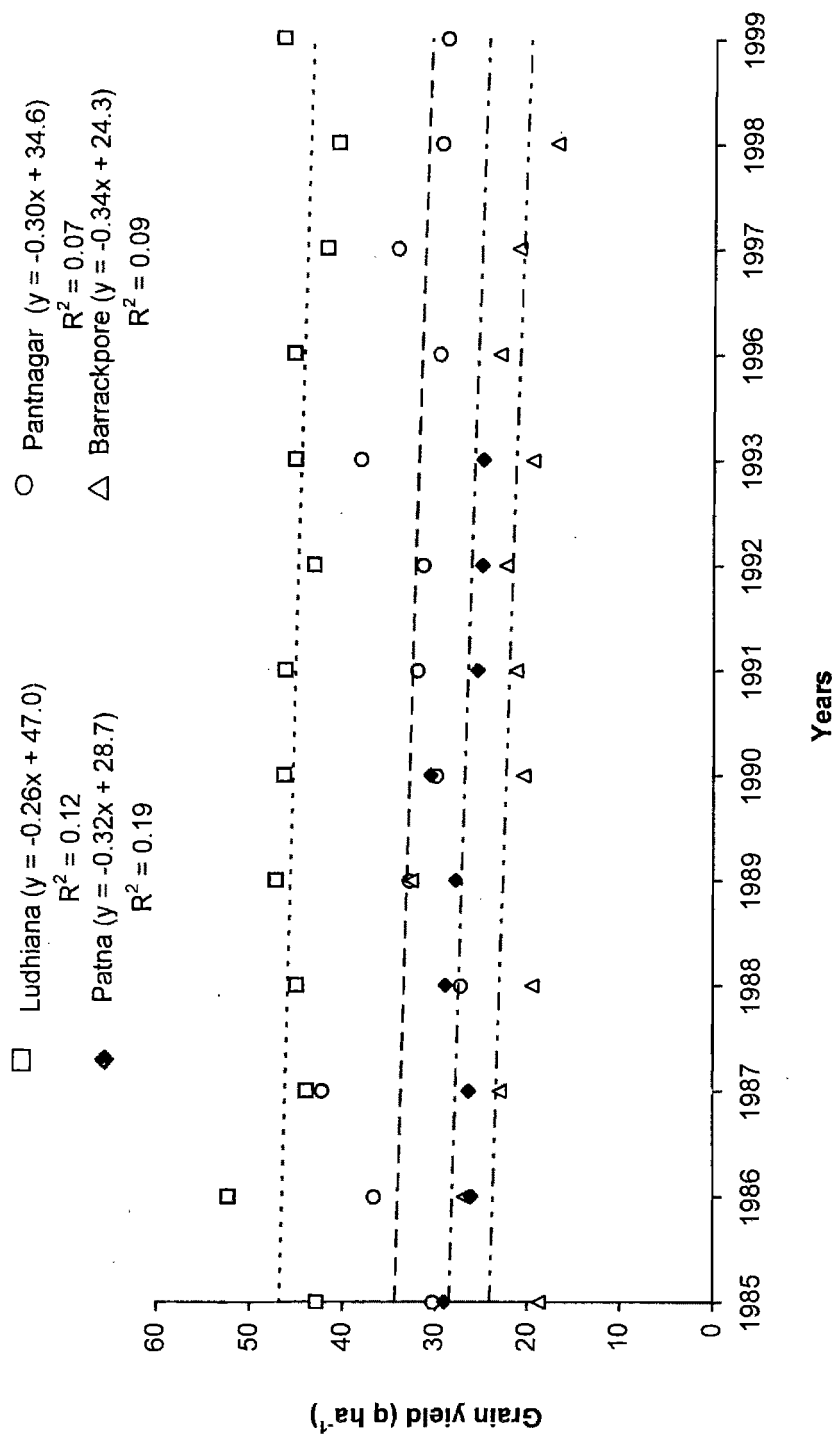


Fig 21. Simulated grain yield ( $q\ ha^{-1}$ ) trend of rice at four locations of Indo-Gangetic Plains

## **Barrackpore**

At Barrackpore, simulated grain yield varied from 17.03 q ha<sup>-1</sup> in 1998 to 32.59 q ha<sup>-1</sup> in 1989 with CV value of 24.3 per cent (Table 23 and Fig. 20). The variation in grain yield was from 23.72 to 42.11 q ha<sup>-1</sup>, from 18.33 to 34.06 q ha<sup>-1</sup> and from 9.03 to 21.60 q ha<sup>-1</sup> in PRH 10, Pusa Sugandh 3 and Pusa Basmati 1, respectively. The highest grain yield in all the rice varieties was simulated in the year 1989. Similar to other three locations, simulated grain yield of Pusa Basmati 1 highly varied than other two varieties with CV value of 25.3 per cent.

In general, coefficient of variation of mean simulated grain yield was highest at Barrackpore (24.3%) as compared to other locations. The simulated result also revealed that PRH 10 was more stable than other rice varieties at all the locations with lower CV values.

Simulated yield trend of rice irrespective of variety, nitrogen and plant population at four locations of Trans-Indo-Gangetic plains of India is illustrated in Fig. 21. The simple regression analysis showed decreasing trend in the simulated grain yield of rice at all the locations. The slope of regression equation at Ludhiana, Pantnagar, Patna and Barrackpore were calculated as -0.26, -0.30, -0.32 and -0.34 with regression coefficient (R<sup>2</sup>) of 0.12, 0.07, 0.19 and 0.09, respectively. The results revealed that the rate of reduction (0.34 q ha<sup>-1</sup> year<sup>-1</sup>) in grain yield was more at Barrackpore than at Ludhiana. It was further noticed that the grain yield reduction was higher toward eastern part than the western part of Indo-Gangetic plain, although the differences were very low.

## CHAPTER V

# DISCUSSION

# DISCUSSION

The results of field and laboratory studies obtained during the course of investigations are presented in this chapter. An attempt has been made to explain the cause and effect relationship which may be responsible for some of the important observations recorded during the course of investigation to derive valid conclusions. The salient research findings emanating from the study on **“Effect of nitrogen levels and spacing on productivity and quality of inbred and hybrid aromatic rice”** are discussed below:

## 5.1 Effect of weather on crops

The results of the field experiments are greatly influenced by weather conditions prevailing during the crop growth period. Therefore, crop-weather relationship needs to be considered in any discussion of experimental results to arrive at correct interpretation and conclusion. The weather variables viz. temperature, relative humidity, total rainfall and sunshine hours pertaining to rice growing seasons are presented in Appendix I and II, and graphically illustrated in Fig. 1.

There was a great variation in the weather variables during the two years of experimentation. The total rainfall of 299 mm during 2002 and 500.5 mm during 2003 was received between June and October i.e. *kharif* rice growing season. The second year rice crop was comparatively more benefited because of well distributed rainfall. During first year erratic and late onset of monsoon coupled with high temperature during early vegetative growth resulted in relatively poor growth and development of rice.

In general, the weather parameters prevailing during 2003 were more favourable for growth and development of the rice. Further, relatively narrow differences between maximum and minimum temperature during grain filling resulted in realizing higher grain and straw yields of rice.

#### **Inbred and hybrid aromatic rice varieties.**

Growth parameters of rice varieties viz. plant height (Table 3), number of tillers hill<sup>-1</sup> (Table 4), leaf area index (Table 5) and dry matter production (Table 6 and 7) were significantly influenced by varieties. Three rice varieties namely PRH 10, Pusa Sugandh 3 and Pusa Basmati 1 involved in the study indicated that rice hybrid PRH 10 maintained its significant superiority in number of tillers hill<sup>-1</sup>, dry matter and leaf area index (LAI) but shorter plant height as compared to other two inbred rice varieties Pusa Sugandh 3 and Pusa Basmati 1. The shorter plant height of rice hybrid PRH 10 at maturity resulted in less lodging. Rice hybrid that shows negative heterosis for plant height, is preferable because of its association with stem stiffness (Singh *et al.*, 1992). Traditional variety Pusa Basmati 1 maintained higher plant height at all the growth stages. The differential growth behaviour of rice varieties could be attributed to the genetical characters of the variety (Kumar *et al.*, 2002a and Adhikari *et al.*, 2004). The dry matter and LAI of rice hybrid PRH 10 was more than inbred varieties due to more number of tillers hill<sup>-1</sup> and wider and longer leaves. Rice hybrids show heterobiltiosis for dry matter production due to higher tillers plant<sup>-1</sup> (Lin and Liang, 1997).

