

**Impact of Climate Change on Different Rice Varieties
under Varied Agroecological Conditions of Kashmir
Using CERES-Rice Model**

Shabana Tabasum
(2010-295-D)



Division of Agronomy
Faculty of Post-Graduate Studies
**Sher-e-Kashmir University of Agricultural Sciences &
Technology of Kashmir**

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Thesis

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Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Division of Agronomy, Shalimar Campus, Srinagar – 190 025

Certificate – I

This is to certify that the thesis entitled, **“Impact of Climate Change on Different Rice Varieties under Varied Agroecological Conditions of Kashmir Using CERES-Rice Model”** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Agriculture (Agronomy)**, to the **Faculty of Postgraduate Studies, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** is a record of bonafide research work carried out by **Ms. Shabana Tabasum (Regd. No. 2010-295-D)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that information received during the course of investigation has duly been acknowledged.

(Dr. K.N. Singh)
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Endorsed

Prof. & Head,
Division of Agronomy

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Division of Agronomy, Shalimar Campus Srinagar – 190 025

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We, the members of the Advisory Committee of **Ms. Shabana Tabasum (Regd. No. 2010-295-D)**, a candidate for the degree of **Doctor of Philosophy in Agriculture (Agronomy)** have gone through the manuscript of the thesis entitled, **“Impact of Climate Change on Different Rice Varieties under Varied Agroecological Conditions of Kashmir Using CERES-Rice Model”** and recommend that it may be submitted by the student in partial fulfilment of the requirements for the award of the degree.

Advisory Committee

Chairman

Dr. K.N. Singh
Prof. & Head, Division of Agronomy,
SKUAST-Kashmir

Members

Dr. Parmeet Singh,
Assistant Professor (Agronomy), Faculty of
Agriculture, Wadura, SKUAST-Kashmir

Dr. Javed Ahamd Wani,
Associate Professor, Division of Soil Science,
SKUAST-Kashmir, Shalimar

Dr. Showkat Maqbool,
Assistant Professor, Division of Agri-Statistics,
SKUAST-Kashmir, Shalimar

Dean PG Nominee

Dr. Kousar Parveen,
Associate Professor, Division of Vegetable
Science, SKUAST-Kashmir, Shalimar

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Shalimar Campus, Srinagar – 190 025

Certificate – III

This is to certify that the thesis entitled, **“Impact of Climate Change on Different Rice Varieties under Varied Agroecological Conditions of Kashmir Using CERES-Rice Model”** submitted by **Ms. Shabana Tabasum (Regd. No. 2010-295-D)** to the **Faculty of Postgraduate Studies, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Agriculture (Agronomy)** was examined and approved by the Advisory Committee and External Examiner on

Chairman
Advisory Committee

External Examiner

Prof. & Head,
Division of Agronomy

Director Education
SKUAST-Kashmir, Shalimar, Srinagar

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Division of Agronomy, Shalimar campus-190 025

Name of the student : **Shabana Tabasum**

Registration No. : 2010-295-D

Major Subject : Agronomy

Minor Subject : Soil Science/Plant Physiology

Major Advisor : **Dr. K.N. Singh**
Prof. & Head,
Division of Agronomy, SKUAST-Kashmir

Title of the Thesis : **“Impact of Climate Change on Different Rice Varieties under Varied Agroecological Conditions of Kashmir Using CERES-Rice Model”**

ABSTRACT

A field experiment was undertaken at Shalimar Campus of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir during 2011 and 2012 with the objective to study the growth and yield of different varieties of rice at varying sowing dates, and to study the impact of climate change on these rice varieties in different locations of Kashmir valley. Experiment was laid in split plot design assigning transplanting dates (25 May, 10 and 25 June) in main plot and four varieties of rice (Jhelum, Shalimar rice-1, SKAU-341 (SR-2) and SKAU-382 (SR-3) in sub-plots. Genetic co-efficient of four varieties were generated for validation of model CERES-rice (DSSAT 4.5). The crop planted on 25 May produced the highest yield of 74.0 and 79.0 q ha⁻¹ during 2011 and 2012 respectively over 10 June (57.3 and 57.1 q ha⁻¹) and 25 June (31.1 and 32.2 q ha⁻¹). Spikelet sterility was 19.08 and 18.18, 20.21 and 20.62, 29.67 and 33.84 with 25 May, 10 June and 25 June transplanting during 2011 and 2012 respectively. Growth characters like dry matter, tillers m⁻² and yield attributes like grains panicle⁻¹, spikelets panicle⁻¹ and test weight were recorded highest with 25 May transplanting and lowest in 25 June transplanting. To complete growth

phases more days were taken by early transplanting. Rice transplanting on 25 May had a longer vegetative phase than later transplanted rice. Variety Jhelum recorded highest grain yields. The superiority of variety Jhelum over Shalimar rice-1, SKAU-341 and SKAU-382 was 3.9, 9.1 and 15.9 per cent, respectively during 2011 and corresponding values for year 2012 were 1.7, 8.5 and 14.7 per cent, respectively. CERES-Rice model, embedded in the Decision Support system for Agrotechnology Transfer (DSSAT4.5) was used for the crop simulation studies and validated in different locations in terms of phenology, grain yield, tops weight and N-uptake their simulated values matched well with observed values. To assess the impact of climate change on productivity of rice, a simulation study was carried out to evaluate the potential consequences of climate change on the rice varieties in terms of yield in different locations of Kashmir valley. The climatic scenario for 2011-2090 under A1B was extracted from a PRECIS run obtained from IITM (Indian Institute of Tropical Meteorology, Pune) showed that in the year 2040 the maximum temperature will increase by 2 °C, minimum temperature by 2.3°C, CO₂ concentration by 80 ppm and the projected precipitation is likely to decrease by 90 mm. It was observed that with the increase of 2°C temperature as estimated by 2040 it was expected an overall decrease of rice yield by 0.7% at all the locations. An estimated increase in minimum temperature by 2.3°C also simulated decrease by 0.55% across different locations. Increase of CO₂ by 80 ppm as estimated by 2040 recorded increase in the yield at Kokernag, Kupwara, Srinagar, Budgam and Anantnag by 6.4, 5.08, 3.78, 4.05 and 0.5% respectively. Precipitation with estimated decrease of 90 mm of rainfall by 2040 record huge decrease in yield at Kupwara, Anantnag, Srinagar and Budgam however decrease in yield at Kukernag was less. On an average decrease across the locations was 38.4%. The cultivar SKAU-341 and Shalimar rice-1 were found more sensitive to climate change as compared to Jhelum and SKAU -382. This is because of the reason that SKAU-341 and Shalimar rice-1 are long duration cultivars compared to Jhelum and SKAU-382. It was concluded that optimum transplanting time of rice under existing agroclimatic conditions was 25 May to 10 June with 3 seedlings hill⁻¹ and suitable varieties are Jhelum, Shalimar rice-1 and SKAU-382. Enhancement of adaptive capacity is a necessary condition for reducing vulnerability, particularly for the most vulnerable regions to climate change conditions.

Key words: Climate Change, Growth, Grain yield, Rice varieties, Sowing dates, Simulation.

Signature of Student
Dated _____

Signature of Major Advisor
Dated _____

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Place : Shalimar, Srinagar

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Chapter – 1

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the major crops to feed the world's growing population (Shimono *et al.*, 2010). It contains a number of energy rich compounds such as carbohydrates, fat, protein and reasonable amount of iron, calcium, thiamine, riboflavin and niacin (Juliano, 1993). Rice is grown in 114 countries across the world on an area of about 158 million hectare with a production of 700 million tones annually (Rice Pedia, 2013). Global rice production must reach 800 million tonnes to meet projected demand in 2030 (FAOSTAT, 2003). More than 90 per cent of the world's rice is produced and consumed in Asia where it is an integral part of culture and tradition.

Rice occupies a pivotal place in Indian agriculture and it contributes to 15 per cent of annual GDP and provides 43 per cent calorie requirement for more than 70 per cent of Indians. In India it is cultivated on an area of 44.6 million hectares under a diverse set of agro-environments varying in seasons, temperatures, rainfall, soil types, hydrology, varieties and input management with a production of 120.6 million tonnes, contributing about 23 per cent of the world rice production. However the average yield of rice in India is 2.3 t ha⁻¹ as against that of 4.37 t ha⁻¹ in the world (FAO, 2012).

Rice crop plays a significant role in livelihood of people of Jammu and Kashmir State. Although area under rice is very small (0.27 m ha), it plays an important role in the state economy. Rice productivity in the state is high compared to the national average productivity. The total annual rice production in the state is about more than 0.59 MT (Anonymous, 2009). The state of Jammu and Kashmir is mainly comprised of three geographical regions, namely Jammu region, Kashmir region and Ladakh region lying north of the Indian Union comprise the extreme western part of the Himalayas (32.44° N and 74.54° E). In Kashmir valley the cultivation of rice extends from the area having altitude

1600m above the mean sea level to high hills 2300 m above msl. In Ladakh there is no cultivation of rice. Rice is grown only once in a year in Kashmir valley because of extreme climatic conditions.

The growth cycle of rice takes 3 to 6 months, depending primarily on temperature and genetic characteristics with regard to photo period sensitivity and thermo sensitivity (De Datta, 1981). Rice is adapted to a wide range of cardinal temperature where minimum temperature for growth is 10 to 12 °C, optimum temperature 30 to 32 °C and maximum 36 to 38 °C (Mavi, 1994).

The growth period of rice crop in Kashmir valley is limited by low temperature in spring and autumn. Temperature fluctuation at flowering and grain filling stage results in high spikelet sterility (Kumar, 2002). Temperature cannot be manipulated easily under field conditions but seeding time can be adjusted to meet the specific requirement for physiological stage of crop growth cycle (Suresh *et al.*, 2001). The adverse effect of sowing dates can also be minimized by selecting a suitable cultivar as the magnitude of yield reduction varies with the varieties (Medhi and Baruah, 2001).

Time of planting is one of the major factors in efficient agricultural management playing a significant role in production control. The sowing date of the rice crop is important for three major reasons. Firstly, it ensures that vegetative growth occurs during a period of satisfactory temperatures and high levels of solar radiation. Secondly, the optimum sowing time for each cultivar ensures the cold sensitive stage occurs when the minimum night temperatures are low. Thirdly, sowing on time guarantees that grain filling occurs when milder autumn temperatures are more likely, hence good grain quality is achieved (Farrell *et al.*, 2003). The delayed sowing result in the poor emergence and reduced heading panicle and spikelets per panicle and ultimately yield is affected (Hayat *et al.*, 2003). Timely transplanting of rice crop is also found to increase the water use efficiency as compared to the delayed planting as gradually snow melt water decreases in the valley.

Rice production and productivity was significantly enhanced with the introduction and cultivation of semi-dwarf, fertilizer responsive and non lodging high yielding varieties in the early seventies leading to the “Green Revolution”. The yield level of high yielding varieties is plateauing in recent year. To meet the demand of increasing population and maintain this self sufficiency the present production level need to be increased up to 140 million tonnes by 2025 which can be achieved only by increasing the rice production by over 2 million tonnes per year in coming decade (Anonymous, 2005). This has to be done against the backdrop of declining natural resource base such as land, water, labour and other inputs and without adversely affecting the quality of environment. Potential yield of varieties varies with the ecology as well as the agro-climatic region.

Agriculture is always vulnerable to unfavorable weather events and climate conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are important factors, which play a significant role to agricultural productivity. Greenhouse gases emissions from human activities are responsible for climate change (IPCC, 2007; Li *et al.*, 2011). Climate change leads to increased temperatures, changing rainfall patterns and amounts, and a higher frequency and intensity of extreme climate events such as floods, cyclone, droughts, and heat wave (IPCC 2007; Tirado *et al.*, 2010; Roudier *et al.*, 2011). Temperature increases and erratic rainfall patterns affect crop agriculture most directly and adversely (Lansigan *et al.*, 2000; Rosenzweig and Tubiello, 2007; Almaraz *et al.*, 2008). Changing climate over time affects rice crop production adversely (Behnassi 2011). Changes in climate generally involve changes in two major climate variables: temperature and rainfall. The increase in temperature shortens the phenological phases of crops (such as planting, flowering and harvesting) (Liu *et al.*, 2010; Roudier *et al.*, 2010; Teixeira *et al.*, 2011) and affects plant growth and development. The fluctuations and occurrence of extreme climate events reduce rice yields significantly, particularly at critical crop growth stages (Lansigan *et al.*, 2000; Teixeira *et al.*, 2011). Rainfall extremes, through

droughts and floods are very detrimental to rice productivity. Higher and/or heavy rainfall results in higher yield losses through flooding (Rosenzweig *et al.*, 2002; Reid *et al.*, 2007; Roudier *et al.*, 2011). In contrast, insufficient rainfall leads to greater drought frequency and intensity, while increased evaporation leads to complete crop failure (Reid *et al.*, 2007; Liu *et al.*, 2010).

While rice production is already under pressure on the demand side due to population growth, the supply side is further exposed to natural pressures through climate change. As a result, overall rice production is forecast to decrease by 17% per annum due to climate change and climatic events (GOB 2005). The climate risk assessment to the agricultural ecosystems holds the key to understand future food security situations in the changing climate scenarios. The assessment is based on the universally accepted rice specific crop simulation model study.

Crop simulation models can be used as a tool for agricultural risk analysis. They allow researchers to explore potential cropping location and appropriate farm management strategies. The generation of new data through agronomic research methods is insufficient to meet these needs. Conducting experiments at particular points in time and space is time consuming and expensive due to the many years of data collection that are required. In recent years, several dynamic crop growth simulation models have been developed as tools to support decision-making for agronomic research, land-use planning and crop production. These models have been embedded within the Decision Support System for Agrotechnology Transfer (DSSAT) (Hoogenboom *et al.*, 2010). The CERES-Rice model is one such crop model. This model is intended to have global application; therefore, genetic coefficients are an essential model component. Crop performance in terms of genetic coefficients used in the model can be used as a tool in choosing varieties and extend the utility of field experimentation. Once a crop model has been validated, it can be used to match variety and site rather than carry out extend field experiments. Modelling of rice growth and development began more than 30 years ago (Bouman and van Laar, 2006).

Rice research is a predominant among agricultural scientific community. There is a constant attempt by the scientists, to evolve newer high yielding genotypes for replacing the existing ones and to know the optimum date of sowing, newer cultural management practices to enhance the productivity; and to find out the causes for yield decline in some parts of rice growing environments etc. But the time required to arrive any confirmed results take years. Simulation modelling is a right tool available now a day to reduce the time required for field study. Crop simulation modelling based studies are increasing in India, however not much studies have been carried out in Kashmir so far.

Keeping the importance of simulation modelling and its applicability, the present investigation was taken up with the following objectives :

- Validation and calibration of CERES-Rice model in different agroecological conditions of Kashmir,
- Assessment of the possible change in the yield of selected varieties due to climatic change, and
- To identify the most productive rice growing location in Kashmir for changing climatic conditions.

Chapter – 2

REVIEW OF LITERATURE

Rice being an important food crop of world has been studied by number of research workers for different inputs and agro-techniques in various parts of India and abroad. In recent years dynamic crop simulation models have been found most useful to predict phenology and yield by using a minimum data set. To increase productivity suitable varieties for different agro-ecological zones need to be evaluated. Appropriate sowing date needs to be assessed so that different physiological phases should match as closely as possible with the ideal temperature requirement for growth processes. The present field trial was designed to find out the “Impact of Climate change on Different Rice Varieties under Varied Agroecological Conditions of Kashmir Using CERES-Rice Model”. In this chapter an attempt has been made to critically review the research works carried out within the country and abroad on the context stated above.