Rice hybrid PRH 10 recorded significantly higher yield attributes viz. number of panicles m<sup>-2</sup>, number of filled grains, panicles and panicle weight than inbred rice varieties

Pusa Sugandh 3 and Pusa Basmati 1 (Table 8). The higher values of yield attributes recorded by PRH 10 over inbred varieties might be due to more number of tillers per unit area, better crop growth and development, higher photosynthetic efficiency due to LAI at flowering and towards physiological maturity. Yang *et al.* (2001) reported that rice hybrid with larger LAI at heading had higher photosynthetic potential from heading to harvest. Panicle biomass production of PRH 10 and Pusa Sugandh 3 did not vary in either of the years, but the panicle weight of rice hybrid PRH 10 at maturity significantly varied which indicated higher translocation of photosynthate in hybrid rice.

Superiority of rice hybrid over inbred varieties for number of panicles  $m^{-2}$ , filled grains panicle<sup>-1</sup> and panicle weight has been reported by Shrivastava and Tripathi (1999), Geethadevi *et al.* (2000), Salgotra (2000), Chandrasekhar *et al.* (2001) and Bhanumathy *et al.* (2003).

Among the inbred rice varieties, Pusa Sugandh 3 had higher test weight and fertility percentage, whereas longer panicle was recorded in Pusa Basmati 1. The variation in the yield attributes of rice varieties have been accounted by Singh and Maurya (1999), Niu *et al.* (2001) and Kumar *et al.* (2002a).

Rice hybrid PRH 10 produced significantly more grain yield than inbred varieties Pusa Sugandh 3 and Pusa Basmati 1 (Table 10). The increase in grain yield of PRH 10 was 36 and 29.8 per cent, and 6.6 and 5.2 per cent over Pusa Basmati 1 and Pusa Sugandh 3 during 2002 and 2003, respectively. The higher grain yield of hybrid over conventional variety was due to heterotic effect (Virmani, 2002).

The greater increase in grain yield of rice hybrid PRH 10 over inbred varieties was due to better yield attributing characters viz. number of panicles  $m^{-2}$ , number of filled grains panicle<sup>-1</sup>, panicle weight, fertility percentage and test weight (Table 8 and 9). Between the inbred varieties, Pusa Sugandh 3 yielded 23.3-27.5 per cent more grain yield than Pusa Basmati 1, which was mainly due to higher number of panicles  $m^{-2}$  and more number of filled grains panicle<sup>-1</sup>, heavier panicle weight and test weight.

Similar to the grain yield, straw yield too was 8.9-9.5 per cent and 6.7-6.9 per cent more in rice hybrid PRH 10 and Pusa Sugandh 3 than Pusa Basmati 1. This increase in straw yield was due to higher LAI and number of tillers per unit area which ultimately increased the dry matter production of PRH 10 and Pusa Sugandh 3.

Both PRH 10 and Pusa Sugandh 3 recorded significantly higher harvest index than Pusa Basmati 1, which might be due to more partitioning of assimilates towards sinks of former two varieties. Further, the relatively smaller sink characterised by less number of grains per panicle and lower test weight of Pusa Basmati 1 resulted in lower harvest index.

There was a significant variation between rice hybrid and inbred rice varieties in different quality parameters (Table 12). Hulling and head rice recovery were relatively higher in PRH 10 and Pusa Sugandh 3 than in Pusa Basmati 1, whereas both inbred rice varieties recorded significantly higher milling percentage than PRH 10. Regarding kernel length before cooking, both inbred rice varieties were superior to rice hybrid, PRH 10, whereas Pusa Sugandh 3 recorded more kernel breadth than PRH 10. The elongation of kernel (after cooking) was significantly more in Pusa Basmati 1 than in PRH 10 and Pusa Sugandh 3. Kernel breadth after cooking varied significantly among the three rice varieties.

This variation in different quality parameters might be due to genetic make up and characteristics of the variety. Regarding protein content, rice hybrid PRH 10 exhibited significantly higher protein content than inbred rice varieties. This finding is in accordance with Salgotra *et al.* (2002) who reported significant positive heterosis for protein content and negative heterosis for kernel length and breadth of rice hybrids over conventional varieties. Yi and Chen (1992) also reported significant cytoplasmic genetic effect of rice hybrids for protein content, brown rice rate and head rice recovery.

Nutrient uptake is a function of nutrient content and total biomass production. Nitrogen uptake significantly varied among rice hybrid and inbred rice varieties at all the growth stages (Table 13), which was due to significant differences in biomass production (Table 7) and nitrogen content (Appendix III). Rice hybrid (PRH 10) exhibited more N uptake than Pusa Sugandh 3 and Pusa Basmati 1 at PI (panicle initiation) and flowering and by grain at harvest, which might be due to higher affinity of the rice hybrid to absorb nitrogen (Luo *et al.*, 1993), and better root growth (Sahai and Chaudhary, 1986 and Souframanien *et al.*, 1998). Nitrogen uptake by straw of PRH 10 and Pusa Sugandh 3 at harvest was at par, which was due to similar in straw yield in these varieties. The total N uptake (grain + straw) was 37.7 and 32.3 per cent and 25 and 22.6 per cent more in PRH 10 and Pusa Sugandh 3 than in Pusa Basmati 1 during 2002 and 2003, respectively. The higher yield of grain as well as straw, and N concentration in PRH-10 resulted in higher total N uptake.

### **Effect of plant spacing**

Plant population as a result of transplanting rice at varied spacings led to variation in growth characters, yield attributes and ultimately grain yield due to inter- and intra-plant competition for solar radiation, space and nutrients. Three spacings viz. 20 x 10, 20 x 15 and 20 x 20 cm involved in the study revealed that narrow spacing of 20 x 10 cm maintained significant superiority in producing comparatively taller plant (Table 3), higher leaf area index (Table 5) and more dry matter production (Table 6 and 7) over the wider spacings of 20 x 15 and 20 x 20 cm. However, total biomass at harvest was more at 20 x 15 cm spacing and number of tillers hill<sup>-1</sup> at 20 x 20 cm (Table 4) than rest of the spacings.

Significantly taller plants at closer spacing of 20 x 10 cm, which had more hills m<sup>-2</sup>, might be due to stiff competition for space, sunlight and other inputs as compared to wider spacings. Ghosh and Sharma (1997), Padmavathi (1997) and Kumar (2001) also found that higher plant densities tended to produce taller plants than lower plant densities. Maintenance of significant superiority number of tillers hill<sup>-1</sup> at 20 x 20 cm over other spacings may be due to less population pressure on the individual hills for space, light and nutrient availability. Krishnan *et al.* (1994), Shrirame *et al.* (2000), Kumar *et al.* (2002a), Verma *et al.* (2002) and Rajesh and Thanunathan (2003) also recorded increase in number of tillers hill<sup>-1</sup> with increase in plant spacing but found more number of tillers per unit area at closer spacings.

Increase in number of plants and tillers per unit area at a spacing of 20 x 10 cm led to higher dry matter production than wide spacing. Shrirame *et al.* (2000) and Kumar *et al.* (2002a) also reported significantly more dry matter at closer spacing than at wider spacing.

Higher leaf area index at a spacing of 20 x 10 cm over rest of spacings might be due to more number of tillers per unit area at closer spacing.

Significant increase in number of panicles  $m^{-2}$  (Table 8) from wider (20 x 20 cm) to closer (20 x 10 cm) spacing might be due to increased number of tillers per unit area. Transplanting aromatic rice varieties at a wider spacing of 20 x 20 cm resulted in higher number of filled grains panicle<sup>-1</sup>, panicle weight and test weight as compared to other spacings (Table 8 and 9). But length of panicle during 2002 and fertility percentage during 2003 significantly varied between 20 x 10 and 20 x 20 cm spacing (Table 9). The appreciable improvement in yield attributing characters of aromatic rice varieties at wider spacing might be due to better utilization of space, solar radiation and other inputs resulting in more number of filled grains panicle<sup>-1</sup> and higher test weight and ultimately more panicle weight as compared to closer spacings. Further, higher dry matter production (Table 6 and Table 7) at closer spacing might have restricted the diversion of reserved and current photosynthates toward reproductive parts i.e. grains. The significant increase in yield attributes viz. number of filled grains panicle<sup>-1</sup>, panicle weight, panicle length, fertility per cent and test weight was registered at wider spacing as compared to closer spacing.

The grain and straw yield as well as harvest index were significantly influenced by transplanting of rice at various spacings during both the years of investigation. The per cent increase in grain yield of aromatic rice varieties due to plant spacing of 20 x 20 cm was in the tune of 16.1 and 16.4 per cent over 20 x 10 cm spacing and 6.5 and 5.7 per cent more over 20 x 15 cm during 2002 and 2003, respectively. While, a spacing of 20 x 15 cm resulted in 9 and 10.2 per cent more grain yield than 20 x 10 cm spacing. The production of

higher grain yield from wider spacing was mainly attributed due to greater number of filled grains panicle<sup>-1</sup>, panicle weight, length of panicle, fertility per cent and test weight as compared to closer plant spacing.

Contrary to grain yield, straw yield of aromatic rice varieties at harvest was significantly more at closer spacing of 20 x 10 cm than wider spacing (20 x 15 and 20 x 20 cm). The increase in straw yield with closer spacing was due to the appreciably higher growth parameters like plant height, number of tillers m<sup>-2</sup> due to more number of hills m<sup>-2</sup>, leaf area index and dry matter production than the wider spacing (Table 3 to 7). The harvest index increased significantly with increase in plant spacing from 20 x 10 to 20 x 20 cm. Higher values of harvest index towards wider spacing might be due to higher grain and lower straw yield.

Wider spacing of 20 x 20 cm maintained its superiority in hulling, milling and head rice recovery of aromatic rice varieties (Table 12) to 20 x 10 cm spacing during both the years of study, except hulling percentage during 2003. The improvement in these quality parameters might be due to better utilization of space, light and other inputs (Kumar *et al.*, 2002a) due to reduced inter- and intra-plant competition which ultimately favoured development of heavy panicles and healthy and plumpy grains at wider spacing. Other quality parameters viz. kernel length and breadth before and after cooking and protein content were not altered due to various spacings, which might be due to the fact that these parameters were governed by genetic constitution of the variety.

Nitrogen uptake was influenced significantly with varying plant spacing at all growth stages during both the years of study. The N uptake at PI and flowering and in straw at

harvest was higher at a spacing of 20 x 10 cm than wider spacing of 20 x 20 cm due to higher total dry matter production. Nitrogen N uptake by grain at harvest increased significantly with the increase in plant spacing from 20 x 10 to 20 x 20 cm. The increase in N uptake by grain at 20 x 20 cm was 17.3 and 19.3 per cent over 20 x 10 cm, and 8.3 and 7.4 per cent more over 20 x 15 cm during 2002 and 2003, respectively. The increase in N uptake by grain under wider spacing of 20 x 20 cm was due to more grain yield and high N content. The higher N uptake by straw with closer spacing of 20 x 10 cm was due to production of more straw compared to other spacings. Similar results on N uptake pattern were reported by Kumar *et al.* (2002b). However, total nitrogen uptake at harvest was not influenced by spacing treatments.

### **Effect of nitrogen levels**

All the growth characters viz. plant height, number of tillers hill<sup>-1</sup>, leaf area index (LAI) and dry matter production at all the growth stages increased significantly with application of N (Table 3 to 7). The superiority in these growth characters with higher nitrogen application may be due to split application of N at different growth stages which might have minimized the loss of nitrogen and induced better growth and development of the crop.

Increase in nitrogen level from 0 to 180 kg ha<sup>-1</sup> significantly increased the plant height at all the growth stages. Similar trend was recorded for number of tillers hill<sup>-1</sup>, LAI and dry matter production. Appreciable improvement in plant height and number of tillers was mainly due to application of nitrogen at critical growth stages as advocated by De Datta (1981). Jaiswal and Singh (2001) and Somasundaram *et al.* (2002a) reported that increase

in plant height and number of tillers  $m^{-2}$  due to nitrogen application was associated with increase in nitrogen availability and photosynthetic products. The beneficial effects of nitrogen application on tiller number  $hill^{-1}$  and LAI was reported by Kalia and Kumar (2002) and Lawal and Lawal (2002).

The total dry matter production increased consistently with advancement in growth and reached the maximum at harvest (Table 6 and 7). Application of  $160 \text{ kg N ha}^{-1}$  significantly increased the dry matter production over 0 and  $80 \text{ kg N ha}^{-1}$ . It may be due to higher tiller production and LAI at all the growth stages which increased the photosynthetic assimilation. Also, increasing levels of N application resulted in its higher absorption and utilization (Halepyati and Sheelawantar, 1993), which accumulated the photosynthetic assimilates for faster growth of rice plant. This caused appreciable improvement in vegetative growth as evinced by significantly taller plants and more number of tillers  $hill^{-1}$  which ultimately resulted in higher dry matter production.

The yield attributes viz. number of panicles  $m^{-2}$ , filled grains  $panicle^{-1}$ , panicle weight, panicle length, fertility percentage and test weight were positively influenced by application of nitrogen (Table 8 and 9). Significant increase in the number of panicles  $m^{-2}$  was recorded with the increase in the level of nitrogen from 0 to  $160 \text{ kg N ha}^{-1}$ . This increase was mainly due to more number of tillers  $m^{-2}$  with increasing level of nitrogen application (Table 4). Higher N uptake at PI stage helped rice plants to produce more number of tillers and panicles (De Datta, 1981). This was also confirmed in the present study wherein higher nitrogen uptake was observed at PI stage during both years of

investigation. Dar *et al.* (2000), Singh and Singh (2000) and Prakash (2002) also observed significantly more panicles  $m^{-2}$  with successive increase in nitrogen application.

Number of filled grains panicle<sup>-1</sup> significantly increased with the application of 80 and 160 kg N ha<sup>-1</sup>. The plants remained green for a longer time with increase in N application and resulted in more contribution of carbohydrates from current photosynthates (Reddy and Reddy, 1989). In this study, higher LAI (Table 5) was recorded with application of 80 and 160 kg N ha<sup>-1</sup> and this might be the reason for increased number of filled grains panicle<sup>-1</sup> due to more availability of carbohydrates through current photosynthates.

Panicle weight was appreciably improved with increase nitrogen levels from 0 to 160 kg N ha<sup>-1</sup> (Table 8) which was due to more filled grains panicle<sup>-1</sup> and test weight. The favourable effect of nitrogen application on panicle weight confirms the findings of Balasubramanian (2002) and Prakash (2002). Length of panicle significantly increased with the application of 80 kg N ha<sup>-1</sup> over no nitrogen application but further increase in nitrogen did not influence the panicle length. Fertility percentage also increased with applied nitrogen from 0 to 160 kg ha<sup>-1</sup>, which might be due to more availability of carbohydrate through current photosynthates as a result of greener leaves towards maturity. Singh *et al.* (2003a) reported positive effect of nitrogen application on fertility per cent of rice.

Test weight of rice varieties significantly improved due to the application of nitrogen from 0 to 160 kg ha<sup>-1</sup>. The effect of nitrogen application on yield attributes is primarily a function of assimilate accumulation, which in turn, facilitated higher N assimilation with adequate supply of photosynthates to grain (Krishna Kumar, 1986).

Nitrogen application had a marked effect on grain and straw yield (Table 10). Grain yield increased significantly with increase in the level of nitrogen. The magnitude of yield increase was to the tune of 34 and 11.8 per cent, and 35 and 6.5 per cent at 160 kg N ha<sup>-1</sup> over 0 and 80 kg N ha<sup>-1</sup> during first and second year of study, respectively. Higher levels of N application caused better N uptake, leading to greater dry matter production and its translocation to sink (Dalal and Dixit, 1997). The significant improvement in panicles m<sup>-2</sup>, panicle weight, filled grains panicle<sup>-1</sup> and test weight was mainly responsible for higher grain yield with supply of nitrogen.