2.1 1 Effect of dates of planting

Planting dates means the effect of edaphic factors and all environmental conditions in large scale on growth and yield of all field crops. Moreover, planting dates is considered the most important factor for rice and has a substantial influence on rice growth characters, yield and yield attributes. However, specific critical date is location specific i.e. it varies from one agro-climatic condition to other.

2.1.1 Growth characters

Kumar and Subramaniam (1991) reported that gradual decrease in LAI with delay in planting beyond 15 July in coastal Andhra Pradesh.

Reddy and Reddy (1992) found that the productive tillers per m² and productive tillers per hill were significantly more when the crop was transplanted on 29 August than that of the crop transplanted on 14 August and 30 July.

Sahu (1994) conducted a field trial with rice cv. 'Mahalaxmi' observed that plant height and leaf area index was significantly higher at all the growth stages under 12 July planting among all the planting dates (12 and 22 July, 1 and 11 August).

Ghosh and Singh (1994) found that timely transplanting of rice have significantly higher LAI at flowering and 15 days after flowering than late transplanting. However, at panicle initiation stage transplanting date did not influence LAI.

Reddy and Reddy (1994) reported that maximum dry matter accumulation per m² and per hill was recorded when planting was done on 29 August which was significantly higher than that of the crop planted on 30 July and 14 August.

Sahu (1994) conducted a field trial with rice cv. 'Mahalaxmi' observed that plant height and leaf area index was significantly higher at all the growth stages under 12 July planting among all the planting dates (12 and 22 July, 1 and 11 August).

According to Shukla *et al.* (1995) leaf area index showed an increasing trend up to 60 DAT then gradually reduced till maturity as a result of decreasing number of functional leaves.

Dhiman *et al.* (1995) observed that higher plant height and dry matter accumulation per plant in earlier planting on 15 July than in delayed planting on 25 July and 5 August.

Parihar (1995) conducted a field experiment at Bilaspur revealed that higher plant height 84.63 and 83.75 cm in 1991 and 1992, respectively and significantly more number of effective tillers of 15 July planting as compared to both early (30 June) and late planting (30 July).

Number of tiller m⁻² counted highest at normal transplanting date (15 July) than early (30 June) and late (30 July) transplanting dates (Parihar *et al.*, 1995).

Xie *et al.* (1995) registered faster increase in height at later sowing dates in the Wuling mountain area of China.

Xie *et al.* (1995) reported that sowing at later dates caused tillers to emerge faster and the number of tillers to increase.

Singh *et al.* (1996) reported significant decrease in plant height by delaying planting from 5 July to 4 August at Kanpur.

Paliwal *et al.* (1996) found that early transplanting on 25 July produced significantly higher plant height (107.4 cm) than delayed transplanting on 10 and 25 August.

On the basis of observations in sub-mountainous region of Swat, Pakistan (Zada *et al.*, 1996); the crop transplanted on June 25 produced the maximum productive tillers hill⁻¹ (14.63), followed by the crops transplanted on May 25 (14.61) and June, 10 (14.25) and the minimum productive tiller hill⁻¹ (11.22) recorded on July.

Singh *et al.* (1996) reported that total tillers per plant of the crop transplanted on 16 May and 31 May was significantly more than that of the crop transplanted on 16 June.

According to Singh *et al.* (1996) dry weight hill⁻¹ decreased with delay in planting from 5 July to 4 August.

Samdhia (1996) found from an experiment conducted at Bhubaneswar taking rice hybrid 'PA 6201' and cv. 'Lalat', that LAI declined gradually as the planting was delayed beyond 15 July and maximum LAI of 4.64 was recorded at 60 DAP.

Hari Om *et al.* (1997) observed highest dry matter accumulation on 25 June transplanting followed by 5 July, 15 June and 25 July transplanting.

Singh *et al.* (1997) conducted a field experiment at Kanpur found that plant height, total tiller and dry matter accumulation of the crop transplanted on 5 July was more than that of the crop transplanted on 20 July and 4 August.

Hari Om *et al.* (1997) conducted an experiment at Haryana obtained maximum plant height from 25 June planting than subsequent planting dates.

Singh *et al.* (1997) reported from Ranchi, Bihar that early planting date (15 June) significantly increased number of productive tillers m^{-2} than late planting date (29 June).

Hari Om *et al.* (1997) observed that the number of productive tillers m^{-2} were highest on 25 June transplanting followed by 5 July, 15 June and lowest in 25 July planting.

Om *et al.* (1997) found, in an experiment with rice hybrids 'PHB 71', 'PMS2A/IR 31802', 'PMS10A/PR 106' and 'HKR 126', that the plant height, productive tillers per m^2 and dry matter accumulation were highest in the crop transplanted on 25 June followed by 5 July, 15 July and 25 July.

Kumar *et al.* (1998) reported that productive tillers per m^2 significantly decreased due to delay in transplanting from 25 July to 15 August in hybrid rice ('PA 103', 'APHR 2' and 'DRRH 1').

Patel (1999) recorded maximum number of total tillers (482 per m^2) when the crop was transplanted on 15 July, which decreased significantly with delayed planting on 30 July and 14 August.

Naher *et al.* (1999) observed in an year round rice transplanting experiment in Bangladesh, that the transplanting dates showed significant differences in plant height. May to August planting showed taller plants whereas October and November planting produced smaller plant.

Obuchi *et al.* (2000) found that the plant height was decreased in later transplanting.

Pattar *et al.* (2001) working under tropical conditions of Karnataka observed that the plant height decreased with delay in transplanting from first fortnight of August to first fortnight of September. Whereas, Suresh *et al.* (2001) noticed reduction in crop height at later sowing dates i.e. second week of October at Ramnad, Tamil Nadu.

Pandey *et al.* (2001) recorded significantly higher number of tillers per hill on 20 July and 5 August than that of planting on 20 August at all the stages of crop under Raipur conditions of Chhattisgarh.

According to Pattar *et al.* (2001), early planting in the first fortnight of August showed significantly more number of productive tillers than delayed planting.

Pandey *et al.* (2001) noted that rice hybrid 'PA 6201' gave significantly higher productive tillers per hill and dry matter accumulation per plant of the crop transplanted on 20 July and 4 August than that the crop transplanted on 20 August.

Pandey *et al.* (2001) the planting on 20 July and 5 August being at par resulted in significantly higher dry matter accumulation than that on 20 August at all the stages of crop.

Manjappa and Kumar (2002) elucidated that the dry matter accumulation per plant decreased significantly with delayed planting and it was significantly highest with the crop planted on 30 June at all the stages in hill zone of Karnataka.

Guilani *et al.* (2002) reported from Ahwaz, Iran that tiller number was different between planting dates.

Manjappa and Kumar (2002) reported that in hilly zone of Karnataka, the leaf area index was recorded significantly highest with the earliest planted crop i.e. 30 June at all the stages.

Farrell *et al.* (2003) observed that sowing on time ensures vegetative growth occurs during a period of satisfactory temperature and high levels of solar radiation, and guarantees that grain filling occurs when milder autumn temperatures are more likely, hence good grain quality is achieved.

Nayak *et al.* (2003) conducted a field experiment on hybrid rice 'PA 6201', reported that early planting of 16 July exhibited the maximum total and effective tillers per clump, LAI and dry matter accumulation than that planting on 31 July and 16 August. One month delay in planting from 16 July reduced total tillers number, LAI and dry matter accumulation by 38, 13 and 18 per cent, respectively.

Jaffuel and Dauza (2004) reported that the cumulated number of leaves on the main stem at each observation date, six leaves were noted after 20 days and nine after 34 days. A total of 12 leaves were present on the main stem after 48 days, with the 15th leaf appearing 35 days later (i.e. on day 83). The number of leaves on the main stem increased linearly overtime for 45–50 days after sowing (i.e. up to the 10–11th leaf).

Dixit *et al.* (2004) observed that rice crop planting on 25 June showed significantly more number of leaves at 60 DAS than that crop planting on 5, 10 and 15 June.

El-Khoby (2004) showed that delaying sowing date sharply decreased the leaf area index, dry matter production and chlorophyll content. In addition, delaying sowing date up to June 15th significantly reduced the period from sowing to heading.

Rakesh and Sharma (2004) hold the opinion that delay in planting resulted in significant decrease in the number of productive tillers per meter square and ultimately the paddy yield.

Khanal (2005) reported that the rate a plant produces leaves (LAR) is important for canopy development, since leaves are the source of carbohydrates for the plant.

Vang and Obi *et al.* (2006) investigated the effect of planting dates on grain yield and some agronomic characters by early and late seeding. The results indicated that planting date was affected the performance of these traits significantly.

Jalali (2007) reported that, less of leaf area index in April 28th planting date was in related to environmental factor pressures especially low environment temperature.

The integration of LAR on the main stem over time gives the number of emerged leaves (NL) on the plant main stem, which is an excellent measure of plant development (Streck *et al.*, 2008; Streck *et al.*, 2005).

Streck *et al.* (2008) reported that the main stem number of leaves in rice is related to the timing of several plant development stages such as tillering, panicle initiation, booting and anthesis.

Singh *et al.* (2009) revealed that LAI is related to the biological and economical yields and increase in LAI causes higher yield.

Haghverdian (2010) reported the most dry matter accumulation was obtained in direct seeding system in planting dates of May 7 and 16, Because of appropriate environmental condition.

Jahani and Adam (2011) a pot experiment and reported that increase in leaf number is of vital importance for plants, because of the physiological importance of leaf for photosynthetic activities.

Dawadi and Chaudhary (2013) carried out a field experiment to study the effect of sowing dates (29 May, 13 June, 29 June and 13 July) and varieties on growth and yield of direct seeded rice during rainy sea. Rice sown on June 13

produced significantly higher plant height, higher number of tillers per square meter, leaves per tiller, leaf area index and total dry matter. Significantly higher dry matter production, leaves per tillers, leaf area index, and filled grains per panicle, heat use efficiency and lower sterility were recorded in June 13 sowing; hence they contributed to significantly higher grain yield (3.84 t ha^{-1}).

Hossain and Paul (2011) reported that highest specific leaf weight is found at 60 days after transplanting.

Alam *et al.* (2009) RGR was more at early stage (25-50 DAT) and showed a decreasing trend with the advancement of plant age. At 25 to 50 DAT the highest RGR was observed.

2.1.2 Yield attributes

Gangwar and Ahamed (1990) recommended planting of rice with in June or latest by first week of July increases yield attributes and grain yield, and delay in planting after first week of July decreased drastically the number of grains per panicle, 1000 grain weight and grain yield.

Many workers have observed adverse effect of late transplanting on various yield attributing traits like panicle weight, panicle length, grains panicle⁻¹ and 1000-grain weight (Parihar *et al.*, 1995; Singh *et al.*, 1996; Siadat *et al.*, 2004).

Singh *et al.* (1996) in 4-year field study at Ludhiana taking cv. 'PR 106', found no effect of different dates of transplanting (16, 31 May and 16 June) on the ear length of rice.

Ahmad *et al.* (1996) showed that delaying in planting date cause improving sterile grains percentage significantly.

In a field experiment at Waraseoni (MP), Paliwal *et al.* (1996) found that significant reduction in panicle length and grain yield due to delay in transplanting beyond 25 July.

Singh *et al.* (1997) recorded significantly higher number of filled grains panicle⁻¹ and 1000-grain weight on early planting (15 June) than on late planting (29 June).

Singh *et al.* (1997) observed that rice planted on 15 June gave 17.8 per cent more productive tillers per m², 20 per cent filled grain per panicle and 29 per cent grain weight per panicle than planted on 29 June.

Patel (1999) under Raipur conditions of Madhya Pradesh reported that delay in transplanting significantly reduced the grains panicle⁻¹ and 1000-grain weight than early transplanting date. Similar findings from temperate Kashmir were reported by Bali *et al.* (2000).

Patel (1999) observed significant reduction in the number of panicles m⁻² with delayed planting dates from 5 September to 25 September.

Bali *et al.* (2000) reported that early transplanting schedules (first week of June) marked an increased number of panicles m⁻² over delayed transplanting schedules under temperate conditions of Kashmir valley.

Sherief *et al.* (2000) studied the effect of sowing dates (April 25th, May 10th, May 25th and June 10th) on yield and yield components of rice. They found that early sowing dates (May 10) had marked effect on number of panicles/m², number of filled grains/panicle, 1000-grain weight, grain and straw yields/fed. As compared with the planting in April 25th, however, late planting in May 25th or June 10 significantly reduced the above mentioned characteristics.

Ahn *et al.* (2000) found that delaying sowing decreased tiller number, panicle length, number of grain/panicle and fertility percentage.

Balaswamy and Kulkarni (2001) recorded more number of panicles m⁻² with 25 July planting than 10 August, 25 August and 10 September at Hyderabad. Whereas, delay sowing (second week of October) resulted in less productive tillers at Tamil Nadu (Suresh *et al.*, 2001).

Pattar *et al.* (2001) reported that early planting in the first fortnight of August showed significantly more number of filled grains panicle⁻¹ and significantly lower number of chaffy grains panicle⁻¹ than delayed planting in Karnataka.

Soomro *et al.* (2001) studied the effect of transplanting dates on yield and its related trait in rice in Pakistan and reported that early planted (16 May) rice took more days to head (110.4 days) and mature (136.0 days) and produced taller plants (102.25 cm). However, the number of panicles per hill (19.75), grains per panicle (109), grain weight per hill (79.13 g), 1000 grain weight (36.10 g) and grain yield (5750 kg/ha) were significantly greater in rice planted on 1 June. The authors concluded that transplanting during the first week of June is ideal for achieving maximum grain yield.

Number of grains panicle⁻¹, 1000-grain weight and panicle length was reduced in the second week of October sowing under the conditions of Tamil Nadu (Suresh *et al.*, 2001).

Maximum number of grain spike⁻¹ was obtained in early June planting date (78 grains) and lowest number of grain spike⁻¹ was found in early May planting date (28 grains) also one thousand grain weight was maximum in early June planting date at Ahwaz, Iran (Guilani *et al.*, 2002).

Siadat *et al.* (2004) working under Ahwaz conditions of Iran noticed that among various sowing dates (2 May to June, within an interval of 10 days), delayed sowing dates decreased the number of panicles per plant

Mesbah *et al.* (2004) inferred that grain yield has a positive and significant correlation with the number of grains per panicle, the number of filled grains per panicle, and the 1000grain weight. Furthermore, the number of grains per panicle and the number of filled grains per panicle are considered as two major effective factors in grain yield. The most effective way for production.

Singh *et al.* (2004) carried out a field experiment on hybrid rice 'PRH 10'

at New Delhi and reported that delay on transplanting significant reduction in yield and yield attributes, timely transplanting on 3 July led to 8.4 and 19.1 per cent higher grain yield than transplanting on 10 and 17 July, respectively.

Siadat *et al.* (2004) delayed sowing dates decreased the number of panicles per plant followed by a decrease in the number of seeds per panicle and single seed weight.

Shah and Bhurer (2005) reported that a higher number of filled grains per panicle was visualized in the early seeding and declined gradually in the successive seeding dates.

Akram *et al.* (2007) reported that the number of grains per panicle was significantly affected as sowing date was delayed.

Khalif *et al.* (2007) conducted a field experiment on some hybrid rice varieties to study response under different dates of sowing. Three sowing dates 1st May, 15th May and 30th May with seedling age transplanted at 26 days. 1st May gave the highest value to all studied characters. While 30th May date of sowing gave the lowest value with all traits under study.

Dehghan (2007) planting date variations affect the degree and quality of correlation between the yield and yield components.

Khalifa (2009) conducted a field experiment under different sowing dates, April 10th, April 20th, May 1st, May 10th, May 20th and June 1st. Results indicated that early date of sowing (April 20th) is the best time of sowing for leaf area index, sink capacity, spikelets/leaf area ratio, Number of grains per panicle, Panicle length (cm), 1000 grain weight (g), number of panicles per m², five Panicle weight (g) and grain yield (t/ha). Sterility per cent was the lowest value in April 20th sowing date. Sowing in 1st June has given the lowest value for all studied traits.

Lack *et al.* (2012) conducted a research in order to investigate the effects of planting dates on the grain yield and yield components. The results showed that

planting date significantly affected grain yield, biological yield, harvest index, 1000 grain weight, fertility percentage, the number of filled grains per panicle and the number of fertile tillers.

Khalifa and Rewainy (2012) Conducted Field experiment under five sowing dates April 1st, April 10th, April 20th, May 1st and May 10th. Results induced that sowing date at April 1st gave the highest value for leaf area index, No. of tillers/hill at PI, Chlorophyll content at H.D, Number of tillers/m² at maturity stage, panicle length (cm), number of grains/panicle, 1000- grains weight (g) and grains yield/ha. While May 10th gave the lowest value for all Preview attributes.

Mukesh *et al.* (2013) conducted field experiment and revealed that early transplanting on 25 June and 10 July were at par and produced significantly more yield attributes viz. number of panicles/m², number of grains/panicle and 1,000 grain weights than late planting (25 July).

Sheehy, and Mitchell (2013) reported that dead leaf at different phonological stages was Panicle initiation (0.1 t/ha), flowering (0.3 t/ha), maximum LAI (0.4 t/ha) and at final harvest (3.2 t/ha).

Khalifa *et al.* (2014) conducted two field experiments at Rice Research and Training Center (RRTC)-Sakha, to study the effect of different of sowing dates (20th April, 1st May and 10th May) on some rice varieties. Earlier sowing time (20th April) date of sowing gave the highest value of all studied characters, while 30th May date of sowing with rice gave the lowest value of all traits under study.

2.1.3 Grain yield

Experiment conducted at DRR, Hyderabad (1990) on traditional scented rice varieties in different dates of planting showed that time of planting significantly influenced the grain yield, 2 July planting produced significantly higher grain yield of 3.30 t/ha. The reduction in grain yield of 16.0, 22.2 and 34.5

per cent were recorded under 16 July, 31 July and 5 August planting as compared to the yield levels reported under 2 July planting (AICRIP, 1991).

The studies from different regions of India enunciated that maximum grain yield obtained was between 10 to 20 July transplanting dates and the yield declined significantly by delaying transplanting beyond this date (Singh and Pillai, 1995; Parihar *et al.*, 1995; Dhiman *et al.*, 1997; Gangwar and Sharma, 1998 and Singh *et al.*, 2000).

Bali *et al.* (1995) studied the effect of transplanting dates on rice and observed that delay in transplanting decreased grain yield significantly. These results were also supported by Dhiman *et al.* (1995).

Bali and Uppal (1995) from a field experiment with Basmati rice, reported earlier transplanting on 10 July gave higher grain yield of 5 and 8.6 per cent in 1989 and 1991, respectively as compared to 30 July transplanting.

The results of experiments conducted at DRR, Hyderabad during *Kharif* 1995 indicated that planting on 25 July registered significantly higher grain yield (5510 kg/ha) than planting on 5 and 15 August (DRR, 1995a). Similar study conducted at Pantnagar showed higher grain yield (6230 kg/ha) of rice hybrids (DRRH 1, APHR 2, PA 103 and CRH 1) with 15 July planting.

Parihar *et al.* (1995) reported that higher grain yield produced on 15 July planting as compared to both early and late planting on 30 June and 30 July.

Zada *et al.* (1996) reported that maximum paddy yield (7.03 t ha⁻¹) was obtained from transplanting on 25 June followed by that of 10 June (6.97 t ha⁻¹).

A field experiment conducted at CRRI, Cuttack in 1996-97 showed that rice hybrids 'PA 103,' 'VRH 4', 'KMRH 2', and DRRH 1, planted on 22 July recorded significantly more grain yield of 3.78 t/ha than that planted on 1 August (3.33 t/ha) and 11 August (3.27 t/ha) (CRRI, 1997).

The per cent reduction in grain yield of 4.86 and 16.20 were recorded under 20 July and 4 August planting as compared to the yield levels reported under 5 July planting (Singh *et al.*, 1997).

Dhiman *et al.* (1997) observed that the magnitude of decline in grain yield was 12.5% from 25 June to 15 July, whereas the reduction was 38.3% from 5 July to 5 August. Sowing of upland rice by 15 June resulted higher yield while delayed sowing by 1st week of July as in vogue (with farmers) resulted in yield reduction to the extent of 32 and 53% (Behera *et al.*, 1997).

Kumar *et al.* (1998) from a 2-year field study with rice hybrids 'PA 103', 'APHR 2' 'DRRH1' reported significantly higher grain yield (5.1 t/ha) due to early planting on 25 July than the delayed planting on 5 and 15 August during both the year of study.

Babapour (1998) reported that in rice cultivated in mountain region at April 14th, April 24th and May 4th planting dates. Most grain yield and least grain yield were related to May 4th and April 24th respectively.

Gravois and Helm (1998) also showed that rice grain yield declined as seeding dates were delayed and that very short-seasoned cultivars did not always produce higher grain yields than mid-season cultivars when seeded late.

Singh and Prasad (1999) noticed that 15 March sown crop produced 12.5 and 34.5 per cent higher grain yield than March 30 and April 15, respectively.

Mahal *et al.* (1999) from a field study at Ludhiana reported that planting on 19 July gave significantly higher grain yield as compared to planting on 5 July and 2 August.

An year round experiment conducted by Naher *et al.* (1999) in Bangladesh with cv 'BR 11' and 'BR 14' revealed that the transplanting dates showed significant differences in grain yield. July planted crop produced higher grain yield than the crop planted in August and September.

Patel (1999) found significantly more grain yield with early planting on 15 July than with delayed planting on 30 July and 14 August.

Hari Om *et al.* (1999) reported that grain yield was higher in 25 June transplanted crop (75.4 q ha^{-1}) than in early (15 June) and late (5 July and 25 July) planting dates

Bali *et al.* (2000) working under temperate conditions of Kashmir reported that earlier transplanted crop (first week of June) had significantly higher mean yield of 36.3 per cent than delayed transplanted crop (first week of July).

Xie *et al.* (2000) concluded that the optimal sowing date in Taihu farming region of China is 10-20 May.

Norman *et al.* (2000b) reported from Arkansas, USA that grain yields of the various cultivars were either similar or slightly larger for the 3 May sowing compared to 23 April and very low yields were obtained with 22 June sowing date. Where, the highest grain yields were measured when rice seeded on 19 April and 2 May, further delayed sowing into June dramatically decreased the grain yields (Norman *et al.*, 2001a).

Ganajaxi *et al.* (2001) observed that crops planted on the 1st fortnight of August recorded significantly higher yield than planted on 2nd fortnight of August, this fifteen days delay in planting reduced the yield by 25%. A linear reduction in grain yield was observed with every 15 days delay in planting from 25 July to 10 September (Balaswamy and Kulkarni, 2001).

According to Pandey *et al.* (2001) the planting on 20 July and 5 August were equally effective for grain yield, however, when the planting was delayed to 20 August, the reduction in grain yield was $26.97\text{ kg ha}^{-1}\text{ day}^{-1}$. Singh and Singh (2000) inferred that grain yields in all the three years as well as pooled grain yields were significantly highest under 15 March sowing and drastic reduction (25.7%) in grain yield was observed when sowing was done on 15 April.

Pandey *et al.* (2001) observed that early planting on 20 July resulted in significantly higher grain yield than with delayed planting on 5 and 20 August.

Manjappa and Kumar (2002) concluded that the two years average grain yield was maximum (7533 kg ha⁻¹) with earliest planted crop (30 June).

Pattar *et al.* (2001) registered significantly higher grain yield during early planting (first fortnight of August) than late planting (first fortnight of September). The yield decreased significantly with delayed planting on 30 July and 14 August by 15.8 and 27.8% in 1st year and 18.8 and 30.6% in 2nd year, respectively than 15 July transplanting (Patel, 1999).

Reddy (2002) reported that highest grain yield were recorded on 16 August transplanting and which was significantly superior to 1 and 16 September transplanting.

Nayak *et al.* (2003) conducted a field experiment to find out the response of hybrid rice 'PA 6201' to dates of planting (16, 31 July and 16 August) and reported that a fortnight delay in planting from 16 July reduced the grain yield by 7.6 and 4.5 per cent during first year and second year, respectively. One month delay in planting from 16 July reduced the grain yield by 24.3 per cent.

Noorbakhshian (2003) stated that both early and delayed planting dates, compared to the optimal date, would reduce rice grain yield in all regions.

Groth and Lee (2003) reported that planting rice after the optimum dates can result in higher disease and insect pest incidence, tropical storm related lodging and possible cold damage during heading and the grain filling period resulting in low yields.

Dixit *et al.* (2004) conducted an experiment on rice hybrid 'Sahyadri' at Maharashtra and observed that 25 June planting showed significantly highest grain yield (53.22 q/ha) than that planting on 5, 10 and 15 June.

Ghosh *et al.* (2004) reported higher grain yield with early planting of rice and delayed planting reduce the yield significantly.

Verma *et al.* (2004) studied the response of hybrid rice 'PA 6201' to date of planting and found that early planting on 20 July produced significantly higher 11 grain yield than late planting on 5 and 20 August.

Different authors used different sowing dates to check contrasting temperature regimes in various summer crops including rice (Rahman *et al.*, 2004; Rahman *et al.*, 2007; Rauf *et al.*, 2007; Safdar *et al.*, 2008; Basal *et al.*, 2009). They concluded that early sowing dates coincided with reproductive phase heat stress while late sowing helps to escape from heat stress. Therefore, early sowing is considered as the vector to reduce the growth and yield.

Dongarwar *et al.* (2005) reported that early transplanting on 15 and 30 July resulted significantly higher grain yield 31.29 and 32.61 q/ha, respectively than late transplanting on 15 August (28.40 q/ha).

Alizadeh and Isvand., (2006) stated that the growth season duration and temperature average have significant effects on rice yield during different growth stages; therefore, planting date plays a substantial role in rice production.

Iqbal *et al.*, (2007) reported that the highest yield was obtained when the rice crop was sown earlier in the season.

Shahzadet *al.* (2007) concluded that although delayed planting causes grain yield to decrease but promotes the grain's protein content. Delayed planting caused a reduction in grain yield due to shortening of the growth period duration.

Habibullah *et al.* (2007), Safdar *et al.* (2008) and in most of the cases, neither too early nor too late sowing proved to give better yield response by offering prolonged growth period while eliminating chances of heat stress during reproductive growth (Hassan *et al.*, 2003; Baloch *et al.*, 2006; Laborte *et al.*, 2012).

Vange *et al.* (2009) conducted an experiment with the aim of studying the effect of sowing date (15 June, 30 June, and 15 July) on grain yield of rice. The sowings on 30 June resulted in the highest yield of 3.32 mg/ha, while the sowings on 15 July gave the least yield of 1.46 mg/ha.

Youssef *et al.* (2011) conducted the Field experiments during the two successive seasons of 2008 and 2009, under different sowing dates (5, 15 and 25 May). Cultivated in early sowing date 5th May gave maximum values for yield and its component. But, cultivated in late sowing date 25th May gave minimum for these characters in two seasons.

Lack *et al.* (2012) conducted a research in order to investigate the effects of planting date 5th May, 25th May, and 15th June on grain yield. The second planting date exhibited the highest grain yield with an average of 6018.3 kg ha⁻¹ and the first planting date and the third first planting assumed the lowest grain yield 3506.7 kg ha⁻¹ and 5418.5 kg ha⁻¹ respectively.

Dawadi and Chaudhary (2013) carried out a field experiment to study the effect of sowing dates (29 May, 13 June, 29 June and 13 July) on growth and yield of rice. Rice sown on June 13 produced significantly higher grain yield (3.84 t ha⁻¹) compared to other sowing dates.

Kaveh and Hamdollah (2013) conducted a field experiment to evaluate the effect of different planting dates (25 May, 9 June and 25 June) on grain yield of rice genotypes. Early planting (22 May) resulted in reducing the grain yield while the maximum value was observed in 25 June planting date.

Moradpour *et al.* (2013) investigated the effect of planting date on important physiological traits that affected rice grain yield. Results showed that most grain yield was related to May 30th and June 9th planting dates (6357 and 6264 kg ha⁻¹ respectively). Least grain yield was obtained in June 19th planting date (5576 kg ha⁻¹).

Kumar *et al.* (2013) reported that grain yield of aromatic rice was

significantly higher with 16 July transplanting (3.91 t/ha) compared to 26 July (3.76 t/ha) and 6 July transplanting (3.57 t/ha).

Mukesh *et al.* (2013) conducted field experiment and revealed that early transplanting dates (25 June and 10 July) increase the grain yield (3.5 and 3.4 t/ha) of basmati rice as compared to late transplanting (25 July).

2.1.4 Straw yield and harvest index

The delay in transplanting beyond second fortnight of July caused considerable reduction in straw yield of rice crop (Parihar *et al.*, 1995; Gohain and Saikia, 1996; Hari Om *et al.*, 1997).

Straw yield was highest in 25 June planting crop, followed by 5 July (Hari Om *et al.*, 1999). Patel (1999) advocated that delay in transplanting significantly decreased the straw yield. Similar finding were reported by Singh and Prasad (1999) from Uttranchal.

Singh and Parsed (1999), Hari *et al.* (1999), Pirdashfy *et al.* (2000) found that delaying sowing decreased the grain, straw yield, harvest index, tiller number, panicle length, number of grain/panicle and fertility percentage.

Singh *et al.* (2000) observed maximum straw yield and harvest index from 7 July transplanting as compared to transplanting on 22 July. However, harvest index of rice increased under late sown conditions reported by Siadat *et al.* (2004).

Ahn *et al.* (2000) found that delaying sowing decreased the grain, straw yield, harvest index.

Under late sown conditions of Ramnad, Tamil Nadu Suresh *et al.* (2001) found significant reduction in straw yield. Singh and Singh (2000) recorded highest straw yield in early sown crop (15 March).

2.2 Effect of genotypes

By definition, each cultivar or variety of a cultivated crop species should differ from other varieties of the species in one or more specific characteristics. There is need for assessing desirable functional traits for achieving high yield, along with seasonal stability indices and locations. Variability indices of different varieties showed that certain indigenous cultivar possessed some better desirable characters i.e. number and length of panicle, seed per panicle, flowering duration and seed weight, which can be used as donor for improvement programme (Devi and Borua, 2002).