Like grain yield, straw yield too followed the same trend. The favourable effect of higher levels of N on plant height, number of tillers hill<sup>-1</sup>, LAI and dry matter production ultimately led to higher straw yield. Om *et al.* (1999), Shrivastava and Tripathi (1999) and Pal *et al.* (2001) found similar results. Application of nitrogen did not influence harvest index, which might be due to similar grain and straw ratio at all levels of nitrogen.

Quality aspect of aromatic rice is of prime importance for growers as well as consumers. Significantly higher hulling, milling, head rice recovery (Table 11) and protein content (Table 12) were registered with the application of nitrogen during both the years of experimentation. Protein content increased appreciably with the application of nitrogen which was mainly due to higher nitrogen concentration. Perez *et al.* (1996) reported that N application at flowering had a large effect on protein content. In this study also, third dose of nitrogen was applied at heading stage which might have contributed to increase in protein content of grains. For these reasons, application of nitrogen increased the protein content which, in turn, might have improved hulling per cent and head rice recovery by

increasing the resistance of grains to abrasive milling process. High-protein rice is more resistant to abrasive milling than low-protein rice (Cagampang *et al.*, 1966). High protein content also has been reported to improve milling and head rice recovery percentage (Nangju and De Datta, 1970 and Perez *et al.*, 1996). However, other quality parameters viz. kernel length and breadth before and after cooking were not influenced due to N levels, which might be due to the fact that these parameters are genetic characters.

Increasing level of nitrogen from 0 to 160 kg N ha<sup>-1</sup> significantly increased the N uptake at all the growth stages (Table 13). The magnitude of increase in total N uptake were 54.8 and 14.0 per cent, and 55.5 and 10.7 per cent with the application of 160 kg N ha<sup>-1</sup> over 0 and 80 kg N ha<sup>-1</sup> during 2002 and 2003, respectively. Increase in N uptake by nitrogen application at all growth stages was both due to increase in dry matter production and nitrogen concentration. Higher nitrogen concentration in plant with the application of nitrogen was probably due to more availability of nitrogen in soil solution.

## **INTERACTION EFFECTS**

### **Rice varieties x Plant spacing**

Interaction effect of rice varieties and plant spacing on number of panicles m<sup>-2</sup>, number of filled grains panicle<sup>-1</sup> and panicle weight was found significant during both the years of study [Table 8(a), 8(b), 8(e), 8(f), 8(i) and 8(j)]. All rice varieties in the study produced higher number of panicles m<sup>-2</sup> at a spacing of 20 x 10 cm whereas number of filled grains panicle<sup>-1</sup> and panicle weight were higher at wider spacing of 20 x 20 cm. Number of panicles m<sup>-2</sup> produced by PRH 10 and Pusa Sugandh 3 at 20 x 20 cm plant spacing were at par with that of produced by Pusa Basmati 1 at a closer spacing of 20 x 10

cm. Transplanting of Pusa Sugandh 3 and Pusa Basmati 1 at a spacing of 20 x 15 and 20 x 20 cm registered similar number of panicles  $m^{-2}$ , number of filled grains panicle<sup>-1</sup> and panicle weight. Whereas PRH 10 registered significantly highest number of filled grains panicle<sup>-1</sup> and panicle weight at a spacing of 20 x 20 cm over other spacings. PRH 10 could only register significantly higher number of filled grains panicle<sup>-1</sup> and panicle weight over Pusa Sugandh 3 at 20 x 20 cm of plant spacing. Miller *et al.* (1991) reported significant interaction effect of plant population on panicle weight and Ma *et al.* (1997) also observed interaction effect between rice hybrid and plant density on number of grains panicle<sup>-1</sup>. The interaction effect of rice hybrid and plant density on yield attributes have been reported by Kumar (2001b).

PRH 10 and Pusa Sugandh 3 produced similar grain yield at the spacing of 20 x 10 and 20 x 15 cm but significantly higher than that of produced by Pusa Basmati 1 at a spacing of 20 x 20 cm. Inbred rice variety Pusa Sugandh 3 registered similar grain yield at a spacing of 20 x 15 and 20 x 20 cm. Similar trend was recorded for Pusa Basmati 1. Significant and non-significant variations in grain yield between rice varieties and plant spacing were mainly due to significant and non-significant variations in yield attributes.

The nitrogen uptake by grain was significantly higher under PRH 10 with the adoption of a spacing of 20 x 20 cm as compared to other two rice varieties, which might be due to significantly higher grain yield of PRH 10 at this spacing. Similar uptake of N by Pusa Basmati 1 at the spacing of 20 x 15 and 20 x 20 cm during both the years of study and by Pusa Sugandh 3 during second year might be due to non-significant variation in grain yield. The results are in close conformity with the findings of Ma *et al.* (1997) and

Kumar *et al.* (2002b). They noticed the interaction effect of rice hybrids and plant density on N uptake by grain.

### **Rice variety x Nitrogen levels**

Interaction effect of rice varieties and nitrogen levels on number of panicles  $m^{-2}$ , number of filled grains  $panicle^{-1}$  and panicle weight was significant during both the years [Table 8(c), 8(d), 8(g), 8(h), 8(k) and 8(l)]. Both rice hybrid PRH 10 and inbred Pusa Sugandh 3 registered significantly highest number of panicles  $m^{-2}$ , number of grains  $panicle^{-1}$  and panicle weight with the application of 160 kg N  $ha^{-1}$ , whereas these yield attributes were at par for Pusa Basmati 1 with the application of 80 and 160 kg N  $ha^{-1}$ . Rice hybrid PRH 10 and Pusa Sugandh 3 recorded significantly higher panicles  $m^{-2}$  at all N levels as compared to Pusa Basmati 1, which might be due to variation in genetic characters of rice varieties. The number of panicles  $m^{-2}$ , number of grains  $panicle^{-1}$  and panicle weight recorded by PRH 10 at 0 and 80 kg N  $ha^{-1}$  was similar to that recorded by Pusa Sugandh 3 at the same levels of nitrogen. Pusa Basmati 1 registered similar number of panicles  $m^{-2}$ , number of grains  $panicle^{-1}$  and panicle weight at 80 and 160 kg N  $ha^{-1}$ . Number of grains  $panicle^{-1}$  produced by PRH 10 at 0 kg N  $ha^{-1}$  was similar to that recorded by Pusa Basmati 1 at 160 kg N  $ha^{-1}$ . Singh (2002) and Adhikari (2003) also observed interaction effect of rice varieties and N levels for yield attributes.

Rice variety and N level interaction on grain yield was also significant during both the years of study. The grain yield of PRH 10 and Pusa Sugandh 3 increased with successive increase in level of nitrogen from 0 to 180 kg N  $ha^{-1}$ , whereas Pusa Basmati 1 produced significantly more grain yield at 80 kg N  $ha^{-1}$  over zero nitrogen and further

increase in nitrogen ( $160 \text{ kg N ha}^{-1}$ ) could not influence the grain yield of Pusa Basmati 1. The average yield of PRH 10 and Pusa Sugandh 3 at control was similar to the yield obtained by Pusa Basmati 1 at  $80$  and  $160 \text{ kg N ha}^{-1}$ , which might be due to non-significant difference in number of panicles  $\text{m}^{-2}$  and number of grains panicle $^{-1}$ . Similar grain yield of PRH 10 and Pusa Sugandh 3 at  $0$  and  $80 \text{ kg N ha}^{-1}$  and that of Pusa Basmati 1 at  $80$  and  $160 \text{ kg N ha}^{-1}$  were also due to non-significant variation in yield attributes of rice varieties at these levels of nitrogen application. Differences in varietal response to nitrogen application have been reported by Subbiah *et al.* (2001) and DRR (2004).