2.2.1 Growth characters

George *et al.* (1993) at Wayanad India obtained maximum height of 142.0 cm in WND2 variety during *kharif* and 109.0 cm in Edavaka variety during *rabi*. Singh and Singh (2000) recorded significantly highest height at maturity in Pant Dhan Majhera 7 (102.7 cm) followed by VL Dhan 206 (100.7 cm) and Majera 3 (98.8 cm).

Bali *et al.* (1995) in their experiment on clay loam soil at Khudwani, Kashmir reported that among different rice genotypes the 'Jhelum' was significantly taller than 'Chenab' but were at par with 'K-39'.

Bali *et al.* (1995) recorded highest LAI in rice cultivar 'SKAU 27 (Jhelum)' than 'SKAU-23 (Chenab)' and 'SKAU-5 (K-39)'

A field experiment with thirty IET lines including a few varieties were raised on clay loam soils at Bangalore resulted that leaf area index differed markedly among genotypes (Nanja Reddy *et al.*, 1995).

Zada *et al.* (1996) reported from Swat Pakistan that the maximum productive tillers hill⁻¹ produced by Basmati 385 (15.37) followed by variety J.P. 5 (13.44). The cultivars MO4 significantly recorded the highest number of effective tillers hill⁻¹ (10.15) and during second year it was closely followed by Cul 23332-2 (George *et al.*, 1993).

Wu and Wilson (1996) conducted field experiment to evaluate dry matter (DM) accumulation and partitioning on three high yielding rice cultivars, Rosemont, Gulfmont and Teqing during the growing season in rice. Results indicated that DM accumulation and partitioning to the different plant parts was similar for each tiller group and cultivar.

Miah *et al.* (1996) reported that compared with low-yielding varieties, high-yielding varieties had higher accumulation of assimilates before heading and greater translocation of these materials during grain filling.

Singh *et al.* (1997) reported that among the rice genotypes 'Rau 4045-10', 'IR 36', and 'Pusa 2-21', productive tillers m⁻² were recorded highest in 'IR 36' at Ranchi, Bihar.

Hari Om *et al.* (1997) in their experiment at Kaul, Haryana observed that hybrid rice variety 'PMS2A/IR 31802' produced highest number of productive tillers m⁻², which was at par with hybrid 'ORI 161' but significantly higher than 'PMS10A/PR 105' and 'HKR 126'.

Hari Om *et al.* (1997) in two year study during wet season at Kaul, Haryana revealed that among four hybrid genotypes of rice 'ORI 161', 'PMS 2A/IR311802', 'PMS10A/PA 105', and 'HKR 126', the highest dry matter accumulation was recorded in 'ORI 161' followed by 'PMS2A/IR31802', 'HKR 126' and 'PMS10A/PR105'.

Singh *et al.* (1998a) recorded maximum plant height in cv. 'NDGR 24' (161.0 cm) followed by 'Madhukar' (152.0 cm), 'Barh Avarodhi' (149.0 cm) and 'Chakia 59' (147.0 cm).

Sitaramaiah *et al.* (1998) observed that the LAI increased from 15 to 60 days after planting (DAP) and hybrids recorded a higher LAI from 30 DAP onwards as compared to control varieties 'Samba Mahsuri' and 'Chaitanya'. In the two year study at Karimganj, Assam, Chaudhary (1999) reported that LAI was

highest in rice variety 'Karsalah' (5.0 in 1994 and 3.8 in 1995) followed by 'IR 36' (4.7, 2.8) and 'Rasi' (4.3, 2.6).

In a study at Pusa, Bihar, Singh *et al.* (1998 b) found that the cultivars 'IET 8002' significantly produced more number of effective tillers than 'Rajshree', 'Radha', 'Pankaj', 'IET 5760', and 'IET 5914'.

Sitaramaiah *et al.* (1998) reported that the hybrids 'MTUHR 203', 'MTUHR 2020', and 'MTUHR 2037' achieved significantly higher biomass production than other genotypes.

Siddiqui *et al.* (1999) reported that in Raipur, Madhya Pradesh at harvest the cv. Suraksha achieved the maximum plant height of 110.0 cm and lowest measured in cv. R 296-260 (98.0 cm).

Effective tillers plant⁻¹ were recorded highest in rice genotypes 'Suraksha' than 'Karanti', 'Mahamaya', and 'R 296-260' (Siddiqui *et al.*, 1999).

In a field experiment, Surekha *et al.* (1999) tested four rice hybrids, 2 of early ('MGR 1' and 'KRH 1') and other 2 of mid-duration ('APRH 1' and 'APRH 2') using 2 checks ('Rasi' and 'Jaya') at Hyderabad. Among the early hybrids 'MGR 1' produced significantly higher tiller than 'Rasi', in the short duration group, 'APRH2' produced significantly more tillers than 'Jaya' followed by 'APRH 1'.

In a study conducted at IRRI, Philippines revealed that the tillering rate of hybrids was significantly lower than or equal to the conventional varieties between transplanting and mid tillering and between mid tillering and panicle initiation in different years and seasons (Laza *et al.*, 2001). The NPT (New Plant Type) x indica lines have more tillers than NPT lines (Peng *et al.*, 2000).

Suresh *et al.* (2001) observed that the number of productive tillers were significantly higher in cultivar 'PMK-2' than 'ASD 17', 'ADT 36', 'RMAS 90003', 'AS 33773' and 'AS 33714'.

Ghosh (2001) working in West Bengal observed that the values of height were higher in hybrids. Among the cultivars of rice hybrids, the plant height was significantly highest in 'ORI 161' (136.6 cm).

Yang *et al.* (2001) reported that cultivar 'JND 13' exhibited a higher dry weight of single holes before heading when compared with 'JND 3'.

The cultivar 'JND 13' achieved a higher leaf area index after heading compared with 'JND3' (Yang *et al.*, 2001).

High yielding hybrid combinations exhibited LAI of 6.5-7.0 at full heading and of 3.5-4.0 at maturation (Xu *et al.*, 2001).

Yang *et al.* (2002a) observed that both new plant type (NPT) and inter sub-specific hybrid rice (IHR) showed higher dry matter accumulation from heading to harvest than the three-line indica hybrid 'Shanyou 63'.

Zhai *et al.* (2002) conducted an experiment conducted at Nanjing, China revealed that the capacity of dry matter production before and after heading was remarkably higher in super high yielding rice cv. 'Xieyou 9308' (the yield of up to 12 t ha⁻¹) than 'Xieyou 63'. The above ground dry matter of J/IHs (Japonica/indica hybrids) was 12.3 Mg ha⁻¹ at heading, which was 38.2% and 1.6% greater than that of their parents and the IVHs (inter varietal hybrids) respectively. The dry matter accumulation of J/IHs was 9.4 Mg ha⁻¹ during ripening phase, which was 52.9 and 73.8% greater than that of their parents and IVHs, respectively.

Zhong *et al.* (2002) revealed that LAI and Plant N status are two major factors that influence tiller production in rice crops. Among the yield components of rice, tiller account for 61% of production.

Yang *et al.* (2002b) found that high yielding hybrid combinations produced a biomass yield of 18, 750 kg ha⁻¹ at maturation.

Xian-qing *et al.* (2003) used super hybrid rice Liangyoupeijiu and Zhongyou to analyze the relationship between specific leaf weight and photosynthetic rate at panicle initiation stage under different transplanting densities. Results showed that there was significant difference in the specific leaf weight and photosynthetic rate under various densities. The linear and positive relationship between the specific leaf weight and photosynthetic rate was observed from the same material.

Yadav and Rao (2003) conducted a field experiment at Chhattisgarh revealed that among cultivars 'IET-7564, 'IET-9219, 'IET-7614, 'IET-7613', 'KET-6155' and Poomima, the highest plant height was attained by 'IET-7564 (110.2 cm).

In a study at Gwalior, Madhya Pradesh, Singh *et al.* (2004) obtained more plant height in Mahamaya than 'IR 64'.

Laza *et al.* (2004) conducted a field experiments at the IRRI Farm in the wet season of 2000 and 2001 resulted that among different cultivars, the highest biomass was produced by 'PSBRc 30' and 'PSBRc 72H' which was significantly different from the lowest biomass in 'IR58' and 'PSBRc 10'. Youssef *et al.* (2011) experimented to study the performance of some rice cultivars (Sakha 101, Sk. 2034 H1 and Giza 178). The data indicated that, there were significant differences between rice cultivars in each growth parameter Plant height (cm); Flag leaf angle (°); Flag leaf area (cm²).

Khalifa (2009) conducted an experiment on four hybrid rice H1, H2, GZ 6522 and GZ 6903. H1 hybrid rice variety surpassed other varieties number of tillers m⁻², plant height and root length at PI and HD stage, chlorophyll content, number of days to PI and HD, leaf area index and sink capacity.

Alam *et al.* (2009) carried out an experiment to study the relative performance of inbred and hybrid rice varieties (BRRI dhan 29, Aloron and Hira-2) the result indicated that Variety did not influence the relative growth rate at all

the growth duration. However, numerically the highest RGR value was observed with Aloron variety and the lowest from the variety BRRI dhan 29 at all the growth duration.

Larijani (2010) conducted a two year experiment has in the Caspian Sea coastal area in Iran and examined the effect three rice cultivars on leaf appearance rate and total leaf number of rice, Fajr and Ghaem with 16.1 leaves had highest, and the short-duration variety Tarom with 14.8 leaves had lowest number of leaves on the main stem at fully emergence of the flag leaf stage.

Jahan1 and Adam (2011) revealed from an experiment that number of leaves per plant increased at all the ages except at 30 DAS in case of BRRI dhan-29 (V1) than BRRI dhan-50 (V2) and variation was significant at 60 DAS.

Jahan and Adam (2011) conducted a pot experiment on cultivar BRRI han-29 (V1) and BRRI dhan-50 (V2). Results showed Relative growth rate (RGR) was maximum at early stage of growth and then declined in both the varieties. RGR was significant during 0 to15 and 45 to 60 DAS in case of V1.

Khalifa and El-Rewainy (2012) conducted a field research to evaluation in between rice varieties (*Oryza sativa* L.) Sakha 106, Sakha 105, G.Z 7576, G.Z. 9057 and G.Z. 9362 under five sowing dates. Main results induced that the Sakha gave the highest value on root length (cm), leaf area index, No. of tillers/hill at panicle initiation, chlorophyll content at heading development while G.Z. 9362h gave the lowest value.

Safdar *et al.* (2013) experimented on eight medium grain rice 999421, KSK 401, KSK 402, PK 7797-1-2-1, KSK 301, KSK 418, KSK 406 and KS 282 to access their growth and yield performance under earlier, mid and late sown conditions.

Azarpour *et al.* (2014) study the effects level of nitrogen fertilizer on yield and physiological traits of rice cultivars (Khazar, Ali Kazemi and Hashemi). Results indicated that Khazar cultivar had the highest RGR and after that Ali-

Kazemi and Hashemi cultivars had the highest RGR. Relative growth rate of Khazar cultivar was lower than two other cultivars until 50 days after sowing but after that it was increased considerably.

Khalifa *et al.* (2014) tested on cultivars Sakha 101, Sakha 103, Sakha 104 found that Sakha 101 gave the highest leaf number, leaf area index, chlorophyll content, panicles length, number of panicles per hill leaf area index, chlorophyll content. while, Sakha 103 inbred rice gave the lowest value of all traits under study.

2.2.2 Yield attributes

Bali *et al.* (1995) reported that rice variety ‘SKAU-27 (Jhelum)’ produced higher number of panicles per unit area (342.5 m^{-2}) than ‘SKAU-23 (Chenab)’ and ‘SKAU-5 (K-39’), however, the difference was insignificant.

Bali *et al.* (1995) reported that different genotypes of rice ‘SKAU 5 (K-39)’, ‘SKAU 23 (Chenab)’ and ‘SKAU 27 (Jhelum)’ did not registered any significant difference in 1000-grain weight.

In a field trial at Hyderabad, Singh and Pillai (1995) recorded maximum panicle number in variety ‘Katarni’ followed by ‘Karnal local’ and ‘Basmati 370’ and lowest in ‘Ranbir Basmati’.

Dhiman *et al.* (1997) observed that, panicle m^{-2} were significantly higher in ‘HKR 228’ than ‘RP 2144’.

Dhiman *et al.* (1997) found significantly highest grains panicle⁻¹ in ‘HKR 228’ (99) and lowest in ‘RP 2144’ (85) during 1992 only.

Singh *et al.* (1998b) recorded highest number of panicle m^{-2} in rice variety ‘Barh Avarwdhi’ followed by ‘NDGR 24’, ‘Madhukar’ and ‘Chakia 59’.

According to Singh *et al.* (1998b) rice cultivar ‘IET 8002’ produced highest number of panicles m^{-2} than ‘IET 5760’, ‘IET 5914’, ‘Rajshee’, ‘Radha’ and ‘Pankaj’.

The rice cultivars showing insignificant difference in 1000-grain weight were also reported by Singh *et al.* (1998b).

Gangwar and Sharma (1998) conducted two years experiment and reported that the difference between rice varieties regarding number of panicle m^{-2} was insignificant in first year, but differed significantly in the next year.

In a study Sitaramaiah *et al.* (1998) observed more grains panicle⁻¹ in hybrids compared to Samba Mahsuri and Chaitanya.

Dhiman *et al.* (1999) in their experiment at Kaul, Haryana on 12 rice varieties, highest number of grains panicle⁻¹ recorded in 'HKR126' than other varieties.

Vange *et al.* (1999) reported that a field experiment conducted at Makurdi, Nigeria during 1994-95 to evaluate 10 early duration rainfed lowland rice genotypes showed significant variation in grains panicle⁻¹ and 1000-grain weight ranged from 116 to 155 and 22.4 to 30.9 g respectively.

Singh *et al.* (1999) reported that mean maximum panicle number (335 m^{-2}) was recorded in genotype 'Vikas' followed by 'IET 9994'.

According to Vange *et al.* (1999) the panicle m^{-2} ranged from 140 to 233 in ten early duration rainfed lowland rice genotypes.

Siddiqui *et al.* (1999) reported that number of grains panicle⁻¹ in different varieties was in the order: 'Karanti' (104) $\geq$ 'R296-260 (104)' > 'Suraksha' (100.5) > 'Mahamaya' (98).

Peng *et al.* (2000) reported that Cultivar developed between 1974 and 1983 (IR30, IR36, IR50 and IR60) produced more panicles than old cultivars such as IR8, PB176, IR20 and IR26.

Singh *et al.* (2000) reported that among the different rice genotypes 'SKAU-27 (Jhelum)' gave significantly more number of grains panicle⁻¹ (80.3) than 'SKAU-23 (Chenab)' but remained at par with 'SKAU-5 (K39)'.

Bhowmick and Nayak, (2000) reported that performance of hybrid variety 'CNHR2' was superior in terms of number of panicles m^{-2} than 'CNHR3', 'IR 36' and 'IR 54').

Singh and Singh (2000) recorded significantly higher values of yield attributes, viz., panicle length, grain panicle⁻¹ and 1000-grain weight in 'Pant Dhan Majhera 7' than 'Majhera 3' and 'VL Dhan 206'.

Suresh *et al.* (2001) revealed among different varieties, the number of grains panicle⁻¹ and test grain were significantly more in 'PMK 2'.

Ganajaxi *et al.* (2001) observed significantly higher mean panicle weight and 1000 grain weight from 'IET-13549' when compared with 'Pusa basmati' and 'Taraori basmati'.

Ghosh (2001) studied the performance of 4 rice hybrids (CNHR 3, Pro Agro 6201, PDSH 35 and GK 5006) and 4 high yielding rice cultivars (MW 10, IET 4786, IR 50 and Parijat). In general, hybrids gave higher value for panicle length and number of filled grains panicle⁻¹ compared to other cultivars.

Ganajaxi *et al.* (2001) recorded significantly more number of panicles m^{-2} in genotype 'IET-13549' as compared to 'Pusa basmati 1' and 'Taraori basmati'. Under the low hill conditions of Uttaranchal, among different varieties, 'Pant Dhan Majhera 7' recorded significantly higher panicles m^{-2} than 'Majhera 3' and 'VL Dhan 206' (Singh and Singh, 2000). Surekha *et al.* (1999) reported that among rice hybrids 'MGR 1' produced highest number of panicle m^{-2} .

Yang *et al.* (2001) reported that in a study at Jilin, China, the cultivar JND3 showed higher panicle number than JND 13.

Yang *et al.* (2002a) reported that the number of total spikelets of new plant type and inter sub-specific hybrid rice was 15.59% and 28.21% higher than that of three-line hybrid of 'Shanyou 63'.

Laza *et al.* (2004) conducted a field experiments at IRRI Farm in the

2000 and 2001 wet season and revealed that there was large difference in panicle number among the cultivars, IR 58 and IR 60 produced about 40% more panicles than PSBRc 54 and PSBRc 80.

In a study with 14 IRRI-released conventional indica-type and two indica-indica F₁ hybrids cultivars, Laza *et al.* (2004) obtained low to intermediate panicle size ranging from 63 to 114 spikelets panicle⁻¹ among cultivars.

Having studied the relationship between the yield and yield components of 17 rice cultivars, Mesbah *et al.* (2004) inferred that grain yield has a positive and significant correlation with the number of grains per panicle, the number of filled grains per panicle, and the 1000 grain weight.

Khalifa (2009) conducted an experiment on four hybrid rice H1, H2, GZ 6522 and GZ 6903. H1 hybrid rice variety surpassed other varieties number of grains per panicle, Panicle length (cm), 1000 grain weight (g), number of panicles per M², five Panicle weight (g).

Youssef *et al.* (2011) experimented to study the performance of some rice cultivars (Sakha 101, Sk. 2034 H1 and Giza 178). The data indicated that, there were significant differences between yield characters rice cultivars Days to heading (day); Number of panicles/hill; Panicle length (cm); Panicle weight (g); Number of filled grains/panicle; Seed set percentage; 1000- grain weight (g). Sakha101 rice cultivar gave highly significant value to 1000-grain weight.

Lack *et al.* (2012) investigated on the rice cultivars Hamar, RedAnbarbou, and Danial. The results showed that cultivars significantly affected 1000 grain weight, fertility percentage, the number of filled grains per panicle and the number of fertile tillers.

Khalifa and El-Rewainy (2012) conducted a field research to evaluation in between rice varieties (*Oryza sativa* L.) Sakha 106, Sakha 105, G.Z 7576, G.Z. 9057 and G.Z. 9362 under five sowing dates. Main results induced that the Sakha

gave the highest value of yield attributes number of tillers/m² at maturity stage, Panicle length (cm), Number of grains/panicle, 1000-grains weight (g).

Mukesh *et al.* (2013) revealed that dwarf varieties differ significantly in respect of panicles/m². Pusa Sughandha 4 recorded the maximum number of panicles/m² followed by Pusa Basmati, CSR 30 and Taraori Basmati. Number of grains/panicle did not differ significantly due to time of transplanting.

2.2.3 Grain yield

Bali *et al.* (1995) working under temperate conditions of Kashmir reported that grain yield of rice genotypes ‘K-39’ (56.7 q h⁻¹), ‘Chenab’ (57.3q ha⁻¹) and ‘Jhelum’ (58.6 q ha⁻¹) in both years as well as pooled data showed insignificant variation.

At Hyderabad, Singh and Pillai (1995) observed that the grain yield of traditional scented varieties differed significantly during the first and third year of investigation. On an average, variety ‘Katarni’ recorded the highest grain yield of 2.87 t ha⁻¹ followed by ‘Karnal local’ (2.82 t ha⁻¹), ‘Basmati 370 (2.64 t ha⁻¹) and ‘Ranbir basmati’ (2.61 t ha⁻¹).

Zada *et al.* (1996) recorded the maximum paddy yield from variety ‘Swat-3’ (6.42 t ha⁻¹) followed by ‘JP5’ (5.79 t ha⁻¹) and minimum was from ‘IR-25865-124-3-3’ (5.14 t ha⁻¹).

Hari Om *et al.* (1997) found that hybrid ‘ORI 161’ produced 7, 23 and 13% and 12, 27 and 21% higher grain yield than ‘PMS2A/IR31802’, ‘PMS10A/PR106’ and ‘HKR 126’ in 1993 and 1994 respectively.

Singh *et al.* (1998a) reported that average grain yield of rice cultivar ‘Barhavaradhi’ (22.8 q ha⁻¹) was significantly higher than ‘NDGR24’, ‘Madhukar’ and ‘Chakia 59’.

In another two year study at Pusa, Bihar, Singh *et al.* (1998b) reported that rice variety 'IET 8002' (46.2 q ha^{-1}) produced highest grain yield during first year, however in second, variety 'Rajshree' (57.2 q ha^{-1}) recorded highest grain yield.

Siddiqui *et al.* (1999) recorded higher grain yield in rice cultivar 'Mahamaya' (68.1 q ha^{-1}) than other cultivars.

Ganajaxi *et al.* (2001) tested three genotypes at Mugad in which 'IET-13549' recorded significantly higher yield (30.8 q ha^{-1}) when compared with 'Pusa basmati 1' (24.2 q ha^{-1}) and Taraori basmati (19.2 q ha^{-1}).

Yang *et al.* (2002b) conducted a field trial at Jiangsu province of China during the rice growing season (May-October) of 1998, 1999 and 2000 concluded that the three hybrids '02428/Yangdao 4', 'PC311/IR36' and 'PC311/Minghui 63' had the greatest yield ($12.6\text{-}12.9 \text{ Mg ha}^{-1}$, respectively) among the 36 Japonica/indica hybrids.

Laza *et al.* (2003) reported The highest yield of 546 g m^{-2} produced by 'IR73409 H' in 1998 (wet season), while 'IR71623 H' recorded the maximum yield of 719 g m^{-2} in 1999 dry season.

Laza *et al.* (2004) reported that the cultivar 'PSBRc 26H', 'PSBRc 72H' and 'PSBRc 26H and 'PSBRc 80' produced highest yield in the 2000 wet season and 'PSBRc26H' and 'PSBRc 80' produced highest yield in the 2001 wet season.

El-Khoby (2004) found significant variations among rice cultivars in growth, yield attributes and grain yield.

Dingkuhn *et al.* (2006) under the same management, the interaction between the genotype and the environmental characteristics is the sole determinant of varietal performance.

Khalifa (2009) conducted an experiment on four hybrid rice H1, H2, GZ 6522 and GZ 6903. The result indicated that H1 hybrid rice variety produced highest grain yield (t/ha) than other varieties.

Messina *et al.* (2009) the final yield of a given cultivar depends on the interaction between the genotypes, its responses to environmental conditions, and management practices.

Youssef *et al.* (2011) experimented to study the performance of some rice cultivars (Sakha 101, Sk. 2034 H1 and Giza 178). The data indicated that Sk.2034 H1 rice cultivar gave highly significant to another cultivars in grain yield t/ha.

Khalifa and El-Rewainy (2012) conducted a field research to evaluation in between rice varieties (*Oryza sativa* L.) Sakha 106, Sakha 105, G.Z 7576, G.Z. 9057 and G.Z. 9362 under five sowing dates. Main results induced that the Sakha gave the highest Grain yield/ha except light penetration it was the lowest value. While G.Z. 9362h gave the lowest grain yield/ha.

Lack *et al.* (2012) investigated on the rice cultivars Hamar, RedAnbarbou, and Danial. The results showed that cultivars significantly affected grain yield. Danial and Hamar cultivars featured the highest grain yield with averages of 5591 and 5549 kg ha⁻¹ respectively; the lowest amount belonged to Red Anbarbou cultivar.

Limochi and Eskandari (2013) conducted an experiment to evaluate the effect of rice genotypes (Short Red-Anbory, Long Red-Anbory and Champa). Results indicated that the highest grain yield was achieved for Champa (3795.4 kg ha⁻¹).

Mukesh *et al.* (2013) revealed that Pusa Sughandha 4 recorde highest grain yield compared to Pusa Basmati, CSR 30 and Taraori Basmati.

2.2.4 Straw yield and harvest index

Bali *et al.* (1995) observed that the varietal variations were insignificant in case of straw yield.

Hari Om *et al.* (1997) reported that hybrid cultivar 'ORI 161' (68.6 q ha⁻¹) gave significantly higher straw yield than other genotypes.

Sitaramaiah *et al.* (1998) recorded significantly higher harvest index in hybrids 'MTUHR 2033', MTUHR2020' and MTUHR2037' than other genotypes.

Singh *et al.* (2000) found significantly maximum straw yield in genotype 'Sugandha' (40.4 q ha^{-1}) than other genotypes; however harvest index was more in 'Pusa basmati 1' (46.5%).

Peng *et al.* (2000) also indicated that the yield improvement of rice cultivars released before 1980 was associated with increase in harvest index, while the yield improvement after 1980 was due to increases in biomass production.

According to Suresh *et al.* (2001) rice variety 'PMK2' (42.8 q ha^{-1}) recorded significantly highest straw yield and lowest was in 'AS 33714'.

Ganajaxi *et al.* (2001) revealed that in a study, among three genotypes, 'IET-13549' produced significantly higher straw yield (43.1 q ha^{-1}) when compared with 'Taraori basmati' (36.3 q ha^{-1}) and 'Pusa basmati-1' (33.5 q ha^{-1}).

Results from the study of Laza *et al.* (2003) suggested that harvest index is more important than biomass production in determining grain yield under sub-optimum conditions.

Laza *et al.* (2004) conducted a field experiments at the IRRI Farm in 2000 and 2001 wet season showed that among different cultivars the average harvest index was highest in 'PSBRc 10' (49.9%) and lowest in 'PSBRc 30' (36.3%) with the difference being significant.

Lack *et al.* (2012) investigated on the rice cultivars Hamar, Red Anbarbou, and Danial. The results showed that cultivars significantly affected biological yield and harvest index.

Khalifa *et al.* (2014) found that Sakha 101 had highest value, straw yield (t/ha) and harvest index, while Sakha 103, Sakha 104 gave the lowest value.

2.3 Phenology

Crop phenology plays a vital role in defining crop growth duration, biomass partitioning and finally crop production. Phenology is the study of plant growth and development with respect to the timing of various growth stages. Accurate prediction of crop phenology is important for modeling, crop improvement and management actions (Yin *et al.*, 1997).

Accurate prediction of crop phenology is important for modeling, crop improvement, and management actions (Yin, 1996).

Yin *et al.* (1996) reported that day temperature (T_d) has a greater influence on development rate as compare to night temperature (T_n).

The number of days to flowering is always modulated by temperature, regardless of the photoperiod and of the genotype (Wallace and Yan, 1998).

Dingkuhn and Asch (1999) reported that Changing the planting date may shift thermo-sensitive phenological stages (panicle initiation or booting) of the rice crop into thermally critical environments which could either prolong the duration, delay flowering, or may severely reduce yields due to poor source or sink formation and spikelet sterility.

A specific growth stage (e.g., flowering) is reached when a certain number of degree-days (Tsum) have been accumulated (Dingkuhn and Asch, 1999).

Ahn *et al.* (2000) observed delay in heading as sowing was delayed from 20 April to 30 May.

Peng *et al.* (2000) reported that the total growth duration was shortest for the cultivars released between 1974 and 1983, 10 days on average shorter than cultivars developed before and after this period. Genotypic difference in the duration of grain filling was smaller than the duration of vegetative and reproductive phases.

Singh and Singh (2000) from Uttaranchal reported that days taken to 75%

heading were not affected significantly by different sowing dates (15 March, 30 March and 15 April).

Norman *et al.* (2000a and 2001b) showed that seeding date primarily influences the length of the vegetative growth period of rice in Arkansas with early seeded rice requiring a greater number of days to accumulate the same number of degree-day units compared with later-seeded rice.

Lee *et al.* (2001) from Korea reported that days from sowing to flowering were shortened as sowing dates were delayed from 25 April to 5 June in field and phytotron experiment.

Biradarpatil and Shekhargouda (2001) reported that the number of days to 50% flowering was highest in December sown crop (114.8) and lowest in August sown crop (99.1).

Butler *et al.* (2002) reported that climatic factors are among uncontrolled agents whose individual variations lead to changes in crop growth conditions. Therefore, it is necessary to determine the thermal requirement of different phenology stages in order to maximally benefit from crops' production potential.

Mandal and Ghosh (2003) reported that the cultivars sown on 10 June, 25 June and 10 July in West Bengal showed that the time taken for maturity ranged from 116.2 to 120.8 days for the different sowing dates and 105.0-127.3 days for the different cultivars.

Hayat *et al.* (2003) reported that the delayed sowing results in the poor emergence and reduces panicle heading per meter square and spikelets per panicle and ultimately yield is affected.

Linscombe *et al.* (2004) conducted experiments at two locations (near Crowley and St. Joseph) of Louisiana revealed that days from seedling emergence to 50% panicle emergence decreased at both locations as planting was delayed, whereas interaction of planting date by cultivars was not significant for number of Julian days from seedling emergence to 50% panicle emergence at either location.

Halder *et al.* (2004) conducted a field experiment in Bangladesh revealed that the development of PI stage among cultivars (Nizersail, BR 11 and BR 22) differed only by one day. Nizersail completed heading stage between 31 October and 9 December when transplanted during 1 August-1 October. BR 11 completed heading between 24 October and 18 November when transplanted during 1 August-1 September. BR 22 completed heading by 2 November-20 December when transplanted between 1 August and 7 October.

A field experiment conducted in Maharashtra during *kharif* season showed that panicle initiation stage was initiated late in early sown crop (5 and 10 June) and 50% flowering was earlier in late crops (25 June) and among the different hybrid rice parents, 827-35-1-1-R required more number of days from flag leaf emergence, booting stage, 50% flowering and maturity stage compared to other lines (Dixit *et al.*, 2004).

Khalifa (2005) found that number of days from sowing up to maximum tillering, panicle initiation and heading date was significant affected by different sowing dates. The number of days was higher under early sowing (April 20th) and gradually decreased with delayed sowing up to May 20th.

Khanal (2005) reported that crops require a specific amount of heat to develop from one point in their life-cycle to another.

Khanal (2005) has conducted an experiment in Lumle, Nepal, to study leaf appearance rate in rice (Khanal, 2005) and found temperature dependency of earlier leaves; with increasing mean air temperature reducing the number of days required for the first leaf to appear. He concluded that development stages of leaves were affected differentially by planting dates.