Uptake of N by grains of PRH 10 and Pusa Sugandh 3 increased up to the application of  $160 \text{ kg N ha}^{-1}$ , whereas N uptake by grains of Pusa Basmati 1 was non-significant at  $80$  and  $160 \text{ kg N ha}^{-1}$ . Nitrogen uptake by grains of PRH 10 and Pusa Sugandh 3 at  $0 \text{ kg N ha}^{-1}$  and that of Pusa Basmati 1 at  $80 \text{ kg N ha}^{-1}$  was similar during both the years, which might be due to combined effect of grain yield and N concentration in grain. In general, nitrogen uptake by grains of all rice varieties was highest at highest level of nitrogen application. Maity (1998) and Adhikari *et al.* (2004) have also reported the interaction effect of rice varieties and levels of N on nitrogen uptake by grains of hybrids and aromatic rice, respectively.

#### **Calibration of model and varietal coefficient**

The parameters needed for characterizing rice varieties i.e. determining the varietal coefficient (Table 14) indicated that rice hybrid PRH required lesser accumulation of thermal degree days for vegetative growth ( $1450^{\circ}\text{C}$ ) as compared Pusa Basmati 1 ( $1600^{\circ}\text{C}$ ), whereas post-anthesis thermal time requirement was lesser for Pusa Basmati 1 compared to PRH 10. Similar pre- and post-anthesis thermal time requirement for rice

varieties supported the findings of Timsina *et al.* (1998). Other coefficients determined through measured data and visual export system also varied among the varieties which was due to the variation in the expression of genetic make-up of the varieties during the field study.

The calibrated resulted showed that the model predicted very well for days to flowering and physiological maturity (Table 15). But, there was 7.2-10.1 per cent under-estimation of simulated grain yield from measured grain yield at zero level of nitrogen. Jand *et al.* (1994) also reported that CERES-Rice model under-estimated the grain yield of rice by 10.9-8.34 per cent of the observed yield. Better closeness than this in between the simulated and measured grain yield could not be achieved which might be due to the model's inability to address the inherent soil fertility (Timsina *et al.*, 1998, McMaster *et al.*, 2003). This also could be due to inadequate calibration of model due to limited measured data. However, Andales *et al.* (2003) advocated that 10 per cent deviation of simulated yields from observed values were acceptable. Thus, from the results it was found that the model was calibrated satisfactorily and the simulated and measured values were within the acceptance range.

### **Validation of model**

The performance of InfoCrop was tested against independent data sets of 36 treatments of the field experiment for nitrogen and plant population effect. The validated resulted indicated that there was close correspondence between simulated and observed values of days to flowering (Fig. 8), days to physiological maturity (Fig. 9) and grain yield (Fig. 10) with smaller values of residual mean square error (RMSE), a slope of closer to

one and a significant regression coefficient. A smaller RMSE indicates lesser deviation of the simulated from the observed values (McMaster *et al.*, 1992) but the acceptable limits of accuracy depend on the user needs (Andales *et al.*, 2003). In this study, RMSE values were smaller up to the range of acceptance. Hundal and Kaur (1999), Zhu *et al.* (2001) and Singh *et al.* (2003b) using different models have reported that simulated days to anthesis and maturity of rice matched well with slight variation in the grain yield.

The comparison of simulated and measured grain yields of the three rice varieties at two levels of nitrogen (Table 16 and Fig. 11) indicated that the trend of simulated yield was similar to that of observed yield. The model's prediction was within the acceptance range. Although the simulated yield was slightly higher than observed values of all the varieties. The higher deviation of simulated over observed grain yield at higher level of nitrogen might be due to the lodging at higher level of nitrogen. The agreement between simulated and measured grain yields establishes the robustness of the model (Aggarwal *et al.*, 1994). In this study, the InfoCrop model showed its validity to simulate the effect of nitrogen on grain yield of rice. Thiyagarajan *et al.* (1997) and Singh *et al.* (2003b) also revealed that rice crop growth models are capable of simulating the effect of nitrogen on grain yield within the acceptance range.

The model was incapable to simulate the effect of plant population on grain yield of all three rice varieties up to a satisfactory level. Irrespective of rice varieties, the simulated grain yield showed some increasing trend with the decrease in the plant population from 50 to 33.3 hills m<sup>-2</sup> but remained same when further decreased to 25 hills m<sup>-2</sup>. However, there was some increasing trend in simulated yield as decrease in the plant population, but not

up to the satisfactory level. Therefore, the model needs improvement for simulating the effect of plant population on grain yield of rice.

### **Influence of nitrogen and plant population on grain yield at different locations of Indo-Gangetic plain**

Validated model was used for predicting the grain yield of rice at four locations of Indo-Gangetic plains as affected by nitrogen application and plant population. The response of rice varieties to nitrogen levels differed among the varieties at all the locations. At Ludhiana, Pantnagar and Patna the response was up to 200 kg N ha<sup>-1</sup> irrespective of rice varieties, whereas it was up to 160 kg N ha<sup>-1</sup> at Barrackpore. The response of Pusa Basmati 1 was found to be up to 120 kg N ha<sup>-1</sup> at Pantnagar, Patna and Barrackpore whereas it was up to 200 kg N ha<sup>-1</sup> at Ludhiana. Similarly the response of rice hybrid PRH 10 and Pusa Sugandh 3 was up to 200 kg N ha<sup>-1</sup> at all locations but yield increase was comparatively less from 160 to 200 kg N ha<sup>-1</sup>. The grain yield response of aromatic rice varieties to nitrogen was reported to be ranged from 100 to 150 kg ha<sup>-1</sup> at various locations of Indo-Gangetic plain (DRR, 2004) which might be due to the spatial variation in soil and weather conditions. The highest grain yield was simulated at Ludhiana at 0 kg N ha<sup>-1</sup> may be due to higher initial nitrogen content in soil (Appendix IV) compared to other locations.

There was no marked effect of plant population on simulated grain yield of rice varieties at any location which was mainly due to insensitiveness of the model in relation to the effect of plant population.

### **Rice yield trend**

There was year to year variation in the simulated grain yield of all three rice varieties at all the four locations (Table 20-23 and Fig. 21-25). Timsina *et al.* (1998) also

reported year to year variation in simulated grain yield of rice. At Ludhiana, Pantnagar, Patna and Barrackpore, highest grain yield was simulated during 1986, 1987, 1990 and 1989, respectively, which might be due to higher solar radiation and favourable temperature during critical growth period and during spikelet formation and grain filling period. The year to year variation in the grain yield might be due to variation in the solar radiation and temperatures during the critical growth period of rice varieties. At all the locations, the yield variation was higher in Pusa Basmati 1 as indicated by higher CV values. This higher variation in yield of Pusa Basmati 1 may be due to the fact that this variety is of longer duration than others and may have experienced higher variation in solar radiation and temperature during its advanced growing period. In general, variation of mean simulated grain yield was highest at Barrackpore as indicated by higher CV value of 24.3 per cent. It indicated higher year to year climatic variability at Barrackpore as compared to other locations.

It is noticed that mean simulated grain yield of multi-year of simulation was lowest at Barrackpore and gradually increased toward north-western regions from Patna to Ludhiana, which might be due to higher solar radiation and lower temperature towards north western regions of Indo-Gangetic plain. Aggarwal *et al.* (2000) opinioned higher rice yield potential in the north-western region compared to the eastern region which was related to solar radiation and temperatures during crop season. Ramasamy (2000) observed distinct impact of latitude and altitude on potential grain yield of rice as simulated by model. He further noticed increase in potential grain yield of rice from lower to higher both latitude and altitude. In this study, similar trend of simulated in grain yield was

recorded, as Barrackpore lies at lower latitude (22°45'N) and altitude (9 masl) whereas Ludhiana lies at higher latitude (30°56'N) and altitude (247 masl).

Simulated grain yield of rice irrespective of variety and nitrogen showed decreasing trend with time at all the four locations of Indo-Gangetic plains of India, although it was non-significant (Fig. 21). Similar decreasing trend in rice grain yield of rice-wheat system of Indo-Gangetic plain under long-term fertility has been reported (Duxbury, 2000). The rate of reduction was higher towards eastern part than the north-western part, although the differences were very low. Same varieties and soil data were used to simulate the grain yield at all the locations for each year. Even then, there was a decreasing trend in rice yield. It indicated some variability in climate which might have influenced the reduction in the grain yield of rice.