Dehghan (2007) mentioned that variation in planting date might influence crop yield through affecting phenology in vegetative and the reproductive growth stages.

Shimono *et al.* (2007) asserted that the minimal temperature of 12 °C is vital for 30 days after sowing rice for producing suitable seedling, and the temperature below 12°C brings about poor germination, low seedling vegetation and reduction in desirable seedling growth.

Khalifa (2009) conducted a field experiment under different sowing dates, April 10th, April 20th, May 1st, May 10th, May 20th and June 1st. Results indicated that early date of sowing (April 20th) is the best time of sowing for important properties such as maximum tillering (MT), panicle initiation (PI), heading date (HD), number of tillers per M², plant height and root length at PI and HD stage, chlorophyll content, number of days to PI and HD.

Khalifa and Rewainy (2012). Conducted Field research for 2 year 2009 and 2010 to evaluation in between rice varieties (*Oryza sativa* L.) under five sowing dates April 1st, April 10th, April 20th, May 1st and May 10th. Results induced that sowing date at April 1st gave the highest value on number of days from sowing up to maximum tillering, panicle initiation and flowering dates. While May 10th gave the lowest value for all Phenological stages.

Khalifa and El-Rewainy (2012) conducted a field research to evaluation in between rice varieties (*Oryza sativa* L.) Sakha 106, Sakha 105, G.Z 7576, G.Z. 9057 and G.Z. 9362 under five sowing dates. Main results induced that the Sakha gave the highest value on number of days from sowing up to maximum tillering, panicle initiation and flowering dates. While G.Z. 9362h gave the lowest value.

Khalifa *et al.* (2014) tested on cultivars Sakha 101, Sakha 103, Sakha 104 found that Sakha 101 gave the highest number of days to maximum tillering, panicle initiation, heading dates. Sakha 103 inbred rice gave the lowest number of days to above phonological characteristics.

2.4 Nitrogen content and uptake

Nitrogen nutrition due to the considerable impact on growth parameters and physiological traits of rice is important. The percentage of light penetration,

photosynthesis active radiation, light use efficiency, dry matter partitioning to different parts are affected by the amount of nitrogen.

Nitrogen is converted into amino acids, the building blocks of proteins which perform both structural and enzymatic functions in all living organisms, including plants. Translocation of N in plants occurs in the form of amino acids; the amino acids are ordered into proteins mostly in the leaf blades although it also takes place in roots (Matsubayashi *et al.*, 1963). It also varies with soil condition, growing season and varieties maturity duration.

Pandey and Aggarwal (1991) reported that as compared to normal transplanting, delay in transplanting by 15 days reduced the nutrient content and uptake in grain and straw.

Dey and Chandra (1994) reported that N content increased from panicle initiation to flowering in all cultivars except 'Mahsuri'.

Bali and Uppal (1995) reported that uptake of N, P and K at panicle initiation and flowering stages was recorded highest from 10 July transplanting as compared to late transplanting of 30 July.

Osaki (1995) examined N content of rice, which decreased significantly at the primordia formation stage.

Hasegawa and Horie (1996) reported that a hydroponics culture experiment, showed that photosynthetic rate increased with increasing leaf N concentration and decreased with plant age, after reaching a peak before panicle initiation.

Aggarwal *et al.* (1997) concluded that if plant N status can be increased without lodging or disease problems, a significant increase in yield requires increased sink capacity, maintenance of high leaf N content and a longer grain filling duration.

Nitrogen is normally a key factor in achieving optimum lowland rice grain yields (Fageria *et al.*, 1997).

Li *et al.* (1997) found that the nitrogen content decreased during panicle initiation and heading.

Singh *et al.* (1998b) reported that nitrogen content and uptake differed significantly between the varieties. The highest nitrogen content (1.12%) and uptake (99.4%) was recorded in genotype 'Rajshree' followed by 'IET 9002', 'Radha', 'Pankaj', 'IET 5914' and 'IET 5760'.

Moriwaki (1999) indicated that excessive plant N and reduced carbohydrate content around meiosis resulted in an abnormal development of pollen grains, which caused spikelet sterility.

Ohsumi *et al.* (2002) reported that the leaf N content of all the genotypes measured declined with the development stage from the panicle initiation and there was quite a large genotypic difference in leaf N content.

De *et al.* (2002) reported that among 14 aromatic rice cultivars, along with a local control cultivar (Tulsibhog), the highest total N uptake (83.60 kg ha⁻¹) recorded in local control cultivar (Tulsibhog).

The relationship between N absorption and N utilization was studied on 17 rice cultivars by Dong *et al.* (2002).

Cho and Kobata (2002) observed a close relationship between spikelet numbers and N content of the plant at heading and between grain yield or shoot dry weight and N content of the plant at maturity.

Yoshida *et al.* (2003) found large genotypic differences in spikelet production efficiency per unit plant nitrogen accumulated 2 weeks before full heading in rice.

In a study at Coimbatore, Geetha and Thiyagarajan (2003) reported that under zero N treatment, leaf N allocation during active tillering-panicle initiation

was negligible for ‘ADT 36’ and ‘ASD 20’, but was 23% in ‘ASD 16’.

The total N and protein N contents in the functional leaves and straw sheaths decreased gradually with progressing stage of growth in the filling stage (Peng *et al.*, 2003).

Ookawa *et al.* (2003) from Japan indicated that the higher nitrogen content in the leaves of cultivar ‘Akenohoshi’ was due to the greater accumulation of nitrogen in the plant before heading and during the ripening stage, and the more effective partitioning of nitrogen to leaves during the ripening stage, which resulted in the maintenance of a high rate of photosynthesis during ripening.

The results of Zhang *et al.* (2004) showed that the N accumulation at heading of high yield type cultivars was significantly higher than those of middle or low yield type cultivars.

Roy *et al.* (2004) observed high N concentration in genotype ‘BR31’ and the lowest was in ‘BR29’.

Janaki and Thiyagarajan (2004) conducted a field experiment at Coimbatore, Tamil Nadu revealed that the reduction in N content was most pronounced up to 35 days after transplanting, after which the value became almost linear up to flowering stage.

Significant variations in N content of different lines of rice were found when the plants reached at maturity stage. The higher the grain out put was, the lower the N content. Field experiments conducted on a sandy clay loam soil, New Delhi showed that N uptake and apparent recovery (AR) of applied N was significantly higher in rice hybrid PRH 3 than the HYV Pusa 834 (Kumar and Prasad, 2004).

The results of Sheehy *et al.* (2004b) showed that the total nitrogen absorption by the plant was high when the fraction allocation to the grain was low and vice-versa. About 30% of the total nitrogen in the grain was acquired before

panicle initiation (45 days after transplanting) and leaves acted as the main reservoir for nitrogen.

Jiang *et al.* (2004) reported that increase in N accumulation increased grain protein content and number of effective panicles but reduced seed setting rate.

Nitrogen (N) is essential for rice, and usually it is the most yield-limiting nutrient in irrigated rice production around the world (Samonte *et al.*, 2006).

Fageria (2007) reported that dry matter partitioning to the reproductive organs depends on number, capacity and activity of physiological sinks.

Zhang *et al.* (2009) nitrogen application increases the pre -anthesis dry-matter accumulation by increasing the number of tillers, LAI, pre-anthesis crop growth rate and translocation to grains.

2.5 Crop Simulation Models

Engineers have used system analysis and simulation for many years and their success with this approach has inspired biologists, agronomists and agro meteorologists to apply similar techniques in their disciplines. The approach can be described by the term systems simulation and models.

2.5.1 System

A system is an isolated part of the real world composed of one or more components and processes selected for the study. The nature of the subject and the objective of the study define the system. System behavior is the sum of all processes or changes in the system. Agricultural systems are called continuous dynamic systems because they exhibit gradual behaviour change.

2.5.2 Model

A model is a simplified representation of system. In the physical science the term “model” is used to provide an explanation for certain phenomenon and to

postulate underlying processes which give rise to the observations under inspection.

2.5.3 Simulation

Simulation is the art of building the mathematical model and the study of its properties with reference to those of the system it represents.

Simulation models are being widely used to simulate the growth of crops and to predict crop yield. Therefore, models take into account the physical, chemical and physiological mechanism underlying crop growth processes. If the basic plant processes viz. production and distribution of dry matter and weather relationships are properly understood, the entire response of the plant to meteorological conditions can be simulated. Simulation provides an insight into crop weather relationship, explains why some factors are more important for growth and yield than other. Through the crop growth simulation modelling it became possible to simulate a living plant through the mathematical and conceptual relationships that govern its growth in the soil plant atmosphere continuum.

Crop growth models can be categorized as qualitative model and quantitative model. Qualitative models represent the conceptual relationship and feedback among the various components of the system. While quantitative models, are the translations of a qualitative model into a computer programme.

The quantitative models can be further subdivided into static or dynamic models. Some typical examples of static models are respiration and its dependence on biochemical processes, dependence of light interception on leaf properties, solar radiation and so on. Dynamic models are obtained when the time dimension is introduced. Static models are often part of dynamic model. In agricultural systems all major elements (such as leaf area, root length, dry weight) change with time or in space in response to changing external factors such as weather, fertilization or irrigation.

Crop growth models have been used to determine potential and attainable yields for a given level of inputs for various crops (Angus, 1989). Rickman *et al.* (1996) reported that the simulation provides appearance time and size estimates for each above ground plant parts (leave, stem, spikes and kernels), length and mass of roots with depth and time, occurrence of phenological events (germination, emergence, tillering, single ridge, double ridge, jointing, boot, heading, anthesis, soft dough, mature and harvest ripe), rate and amount of water evaporated and transpired, uptake of nitrogen from the soil profile and estimate of daily net photosynthesis. Strengths of the simulation model include that it predicts date for all crop phenological stages; it estimates size for all plant parts on a daily basis for comparisons with almost any observed field data. It is organized according to the natural structure of the system being simulated and it is designed to be changed.

Crop growth models have been used to determine the potential yield and attainable yields for a given level of inputs for various crops (Angus, 1989; Van lanen *et al.*, 1992).

Crop simulation models are effective tools for assessment of growth and yield of crops as well as to suggest optimal resource management options (Kalra and Aggarwal, 1995); desired cultivar characteristics (Aggarwal *et al.*, 1997); inter-seasonal climatic variability impacts (Aggarwal and Kalra, 1994); performance evaluation of weather forecasts (Kalra and Aggarwal 1996, Singh *et al.*, 1997).

2.6 Application of Crop Simulation Models

Most crops have greater potentiality than is being realized through existing agronomic practices. Crop production can be improved by improving our understanding of interaction between crop and its environment viz. weather, soil and other biological factors. According to Boote *et al.* (1996), there are three types of primary uses of crop models as:

2.6.1 CSM Application for Understanding Crop and its Environment Interaction

Crop simulation model is used as research tools e.g. synthesize research understanding; integrate knowledge across discipline, experiments documentation, yield gap analysis and assistance in genetic improvement of crop.

Aamir and Sinclair (1990) developed a model to analyze the effect of temperature and solar radiation on spring wheat using the relationships to defined leaf area development as a function of temperature and biomass as a function of intercepted radiation. They used daily weather data of solar radiation, minimum and maximum temperature over a ten-year period at Gilast, Israel for simulations. The study indicated the influence of temperature on the development of crop leaf area, biomass accumulation and grain yields.

2.6.2 CSM Application for Crop management

Crop simulation model is used for in-season decision aid for Water fertilizer and cultural management. It is also used for precision farming.

Dingkun *et al.* (1991) reported the use of crop growth simulation models in which nitrogen partitioning patterns were modified in flooded rice crop to simulate the hypothetical genotypes of rice plant. Thus they studied the interaction of physiology and breeding to design alternative plant types by use of modeling.

A number of crop modeling groups have attempted to optimize water and nitrogen management over long term historical weather years (Hodges *et al.*, 1987; Keating *et al.*, 1993; Aggarwal and Kalra, 1994). Models used for this purpose must have reliable soil water and soil nitrogen balance components. These optimization efforts can suggest the best long term strategy for water and nitrogen application (often growth stage dependent) and also show that enhanced

decisions can be made if additional information such as future weather forecast or leaf tissue testing were available.

Aggarwal and Kalra (1994) used a wheat simulation model to show that delay in sowing date decreased wheat yield in India.

2.6.3 CSM Application for Policy Design

It includes assistance in form of best management decisions to reduce fertilizer and pesticide leaching and soil erosion, yield forecasting and evaluating the effects of climate factors.

Abbaspour *et al.* (1992) demonstrated the use of crop simulation model for deciding crop insurance premium policy for wheat and barley in two locations north and South Peace River regions in British Columbia, Canada. He developed a crop risk model consisting two components a relative yield model and a risk analysis module. The estimated prediction standard errors for wheat were 0.34 t ha⁻¹ in the North and 0.26 t ha⁻¹ in the south; while for barley standard prediction errors were 0.21 t ha⁻¹ and 0.31 t ha⁻¹ in the North and South areas, respectively. The estimates of crop losses ranged from 20 to 61 per cent for wheat and 14 to 16 per cent for barley.

Simulation models are used increasingly for environmental characterization and agro-ecological zoning (Aggarwal, 1993), defining research priorities, technology transfer (Jones, 1993), estimating production potentials (Aggarwal, 1998), strategic and tactical decision making (Angus *et al.*, 1993; Kalra and Aggarwal, 1994) and for predicting the effects of climate change and climatic variability (Adams *et al.*, 1990; Aggarwal and Sinha, 1993).

Timsina *et al.* (1998) used the CERES-Wheat and CERES-Rice models to quantify the phenology, yield and yield components of rice and wheat cultivar response. The simulation results indicated that without nitrogen fertilizer applications, nitrogen would be limiting across sites and long-term weather conditions for both rainfed and irrigated crops.

2.7 CERES Rice Model

The CERES (Crop Environment REsource Synthesis) model is a dynamic crop growth model, which predicts status of crop on real time basis as a function of exogenous parameters. It consists of four major sub-routines namely, Water balance, Nitrogen balance, phenology and growth (Varshneya *et al.*, 1996). CERES model contains genetic coefficients, which describe the development of any genotype influenced by environmental factors such as maximum and minimum temperature, day length and rainfall (Ritchie and Algarswammy, 1989 a and b).

The CERES rice model under Punjab conditions predicted phenological stages quite close to observed stages for rice cv. PR-106 and PR-109. Comparing the yield and yield contributing characters with those of model predictions, it was found that the prediction varied from 10.9 to 8.34% of the observed yield (Jand *et al.*, 1994).

Rao and Subash (1996) compared the actual and simulated grain yield with CERES-Rice model at Kerala. Simulated and actual yields agreed well in the 1993 *kharif* season, while simulated yield was higher than that observed during *kharif* 1994.

The CERES-rice simulation model was used to simulate the response of dry land rice in the North Pacific Region of Costa Rica to several climatic scenarios that represent global warming characteristics. The results showed a strong relationship between temperature and duration of the period between sowing and flowering and found different responses to the increase in temperature when maximal or minimal temperature considered; therefore mean temperature would not be adequate (Villalobos and Retana, 1997).

A simulation model was used by Aggarwal *et al.* (1997) to examine the opportunities for increasing irrigated rice yield in the dry season of a tropical climate by altering durations of juvenile and panicle formation phases, specific

leaf area, maximum leaf N concentration, spikelet growth factor and potential grain weight. The simulations predicted that significantly higher rates of N input and precise timing are required to attain a grain yield potential greater than 10 t ha⁻¹ and concluded that if plant N status can be increased without lodging or disease problems, a significant increase in yield requires increased sink capacity, maintenance of high leaf N content and a longer grain filling duration.

In a study, Saseendran *et al.* (1998) determined optimum transplanting dates for rice at five locations in Kerala by using CERES-Rice V 3.0 and ClimProb (a PC-based software package). Under rainfed conditions, the optimum transplanting dates were from the 23rd to 26th week for multiple cropping in a year, and from the 26th to 32nd week for a rainfed monocrop.

In Punjab, India, Hundal and Kaur (1999) used the CERES-Rice model and results showed that the optimum date of transplanting for rice was June 15, but the earlier transplanted (June 1) rice may perform better if seedling age is reduced from 40 to 30 days. Young transplanting seedlings (20 and 30 days old) proved better than older (40 days) seedling. An increase in plant population from 11 to 44 hills m⁻² and an increase in number of seedlings hill⁻¹ from 1 to 6, showed an increasing trend in rice yields as simulated by the model.

The CERES-Rice model was used to predict physiological impact of genetic manipulation under the environments of Yangtze Valley China. The results indicated that increasing single grain weight has a positive effect on yield and negative effect on grain number. Increasing spikelet production potential greatly increases grain number and yield. Decreasing tillering ability reduces spike number, but increased grain number, yield and single stem weight up to a peak (Du and Cao, 1999).

Saseendran *et al.* (2001) Realising the importance of utilising the highly advanced techniques in agricultural research, the CERES-Rice v 3.0 crop growth simulation model has been calibrated and validated for the agroclimatic conditions

of Kerala. Validation studies showed that the model is able to predict the phenological occurrence of the crop fairly well to enable the farmers to take crop management decisions related to it.

In Thailand, Cheyglinted *et al.* (2001) found that the model reasonably simulated the phenology and yields of the RD23 and KDML105 cultivars.

Kerdsuk (2002) found that the model was able to simulate suitable planting time and yield potential of KDML105 under natural rainfall and irrigation in Tung Samrit area, Nakhon Rachasima province, Thailand.

The comparison of two popular rice growth models, Ceres-Rice and ORYZA 1N under same input conditions resulted that both predicted satisfactorily the trends of leaf area and dry matter growth, grain number, days to flowering and grain yield. Simulated yields were within +15% of the measurements (Mall and Aggarwal, 2002).

A simulation model for phasic development and phenology in rice was developed using the scale of physiological development time based on the ecophysiological development processes. The stages of emergence, panicle initiation, heading and maturity were validated using the data of sowing dates under different ecological environments, with root mean square error of 1.47, 5.10, 4.58 and 3.37 days, respectively (Meng *et al.*, 2003).

Timsina *et al.* (2004) calibrated and validated the recently released version 4.0 of CERES Rice model and showed that the model performed satisfactorily in terms of grain yield and N uptake when simulated results were compared to data from field experiments from 3 locations in northwest India. Potential yields ranged from 10.0 to 10.8 Mg ha⁻¹ across the three locations, compared with research station yield of 6.2 to 7.8 Mg ha⁻¹ and farmer average yield of 3.3 to 5.6 Mg ha⁻¹.

At Himachal Pradesh, Kumar and Sharma (2004) by using CERES-Rice model reported that the association between actual and simulated data on number

of days to flowering and physiological maturity was significant. The model failed to simulate the number of panicle m^{-2} . However, the number of grains m^{-2} , single grain weight, grain yield, straw yield and harvest index were satisfactorily simulated and the association between simulated and actual data on these parameters was significant.

The application of CERES-Rice model in Bangladesh showed that average potential yield of 6077 kg ha^{-1} and 4217 kg ha^{-1} obtained, when transplanted on 15 July and 15 August, respectively (Mahmood *et al.*, 2004).

Yao *et al.* (2005) showed that the model could simulate days to anthesis, grain number, yield and biomass in diverse agro-environments of China.

CSM-CERES-Rice is widely used as a technological tool to support strategic decision-making (Sarkar and Kar, 2006).

Singh *et al.* (2007) in the temperate Kashmir valley in India noted that the model could be used to estimate crop productivity and optimize management practices.

Sreenivas and Reddy (2007) conducted a field experiment under 3 different planting dates and 5 nitrogen levels to assess the impact of modified weather on yield and biomass of rice using CERES-Rice at Agricultural Research Institute, Acharya N. G. Ranga Agricultural University, Hyderabad. The per cent error was 7 and -11.4% in grain yield when crop was planted on 25th July and 29th August, respectively.

Min and Zhi-qing (2009) used the CERES-Rice to upscale the genetic parameters. The results showed that the best fitness was obtained by using the Method. The coefficients of correlation between the simulated yield and the statistical yield were significant at 0.05 or 0.01 levels and the root mean squared error (RMSE) values were less than 9% for all the four rice regions.

Kumar *et al.* (2010) carried out investigation to investigate the CERES model validations for rice at different dates of transplanting (5th July and 25th July)

and different varieties. The simulation modelling was subsequently validated against observed data from field experiment. Among the transplanting dates 5th July transplanting was better in comparison to 25th July transplanting.

Tragoolram *et al.* (2011) calibrated and validated the CERES-Rice model to assess the impact of climate change on the rice production in Khon Kaen province and to analyze impacts of climate change on rice production under different weather condition. The results have shown that the temperature and precipitation in the future fluctuate according to the year, which is quite hard to elucidate. After the year 2010, the temperature decrease and slightly fluctuate. It also can be seen that the rainfall varies with years, and so does the rice yield.

Vilayvong *et al.* (2012) evaluated the ability of CSM-CERES-Rice to simulate responses of lowland rice cultivars to different N-fertilizer applications in a tropical area. Experiments on 4 planting dates (July 6, August 5, and September 9, 2010 and January 14, 2011) were conducted in Khon Kaen province, Thailand. The results for model calibration showed that the derived genetic coefficients provide simulated values of phenological events, biomass accumulation and grain yields that were in good agreement with their corresponding observed values.

Ahmad *et al.* (2012) used CSM-CERES-Rice for identifying the optimal combination of plant density and N levels for rice production in Pakistan.

2.8 Climate change

Climate is one of the major controlling factors for the well-being of the residents of the world. Global climate has been changing due to natural forcing as well as anthropogenic activities, especially emissions of greenhouse gases and aerosols, and land use changes in recent decades. Climatic factors such as temperature, rainfall, atmospheric carbon dioxide, solar radiation etc are closely link with agriculture production. Therefore, rice production would be major concern in recent years due to changing climatic conditions, because there is a

significant amount of rice yield may hamper for only fluctuations of those climatic parameters.

Mechanistic crop growth models are useful tools to study the impact of climate change on crop growth and yield in diverse agro-environments. Several models of rice are now available. Ceres-rice (Singh *et al.*, 1993) and ORYZA series (Drenth *et al.*, 1994) are two popular models that are widely used in several countries. Few studies based on such models have been conducted in recent years to assess the likely effects of climate change on rice production in Asian regions. Some of these focused on the aggregated response of the whole country or continent (Karim *et al.*, 1991; Matthews *et al.*, 1995) or considered the effect of temperature changes without including the influence of CO₂ (Okada, 1991).

In Bangladesh, the impact of climate change on high yield rice varieties was studied by Karim *et al.* (1994), using the CERES-Rice model and several scenarios and sensitivity analysis. They found that high temperatures reduced rice yields in all seasons in most arid locations; the detrimental effects of temperature rise more than offsets the positive effect of increased CO₂ levels.

Much research has reported that high temperatures, variable rainfall, floods, droughts and cyclones would cause a significant decrease in world food production, especially in developing countries (Rosenzweig and Parry 1994; Parry *et al.*, 1999; Reilly *et al.*, 1999; Gregory *et al.*, 2005).

According to Rosenzweig and Hillel (1995), air temperature and atmospheric CO₂ concentration will directly affect plant growth through photosynthesis and respiration. Higher CO₂ concentration in the atmosphere, to a certain extent, enhances photosynthesis.

Plant growth is very sensitive to temperature. Often a difference of a few degrees in temperature leads to a noticeable change in growth rate (Rosenzweig and Hillel, 1995).

Amien *et al.* (1996) found that rice yields in east Java could decline by 1% as a result of increases in temperature.

Mahmood (1997) estimated the effects of temperature variations on Boro rice applying the YIELD model for 12 major rice growing districts. The results suggest the planting date plays an important role in the yields of Boro rice.

Mahmood (1998) compared the relative performance of the YIELD and the CERES-RICE models for temperature increases and rice productivity. In this study, the productivity estimates of the CERES-RICE model appeared to be more responsive to a small rise in temperature than the YIELD model.

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Amien *et al.* (1999) Simulated rice yields as affected by interannual climate variability and possible climate change in Java. In the higher rainfall and lower temperature of the West Java site, the climate change scenarios reduced rice grain yield in both the first and second crops. During normal years in the relatively warmer and dryer climate of the East Java site, there was no significant yield reduction due to climate change. Because high temperature and CO₂ concentration favour rice growth, development of more heat-tolerant varieties probably can compensate for the yield losses due to climate change in the future.

Parry *et al.* (1999) projected the impact of climate change scenarios, developed from the HadCM3 global climate model, on crop production, yield and the risk of hunger. The results from their research indicate that crop yields will decline significantly both regionally and globally, due to the expected large increase in temperatures globally.

Agricultural crop production might be significantly affected by the predicted changes in climate and atmospheric CO₂. Elevated CO₂ alone increases plant photosynthesis, and thus increases crop yields (Tubiello *et al.*, 2000).

The predicted changes in temperature and precipitation might further affect crop yields, by hastening plant development, and by altering the water and nutrient budget in the fields, and modifying plant stress (Tubiello *et al.*, 2000).

Matsui *et al.* (2000) increase in temperature increased spikelet sterility due to reduced pollen viability at flowering stage and shortens grain filling phase which in turn effects on grain quality.

Amthor (2000) reported that Plant maintenance respiration increases with increasing temperature and that a greater rate of maintenance respiration reduces the amount of assimilates available for growth and yield.

Saseendran *et al.* (2000) showed that for every one degree rise in temperature the decline in rice yield would be about 6%.

Rice is particularly responsive to increased carbon dioxide concentration. High carbon dioxide concentrations also increase water use efficiency (Hunsaker *et al.*, 2000).

Climate change is expected to significantly impact on global agricultural production. This will occur because agricultural production is highly dependent on climate and is adversely affected by increasing anthropogenic climate change and climate variability (Smit *et al.*, 2000; IPCC 2007; Chandrappa, *et al.*, 2011). Therefore, weather patterns considerably affect crop production.

Temperature increases and erratic rainfall patterns affect crop agriculture most directly and adversely (Lansigan *et al.*, 2000; Rosenzweig and Tubiello 2007; Almaraz *et al.*, 2008).

Several studies using temperature gradient tunnels (TGTs), crop simulation models, and field experiments have been conducted to evaluate the

effects of climate change particularly to temperature increase, and/or doubled CO₂ concentration on crop (rice) growth and development (Lansigan, 2001).

High carbon dioxide levels increase plants' resistance to salinity and drought, and increase nutrient uptake (Kaya *et al.*, 2001).

At elevated CO₂ the carboxylation rate increases which will increase photosynthesis of C₃ plants. Studies with rice have indicated that elevated CO₂ generally increases tiller number, photosynthesis, biomass and grain yield as well as plant nitrogen (N) uptake and biological N fixation (Cheng *et al.*, 2001; Kim *et al.*, 2001).

High temperature stress disrupts the biochemical reactions fundamental for normal cell function in plants. Water availability is expected to be highly sensitive to climate change and severe water stress conditions will affect crop productivity. In combination with elevated temperatures, decreased precipitation could cause reduction of irrigation water availability and increase in evapotranspiration, leading to severe crop water-stress conditions (IPCC, 2001).

Mathews and Stephens, (2002) the relationship between climate changes and agriculture is particularly important issue, as the world's food production resources are already under pressure from rapidly increasing population.

The phenological seasons of natural vegetation have also been shown to change spatially and temporally in response to trends in climate change by using the observed data from phenological networks (Zheng *et al.*, 2002).

The responses of natural vegetation to climate change have been investigated by analysing satellite data, including changes in vegetation greenness, phenology (Zhang *et al.*, 2004), and net primary production (NPP).

The potential impacts of climate change on natural and managed ecosystems are of concern and have been extensively evaluated by various simulation models (Parry *et al.*, 2004), but few studies have examined how rising temperatures have actually affected crop development and production in the field.

In Germany, a shift in phenology of fruit trees and field crops due to increased temperature from 1961 to 2000 has been observed, but the changes in plant development are still moderate so no strong impacts on yield formation processes have been observed so far (Chmielewski *et al.*, 2004).

In the Philippines, rice grain yield was found to decline by 10% for each 1 °C increase in growing-season minimum temperature in the dry season (January–April) from 1992 to 2003 (Peng *et al.*, 2004).

When C3 plants, such as rice, are exposed to high CO₂ concentration, the net photosynthesis rate (*PN*) of their leaves is accelerated due to both enrichment of substrate CO₂ and inhibition of photorespiration by high CO₂ concentration (Long *et al.*, 2004).

Research done in important rice growing areas around the world show that rice yields are vulnerable to climate change (Ferrero and Nguyen, 2004).

Climate change may affect food systems in several ways ranging from direct effects on crop production (e.g. changes in rainfall leading to drought or flooding, or warmer or cooler temperatures leading to changes in the length of growing season), to changes in markets, food prices and supply chain infrastructure (Gregory *et al.*, 2005).

However, the stimulatory effect of high CO₂ concentration decrease gradually as the time of the exposure is prolonged (Gen-Yun Chen *et al.*, 2005).

Climate change directly affects all dimensions of food security: availability, accessibility, stability and utilization (Gregory *et al.*, 2005).

The anticipated changes in temperature and CO₂ have been modeled to have opposite effects on the Production. Increasing temperatures shortened the growing season leading to decreased yields, while elevated CO₂ increased the yields (Erda *et al.*, 2005).

Sheehy *et al.* (2006) used the models ORYZA2000 and EEQ to estimate

the effect of temperature change within -2 to +2°C on change in yields under constant daily irradiance and concluded that the yield decrease is 0.5 t/ha or 6%/ha from a base yield at 26°C.

Tao *et al.* (2006) synthesized crop and climate data from representative stations across China during 1981–2000 to investigate whether there were significant trends in changes of climate variables in different regions, and whether these changes have had significant impact on the development and production of the staple crops (i.e. rice, wheat, and maize). Results showed that significant warming trends were observed at most of the investigated stations and the changes in temperature have shifted crop phenology and affected crop yields during the two decades. The observed climate change patterns, as well their impacts on crop phenology and yields are spatially diverse across China.

The IPCC (2007) report corroborated previous scenarios that by 2100 mean planet-wide surface temperatures will rise by 1.4 to 5.8°C, precipitation will decrease in the sub-tropics, and extreme events will become more frequent.

Climate change affects agriculture and food production in complex ways. It affects food production directly through changes in agro-ecological conditions and indirectly by affecting growth and distribution of incomes, and thus demand for agricultural produce. Impacts have been quantified in numerous studies and under various sets of assumptions (IPCC, 2007a).