## **CHAPTER VI**

# **SUMMARY & CONCLUSION**

# SUMMARY AND CONCLUSION

There is a need to increase the production and productivity of aromatic (Basmati) rice in order to enhance quantum of exports for foreign exchange reserves. Newly-released hybrid and inbred aromatic rices have provided an opportunity to increase the production as well as productivity. Plant density and nitrogen requirement differ among the rice varieties for optimum productivity. Research results of one location do not necessarily apply to other locations and require situation-specific evaluation over years. A well calibrated and validated crop growth simulation model is the right tool to reduce the time required for the field study and is increasingly being used for technology transfer in agriculture.

Therefore, the present investigation entitled **“Effect of nitrogen levels and spacing on productivity and quality of inbred and hybrid aromatic rice”** was undertaken with the following objectives:

- To find out the appropriate plant spacing and nitrogen requirement for inbred and hybrid aromatic rice,
- To evaluate the influence of spacing and nitrogen on growth, yield, N uptake and quality of aromatic rice,
- To calibrate and validate the crop model by simulating the effect of spacing and N levels on aromatic rice, and
- To simulate the effect of nitrogen and spacing on productivity of aromatic rice at different locations of Indo-Gangetic plains of India.

A field experiment was carried out at the research farm of Indian Agricultural Research Institute, New Delhi during 2002 and 2003. The soil of the experimental field was

sandy clay loam, low in N, medium in available P and high in available K content, with soil pH 7.7 in 0-15 cm soil layer. A total rainfall of 299 mm and 500.5 mm was received during 2002 and 2003 rice crop season, respectively. The experiment was laid out in split plot design with three replications consisting of 27 treatment combinations involving 3 varieties viz. PRH 10, Pusa Sugandh 3 and Pusa Basmati 1 and 3 plant spacings viz. 20 x 10, 20 x 15 and 20 x 20 cm in main plots; and 3 levels of nitrogen viz. 0, 80 and 160 kg ha<sup>-1</sup> in sub-plots. For calibration of model, individual data sets of 18 treatment combinations involving 3 spacings, 3 varieties, 0 level of nitrogen and 2 years were used; while for model validation rest of 36 treatment combinations of two years were used. For model application, 3 varieties viz. PRH 10, Pusa Sugandh 3 and Pusa Basmati 1, 4 plant populations viz., 66.7, 50, 33.3 and 25 hills m<sup>-2</sup>, 6 levels of N viz. 0, 40, 80, 120, 160 and 200 kg ha<sup>-1</sup>; and 4 locations viz. Ludhiana, Pantnagar, Patna and Barrackpore were selected. Besides biometric observations on growth and yield, quality parameters of rice varieties were also studied. The salient findings obtained from the investigations and conclusions drawn are summarised here under:

### **Aromatic rice varieties**

**6.1** Newly released rice hybrid PRH 10 registered significantly higher values of number of tillers hill<sup>-1</sup>, leaf area index and dry matter production over inbred varieties, Pusa Sugandh 3 and Pusa Basmati 1. Between the inbred aromatic rice varieties, Pusa Sugandh 3 was superior to Pusa Basmati 1 in terms of growth attributes. Whereas Pusa Basmati 1 was longer in plant stature.

**6.2** Rice hybrid PRH 10 recorded significantly more number of panicles  $m^{-2}$ , filled grains panicle<sup>-1</sup> and heavier panicle weight, while Pusa Sugandh 3 registered higher fertility percentage and test weight. Pusa Basmati 1 had the longest panicles.

**6.3** Rice hybrid PRH 10 produced (36 and 29.8 per cent, and 6.6 and 5.2 per cent) significantly higher grain yield as compared to Pusa Basmati 1 and Pusa Sugandh 3 during 2002 and 2003, respectively. The newly-released inbred variety Pusa Sugandh 3 registered 27.5 and 23.3 per cent more grain yield than Pusa Basmati 1. PRH 10 and Pusa Sugandh 3 produced (8.9-9.5 and 6.7-6.9 per cent) higher straw yield than Pusa Basmati 1, respectively.

**6.4** Rice hybrid PRH 10 and inbred variety Pusa Sugandh 3 registered higher hulling percentage and head rice recovery, but milling percentage was higher in Pusa Sugandh 3 and Pusa Basmati 1 than PRH 10. Pusa Basmati 1 registered significant increase in elongation of kernel after cooking compared to PRH 10 and Pusa Sugandh 3. However, PRH 10 exhibited significantly higher protein content than other two inbred rice varieties.

**6.5** Significantly higher uptake of nitrogen was recorded with PRH 10 compared to Pusa Sugandh 3 and Pusa Basmati 1 at all the growth stages, except uptake by straw of Pusa Sugandh 3. PRH 10 registered 32.3-37.7 per cent 22.6-25 per cent more N uptake than Pusa Sugandh 3 and Pusa Basmati 1, respectively.

### **Plant spacing**

**6.6** A plant spacing of 20 x 10 cm registered significantly taller plants, more LAI and higher dry matter production compared to 20 x 15 cm and 20 x 20 cm. The number of tillers hill<sup>-1</sup> was significantly more at 20 x 20 cm than other spacings.

**6.7** A wider plant spacing of 20 x 20 cm maintained its superiority in producing number of filled grains panicle<sup>-1</sup>, panicle weight, length of panicle, fertility percentage and test weight as compared to a closer spacing of 20 x 10 cm during both the years of study. However, number of panicles m<sup>-2</sup> was the highest at a spacing of 20 x 10 cm.

**6.8** The grain yield and harvest index were significantly maximum at a spacing of 20 x 20 cm, followed by 20 x 15 and 20 x 10 cm. The magnitude of increase in grain yield at a plant spacing of 20 x 20 cm was to the tune of 16.1-16.4 per cent, and 5.7-6.5 per cent over 20 x 10 and 20 x 15 cm, respectively. The trend was just reverse in case of straw yield.

**6.9** The quality parameters viz. hulling, milling and head rice recovery were significantly higher at 20 x 20 cm over 20 x 10 cm. However, kernel length and breadth before and after cooking, and protein content of milled rice remained unaffected due to plant spacings.

**6.10** Significantly higher values of N uptake at PI and flowering, and by straw at harvest were recorded at 20 x 10 cm over 20 x 15 and 20 x 20 cm spacings. But, N uptake by grain increased significantly with successive increase in the plant spacing with maximum uptake at a spacing of 20 x 20 cm. However, total N uptake was not influenced by plant spacings.

#### **Levels of nitrogen**

**6.11** Growth characters of aromatic rice viz. plant height, number of tillers hill<sup>-1</sup>, leaf area index and dry matter production were significantly increased with successive increase in levels of nitrogen from 0 to 160 kg ha<sup>-1</sup>.

**6.12** There was a significant improvement in yield attributing characters viz. number of panicles  $m^{-2}$  and filled grains panicle $^{-1}$ , test weight, length of panicle, fertility percentage and panicle weight of rice with application of nitrogen up to 160 kg N  $ha^{-1}$ .

**6.13** Application of 160 kg N  $ha^{-1}$  produced 34.0 and 11.8 per cent, and 35.0 and 6.5 per cent more grain yield than 0 and 80 kg N  $ha^{-1}$  during 2002 and 2003, respectively. Straw yield was also increased with increase in the levels of nitrogen from 0 to 160 kg N  $ha^{-1}$ . Harvest index was not influenced due to application of nitrogen.

**6.14** Significantly higher values of hulling, milling, head rice recovery and protein content were registered with the application of nitrogen during both the years of study. Maximum values of these quality parameters were recorded with the application of 160 kg N  $ha^{-1}$ . Other quality parameters viz. kernel length and breadth before and after cooking were not altered due to application of nitrogen.

**6.15** Nitrogen uptake by rice at all the growth stages was enhanced with increase in levels of nitrogen. The increase in total N uptake was more conspicuous with the application of 160 kg N  $ha^{-1}$ . The magnitude of increase in total N uptake was 54.8 and 14.0 per cent, and 55.5 and 10.7 per cent with the application of 160 kg N  $ha^{-1}$  over 0 and 80 kg N  $ha^{-1}$  respectively during two years of experimentation.

### **Interaction effects**

**6.16** Rice hybrid PRH 10 registered significantly more number of filled grains panicle $^{-1}$  and weight of panicle at a spacing of 20 x 20 cm than other spacings, whereas Pusa Sugandh 3 and Pusa Basmati 1 were at par with respect to number of filled grains panicle $^{-1}$  and weight of panicle at 20 x 15 and 20 x 20 cm.

**6.17** PRH 10 produced highest grain yield (53.91 and 57.40 q ha<sup>-1</sup>) at a spacing of 20 x 20 compared to other spacings, while the inbred rice varieties Pusa Sugandh 3 and Pusa Basmati 1 produced equal grain yield at the spacings of 20 x 15 and 20 x 20 cm. Grain yield produced by PRH 10 at a spacing of 20 x 10 cm was significantly higher than that by Pusa Basmati 1 at a spacing of 20 x 20 cm. Nitrogen uptake by rice varieties too followed the similar trend as observed for interaction for grain yield.

**6.18** PRH 10 and Pusa Sugandh 3 registered the highest number of panicles m<sup>-2</sup>, number of filled grains panicle<sup>-1</sup> and panicle weight with application of 160 kg N ha<sup>-1</sup>. However, these yield attributes in Pusa Basmati 1 were at par with application of 80 and 160 kg N ha<sup>-1</sup>.

**6.19** Grain yield and N uptake by grains of PRH 10 and Pusa Sugandh 3 were significantly increased with each increase in the levels of nitrogen up to 160 kg ha<sup>-1</sup>. But grain yield and N uptake by grains of Pusa Basmati 1 increased significantly up to application of 80 kg N ha<sup>-1</sup>. Further increase in the level of nitrogen did not cause a significant influence on these parameters.

### **Model Calibration and Validation**

**6.20** Days to flowering and physiological maturity of PRH 10, Pusa Sugandh 3 and Pusa Basmati 1 at 0 level of nitrogen were accurately simulated by InfoCrop model after determining the coefficients of each variety. The deviation of simulated grain yield from measured yield of these varieties at 0 level of nitrogen after calibration of the model ranged from 7.2 to 10.1, indicating some inability of the model to assess the spatial and temporal

inherent soil fertility. However, the deviations in simulated grain yield were within the acceptable range.

**6.21** InfoCrop model also simulated days to flowering and maturity, and grain yield reasonably well at 80 and 160 kg N ha<sup>-1</sup>. Both simulated and measured number of days to flowering and maturity, and grain yield of all rice varieties were closely related. This indicated that model was capable of satisfactorily simulating the effect of nitrogen but not of plant population. Thus the model needs improvement in its structure to simulate the effect of plant population.

#### **Simulated grain yield in Indo-Gangetic plains**

**6.22** Simulated grain yield of PRH 10 and Pusa Sugandh 3 was maximum at Ludhiana, Pantnagar, Patna and Barrackpore with the application of 200 kg N ha<sup>-1</sup>. On the other hand, Pusa Basmati 1 produced comparable simulated grain yield with the application of 120 and 160 kg N ha<sup>-1</sup> at all the three locations, except Ludhiana.

**6.23** Year to year variation in simulated grain yield of all the rice varieties at different locations indicated variation in climatic condition of these locations and the highest variation in simulated grain yield was found at Barrackpore. Mean simulated grain yield increased from eastern (Barrackpore) to north-western region (Ludhiana) of Indo-Gangetic plain.

**6.24** There was a decreasing trend in the simulated grain yield at all the locations and the magnitude of decrease was higher towards eastern region (Barrackpore), although the decrease was non-significant at all the locations.

## CONCLUSION

- Aromatic rice hybrid PRH 10 proved better as compared to newly-released inbred varieties, Pusa Sugandh 3 and Pusa Basmati 1 in terms of grain yield, nitrogen uptake and protein content. Pusa Sugandh 3 and Pusa Basmati 1 were superior in quality parameters to PRH 10.
- Transplanting of PRH 10 at a plant spacing of 20 x 20 cm with application of 160 kg N ha<sup>-1</sup> was most appropriate combination for realizing higher grain yield, whereas Pusa Sugandh 3 and Pusa Basmati 1 performed better at a spacing of 20 x 15 cm with 160 and 80 kg N ha<sup>-1</sup>, respectively.
- Hulling, milling and head rice recovery were higher at wider spacing and with application of nitrogen. But, kernel length and breadth before and after cooking were unaffected by spacing and nitrogen application.
- InfoCrop model was capable of satisfactorily simulating the effect of nitrogen on rice productivity. The model simulated the decreasing trend in grain yield of rice and the magnitude was higher towards eastern part of Indo-Gangetic plain. However, the model needs improvement in its structure to simulate the effect of plant population.

## Future lines of work

- Based on these studies, it is suggested that the studies on organic farming in aromatic rices are needed in respect of productivity and quality.
- Detailed experimental data must be generated for the improvement of the model to simulate the effect of plant population on productivity of rice.
- More studies are needed on soil dynamics, rooting behaviour, weeds, pests and water management, dates of transplanting and seedling age to simulate their effect on growth and productivity of crops.

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# APPENDICES

**APPENDIX I. Mean weekly meteorological variables during the *kharif* 2002**

Month	Standard weeks	Temperature (°C)		Sunshine (hrs. day <sup>-1</sup> )	Wind velocity (km hr <sup>-1</sup> )	R.H. (%)	Rainfall (mm)
		Max.	Min.				
June	23	40.0	28.8	7.5	6.5	45.0	2.8
	24	41.5	28.7	5.6	9.1	51.0	0.0
	25	40.3	28.8	7.5	8.6	53.0	2.6
	26	36.2	28.6	5.6	8.8	63.0	34.0
July	27	39.4	30.0	5.7	10.3	54.0	0.0
	28	40.5	21.5	6.4	12.2	49.0	0.0
	29	39.7	29.6	6.8	9.2	51.0	14.8
	30	38.2	29.9	3.9	11.6	51.0	0.0
August	31	36.7	28.4	2.3	6.3	67.0	1.5
	32	35.2	27.7	2.3	5.7	74.0	42.0
	33	32.3	26.9	2.9	3.4	76.0	49.6
	34	34.1	26.8	5.1	6.2	71.0	1.4
September	35	38.4	26.3	6.0	4.6	73.0	14.2
	36	30.8	23.8	4.0	2.9	82.0	15.0
	37	31.1	23.0	3.9	1.8	89.0	158.5
	38	32.5	23.5	8.2	3.2	71.0	2.5
	39	33.7	21.7	8.5	3.4	59.0	0.0
October	40	35.8	19.2	9.2	2.9	53.0	0.0
	41	32.2	20.8	7.8	3.4	64.0	2.0
	42	31.9	19.3	6.7	1.1	68.0	0.0
	43	30.7	15.9	7.4	2.5	58.0	0.0
November	44	31.3	16.3	5.9	1.2	60.0	0.0
	45	28.3	14.5	3.3	1.1	66.0	0.0
	46	26.8	13.2	6.4	2.7	62.0	0.0
	47	27.3	10.5	6.4	1.5	54.0	0.0

**APPENDIX II. Mean weekly meteorological variables during the *kharif* 2003**

Month	Standard weeks	Temperature (°C)		Sunshine (hrs. day <sup>-1</sup> )	Wind velocity (km hr <sup>-1</sup> )	R.H. (%)	Rainfall (mm)
		Max.	Min.				
June	23	43.1	31.0	3.4	7.1	41.0	2.0
	24	42.8	30.0	5.5	5.2	41.1	-
	25	35.1	26.6	2.8	3.2	73.1	20.8
	26	37.5	27.9	3.2	3.7	59.7	8.1
July	27	36.0	26.8	6.2	3.5	67.7	123.2
	28	31.0	24.8	3.2	3.5	86.7	243.0
	29	32.0	26.0	3.9	2.2	88.0	106.4
	30	33.8	26.6	7.5	2.6	76.4	82.0
August	31	29.6	25.8	1.3	4.2	85.3	57.6
	32	32.9	26.9	5.0	1.5	76.6	7.0
	33	31.2	25.5	3.3	2.2	79.3	94.8
	34	33.9	27.0	6.3	3.0	74.0	4.6
September	35	30.5	26.9	4.7	1.6	68.0	9.8
	36	31.3	25.0	3.1	1.2	76.6	30.2
	37	30.9	24.9	0.9	0.4	85.1	11.0
	38	33.7	25.0	5.7	0.9	71.3	0.0
	39	31.9	22.5	6.6	1.8	68.8	0.0
October	40	33.6	17.8	9.2	1.3	57.6	0.0
	41	33.4	17.6	7.0	0.8	55.4	0.0
	42	32.3	16.1	6.5	0.9	52.4	0.0
	43	31.2	15.1	5.0	0.2	62.7	0.0
November	44	30.8	13.6	6.1	0.5	52.7	0.0
	45	31.3	13.4	6.6	1.0	55.0	0.0
	46	26.4	12.3	3.5	0.9	64.6	0.0
	47	24.8	8.6	6.3	1.9	58.6	0.0

Appendix III. Effect of plant spacing and levels of nitrogen on nitrogen concentration (%) of aromatic rice at various growth stages

Treatments	Nitrogen concentration (%)							
	PI stage		Flowering stage		At harvest			
	2002	2003	2002	2003	2002	2003	2002	2003
<b>Rice varieties</b>								
PRH 10	2.254	2.263	1.203	1.214	1.334	1.356	0.521	0.531
Pusa Sugandh 3	2.227	2.237	1.173	1.193	1.331	1.318	0.502	0.513
Pusa Basmati 1	2.211	2.221	1.145	1.155	1.208	1.222	0.482	0.501
<b>SEm ±</b>	<b>0.005</b>	<b>0.0035</b>	<b>0.003</b>	<b>0.004</b>	<b>0.016</b>	<b>0.010</b>	<b>0.004</b>	<b>0.002</b>
<b>CD (P=0.05)</b>	<b>0.015</b>	<b>0.0107</b>	<b>0.009</b>	<b>0.012</b>	<b>0.047</b>	<b>0.030</b>	<b>0.012</b>	<b>0.006</b>
<b>Spacing (cm)</b>								
20 x 10	2.209	2.219	1.164	1.177	1.274	1.285	0.492	0.506
20 x 15	2.223	2.232	1.173	1.186	1.283	1.294	0.500	0.514
20 x 20	2.259	2.269	1.185	1.200	1.316	1.316	0.513	0.526
<b>SEm ±</b>	<b>0.005</b>	<b>0.0035</b>	<b>0.003</b>	<b>0.004</b>	<b>0.016</b>	<b>0.010</b>	<b>0.004</b>	<b>0.002</b>
<b>CD (P=0.05)</b>	<b>0.015</b>	<b>0.0107</b>	<b>0.009</b>	<b>0.012</b>	<b>NS</b>	<b>NS</b>	<b>0.012</b>	<b>0.006</b>
<b>N levels (kg ha<sup>-1</sup>)</b>								
0	1.995	2.004	1.131	1.141	1.196	1.191	0.447	0.461
80	2.339	2.349	1.176	1.188	1.320	1.339	0.518	0.531
160	2.358	2.368	1.215	1.234	1.357	1.365	0.541	0.553
<b>SEm ±</b>	<b>0.0037</b>	<b>0.003</b>	<b>0.004</b>	<b>0.005</b>	<b>0.013</b>	<b>0.007</b>	<b>0.003</b>	<b>0.0025</b>
<b>CD (P=0.05)</b>	<b>0.0105</b>	<b>0.009</b>	<b>0.011</b>	<b>0.014</b>	<b>0.037</b>	<b>0.019</b>	<b>0.009</b>	<b>0.007</b>

#### APPENDIX IV. Soil parameters of Ludhiana used in the InfoCrop model

Description	Soil depth (cm)		
	0-30	30-90	90-210
<b>Mechanical composition</b>			
Sand (%)	46	49	50
Silt (%)	33	30	30
Clay (%)	21	21	20
Saturation fraction	0.36	0.41	0.41
Field capacity fraction	0.16	0.21	0.21
Wilting point fraction	0.06	0.06	0.07
Saturated hydraulic conductivity (mm day <sup>-1</sup> )	113	112	90
Bulk density (g cm <sup>-2</sup> )	1.45	1.50	1.50
Organic carbon (%)	0.38	0.30	0.30
Soil pH	8.2	-	-
Soil moisture fraction at transplanting	0.12	0.15	0.16
Initial soil NH <sub>4</sub> <sup>+</sup> (kg ha <sup>-1</sup> )	11.0	10.0	1.0
Initial soil NO <sub>3</sub> <sup>-</sup> N (kg ha <sup>-1</sup> )	11.8	1.0	1.0
Texture	← Sandy clay loam →		

## APPENDIX V. Soil parameters of Pantnagar used in the InfoCrop model

Description	Soil depth (cm)		
	0-5	5-15	15-30
<b>Mechanical composition</b>			
Sand (%)	23.8	26.2	28.5
Silt (%)	44.6	44.3	43.9
Clay (%)	31.6	29.5	27.6
Saturation fraction	0.49	0.48	0.46
Field capacity fraction	0.26	0.24	0.22
Wilting point fraction	0.13	0.12	0.12
Saturated hydraulic conductivity (mm day <sup>-1</sup> )	140	130	100
Bulk density (g cm <sup>-2</sup> )	1.34	1.38	1.42
Organic carbon (%)	1.0	0.8	0.5
Soil pH	7.7	7.5	7.5
Soil moisture fraction at transplanting	0.20	0.18	0.15
Initial soil NH <sub>4</sub> <sup>+</sup> (kg ha <sup>-1</sup> )	10.3	10.4	7.2
Initial soil NO <sub>3</sub> -N (kg ha <sup>-1</sup> )	10.1	9.8	5.1
Texture	← Silty clay loam →		

## APPENDIX VI. Soil parameters of Patna used in the InfoCrop model

Description	Soil depth (cm)		
	0-45	45-80	80-105
<b>Mechanical composition</b>			
Sand (%)	39.1	27.6	38.7
Silt (%)	37.8	43.6	40.4
Clay (%)	23.1	28.8	20.9
Saturation fraction	0.34	0.41	0.31
Field capacity fraction	0.17	0.20	0.15
Wilting point fraction	0.06	0.08	0.05
Saturated hydraulic conductivity (mm day <sup>-1</sup> )	140	97	138
Bulk density (g cm <sup>-2</sup> )	1.43	1.38	1.46
Organic carbon (%)	0.40	0.31	0.26
Soil pH	7.30	-	-
Soil moisture fraction at transplanting	0.12	0.14	0.11
Initial soil NH <sub>4</sub> <sup>+</sup> (kg ha <sup>-1</sup> )	2.0	1.55	1.30
Initial soil NO <sub>3</sub> <sup>-</sup> -N (kg ha <sup>-1</sup> )	6.0	4.65	3.90
Texture	← Loam →		

**APPENDIX VII. Soil parameters of Barrackpore used in the InfoCrop model**

Description	Soil depth (cm)		
	0-22.5	22.5-52.5	52.5-82.5
<b>Mechanical composition</b>			
Sand (%)	54	50	52
Silt (%)	28	26	27
Clay (%)	18	24	21
Saturation fraction	0.44	0.40	0.35
Field capacity fraction	0.15	0.15	0.10
Wilting point fraction	0.07	0.08	0.07
Saturated hydraulic conductivity (mm day <sup>-1</sup> )	160	40	90
Bulk density (g cm <sup>-2</sup> )	1.30	1.32	1.33
Organic carbon (%)	0.71	0.51	0.40
Soil pH	7.1	7.3	7.6
Initial soil NH <sub>4</sub> <sup>+</sup> (kg ha <sup>-1</sup> )	5.25	4.1	2.9
Initial soil NO <sub>3</sub> <sup>-</sup> N (kg ha <sup>-1</sup> )	3.75	2.3	1.7
Texture	← Sandy loam →		

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