However, changes in climate are already being observed—the last 60 years were the warmest in the last 1000 years and changes in precipitation patterns have brought greater incidence of floods or drought globally (Wassmann and Dobermann, 2007).

Some studies have demonstrated that the distribution of food supplies in different parts of the world might also be affected greatly by climate change (Schmidhuber and Tubiello, 2007).

Climate change represents an additional pressure on the world's food

supply system and is expected to increase yields at higher latitudes and decrease yields at lower latitudes (IPCC, 2007).

Rashid and Islam (2007) identified drought, flood, soil salinity and cyclone as the major extreme climatic events which affected agricultural operations and production adversely.

Insufficient rainfall leads to greater drought frequency and intensity, while increased evaporation leads to complete rice crop failure (Reid *et al.*, 2007; Liu *et al.*, 2010).

Employing district level data, Sanghi and Mendelsohn (2008) showed that climate change was likely to cause huge damage in Brazil and India by 2100.

Assessment of the effects of global climate changes on agriculture might help to properly anticipate and adapt farming to maximize agricultural production (Fraser, 2008).

Down-regulation of photosynthetic activity under CO₂ enrichment is caused by decreasing leaf N concentration, and reduced rate of transpiration owing to decreased stomatal conductance was partially responsible for poor N translocation (Kanemoto *et al.*, 2009).

High night temperature during the reproductive growth stage reduced the stimulatory effect of elevated CO₂ on brown rice yield (Cheng *et al.*, 2009).

Crop agriculture is most vulnerable to extreme temperatures, droughts, cyclone, and salinity intrusion. These findings are consistent with those of Roy *et al.* (2009) and Karim *et al.* (1999).

Rimi *et al.* (2009) analysed the trend of climate variables for the 1950–2006 period and evaluated their likely impact on rice production in the Satkhira district, using the DSSAT crop simulation model. Trend analysis of seasonal rainfall revealed a statistically non-significant increasing trend of annual maximum and minimum temperature and annual total rainfall. The crop

simulation model showed that the yields of Aus, Aman and Boro rice were adversely affected by the rise in temperature, unpredictable rainfall, flooding, drought and salinity. However, the yield reduction was higher for Aus and Aman than that for Boro. This study also suggested some adaptive strategies such as developing crop cultivars tolerant to these hazards, increasing the use of short-duration crop varieties, shifting planting dates, and using raised bed and less water-consuming crops.

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Increased atmospheric CO₂ concentrations in the future, one of the major drivers of global warming, may also enhance plant growth through the fertilization effect since CO₂ is an essential component of photosynthesis (Watanabe and Kume, 2009).

Wassmann *et al.* (2009) climate change scenario indicate that temperature rise potentially affects rice grain yields through changes in metabolism and phenology.

Basak *et al.* (2010) assessed the impacts on the yields of BR3 and BR14 varieties of Boro rice for 12 districts using the DSSAT model. The model forecast an average yield reduction of over 20 and 50% for the two rice varieties for the years 2050 and 2070, respectively. The rise in daily maximum and minimum temperatures was found to be largely responsible for this yield reduction. This

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Wikarmpapraharn and Kositsakulchai (2010) CERES-Rice has been tested and applied for years. The result showed that both models predicted satisfactorily leaf area, days to panicle initiation, days to flowering and grain yields. Simulated yields were within $\pm 12\%$ of the measurements in term of RMSE statistical index. It might be concluded that CERES –Rice model, is adequate to simulated rice growth and development.

Yu *et al.* (2010) used a CGE model to explore the economy-wide impact of climate change. The study estimated an average of 7.4% reduction in long-term rice production every year during the simulation period of 2005–2050. This result showed a reduction in Aman and Aus rice production in all sub-regions. Climate variability and extreme climate 35 events have predominantly negative implications for Boro rice production and will hinder its capacity to compensate for the lost Aman and Aus rice production, further jeopardising the country's food security.

Climate change impacts are already being experienced through increasing temperatures, variable rainfall and climate related extreme events such as floods, droughts, cyclone, sea level rise, salinity and soil erosion (Asaduzzaman *et al.*, 2010; Yu, *et al.*, 2010; Hossain and Deb, 2011).

The increase in temperature shortens the phenological phases of crops (such as planting, flowering and harvesting) (Liu *et al.*, 2010; Roudier *et al.*, 2010; Teixeira *et al.*, 2011) and affects plant growth and development.

Changing climate over time affects rice crop production adversely (Behnassi and Yaya, 2011).

Climate change results in changes in long-term weather conditions globally. More explicitly, climate change denotes a significant statistical variation either in the average condition of the climate or in its variability that continues for long periods, typically decades or longer (Vijaya Venkata Raman *et al.*, 2011).

The fluctuations and occurrence of extreme climate events reduce rice yields significantly, particularly at critical crop growth stages (Teixeira *et al.*, 2011).

Shrestha *et al.* (2011) considering the effects of abiotic factors on developmental phases, lower temperature increase crop duration from germination to flowering.

Rainfall extremes, through droughts and floods are very detrimental to rice productivity. Higher and/or heavy rainfall results in higher yield losses through flooding, where as low rainfall may cause complete failure of crop due to moisture stress (Roudier *et al.*, 2011).

Shrestha *et al.* (2011) in high altitudes where low temperature is the main constraint, rice production will benefit from climate change induced temperature increase in terms of crop duration, grain yield, broader varietal choice and a widened window for introducing new crops into the cropping calendar.

El-Marsafawy *et al.* (2012) employed the DSSAT simulation model to measure the adverse impacts of climate change on some rice varieties at different agroclimatological zones in Egypt. Results recorded showed that deficit irrigation water could be reduced rice yield at Sakha area ranging from 41% up to 49% and in Gemmiza area the reduction will be ranged from 41 to 57%. The

change per cent in productivity of different rice varieties ranging from -34 to -47% at Gemmiza area and -26 to -36% at Sakha area compared with their productivity under current conditions. The most sensitive variety to water deficit was found for V3 which registered more reduction in rice yield. The highest tolerant variety to high temperature under future climate was found for V2 at the two areas.

Rahman *et al.* (2012) used the MRI-AGCM simulation model to simulate mean temperature and rainfall for the 2075–2099 period. They projected varying changes in rainfall across different seasons: 0.64% in monsoon, 1.90% in post-monsoon and 13.46% in winter. Their projection for the change in mean temperature was almost 2.5°C over the same period.

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Oteng-darko *et al.* (2012) calibrated and evaluated the CERES-Rice (Ver. 4.0) model for use in simulating rice yields under different climate change scenarios in Ghana using data from the Anum Valley Irrigation Project. Eighteen years of weather data (1989-2006) was used to run the model. The model was found to be sensitive to climatic parameters (temperature, CO₂ concentration, solar radiation and rainfall) and had various effects on rice. Simulations demonstrate that the effects of planting dates cannot be overlooked in finding measures to increase rice yield under climate change mitigations.

Chapter – 3

MATERIALS AND METHODS

The present investigation entitled “impact of climate change on different rice varieties under varied agroecological conditions of Kashmir using CERES-Rice model” was carried out at Agronomy Farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-Kashmir), Shalimar Srinagar during *Kharif* season 2011 and 2012. The details of climatic conditions, materials used and methods employed during the course of investigation have been described in this chapter.

3.1 Location of the experimental site

The Agronomy Farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir is geographically located at 34°-05′ N latitude and 74°-89′ E longitude at an altitude of 1587 meters above the mean sea level. The campus is situated 16 km away in north of Srinagar. The experimental field had fairly leveled topography and good drainage system.

3.2 Climate and weather conditions

Kashmir valley enjoys temperate climate of the country. The experimental site is in mid to high altitude humid temperate zone characterized by hot summers and severe cold winters. The annual precipitation ranges from 676 to 1193 mm with an average of 944.6 mm, most of the precipitation is received from December to April in the form of snow and rains as a result of western disturbances. The minimum and maximum temperature ranging between –8.0 to 33°C, exhibit considerable fluctuation both in summer and winter (Weather Observatory Records, Division of Agronomy, SKUAST-K, Shalimar).

The meteorological data prevailing during the experimental period in the year 2011 and 2012 was obtained from the meteorological observatory at Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar are presented in Fig. 1 and Appendix–I.

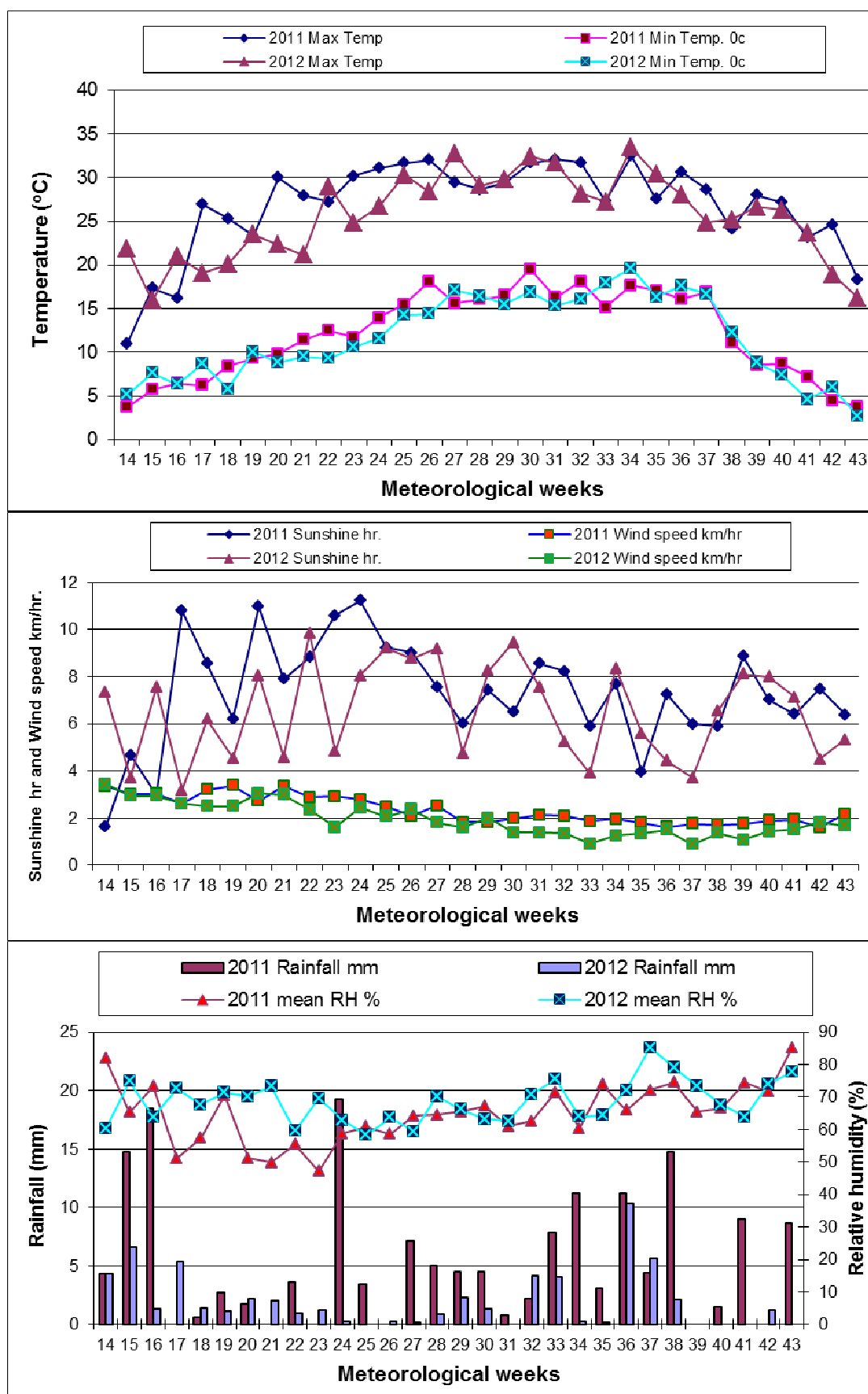


Fig. 1 : The temporal change in weather parameters during field experiment

3.3 Soil characteristics

In order to determine the fertility status of the soil and input data for CERES-rice model before sowing a composite sample were collected randomly up to 0-15 cm depth from various plots in the experimental field. The soil sample were mixed properly, dried under shade, ground and sieved through 2 mm sieve and subsequently analysed for physiochemical properties. The results of the soil analysis are presented in the Table 1.

Table 1: Physico-chemical properties of the soil of experimental field

Soil property	Value			Method employed
A) Mechanical analysis				
Coarse sand (%)	1.34			International pipette method (Piper, 1966). The textural class of the soil was determined from textural diagram (Black, 1965)
Fine sand (%)	17.35			
Silt (%)	44.08			
Clay (%)	36.46			
Texture	Silty clay loam			

B) Chemical analysis	0-15 cm	15-30 cm	30-45 cm	

Electrical conductivity (dS m ⁻¹)	0.07	0.08	0.10	1:2 soil water suspension with solubridge conductivity metre (Jackson, 1973)
pH	7.41	6.8	6.6	1:2.5 soil water suspension using systronics pH meter (Jackson, 1973)
CEC (c mol kg ⁻¹)	17.3	15.4	14.8	Leaching soil with neutral normal NH ₄ OAC (Jackson, 1973)
Organic carbon (%)	1.23	1.01	0.93	Wet digestion method [Walkley and Black's rapid titration method (Walkley and Black 1934)]
Available N (kg ha ⁻¹)	398.1	284.2	254.7	Modified Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg ha ⁻¹)	31.2	22.5	19.8	Extraction with 0.5 N NaHCO ₃ (Olsen <i>et al.</i> , 1954) using systronics spectrophotomter)
Available K (kg ha ⁻¹)	179	148	130	Extraction with neutral normal NH ₄ OAC using systronics flame photometer (Merwin and Peech, 1951)
Bulk density (g cm ⁻³)	1.38	1.44	1.52	Core method (Black, 1965)

3.4 Cropping history of the experimental field

The productive potential of the experimental field can be judged from its cropping history. During the 1st years of field experimentation rice crop was followed by brown sarson and during the 2nd year the field was kept fallow. The detail account of the cropping history of experimental field prior to the present experiment has been given in Table 2.

Table 2: Cropping history of the experimental field from 2006-2012

Year	Season	
	<i>Kharif</i>	<i>Rabi</i>
2006-2007	Rice	Brown sarson
2007-2008	Rice	Wheat
2008-2009	Rice	Wheat
2009-2010	Rice	Brown sarson
2010-2011	Rice	Wheat
2011-2012	Rice	Fallow

3.5 Experimental details

3.5.1 Experimental design and treatments

The experiment was laid out in split plot design with four replications having date of planting in main plots and cultivars in sub plots. Treatments were allotted in each experimental plot randomly. The details of treatments are given as:

Treatment details

A) Main plot treatment

Transplanting dates

1. 25 May (D_1)
2. 10 June (D_2)
3. 25 June (D_3)

B) Sub plot treatment

Cultivars

1. Shalimar rice-1 (V_1)
2. Jhelum (V_2)
3. SKAU-382 (V_3)
4. SKAU-341 (V_4)

Field experiments were conducted at three locations for validation of CERES-rice model.

1. Srinagar
2. Badgam
3. Anantnag

Data for climate change were used from five locations.

- 1 Srinagar
- 2 Badgam
- 3 Anantnag
- 4 Kokernag
- 5 Kupwara

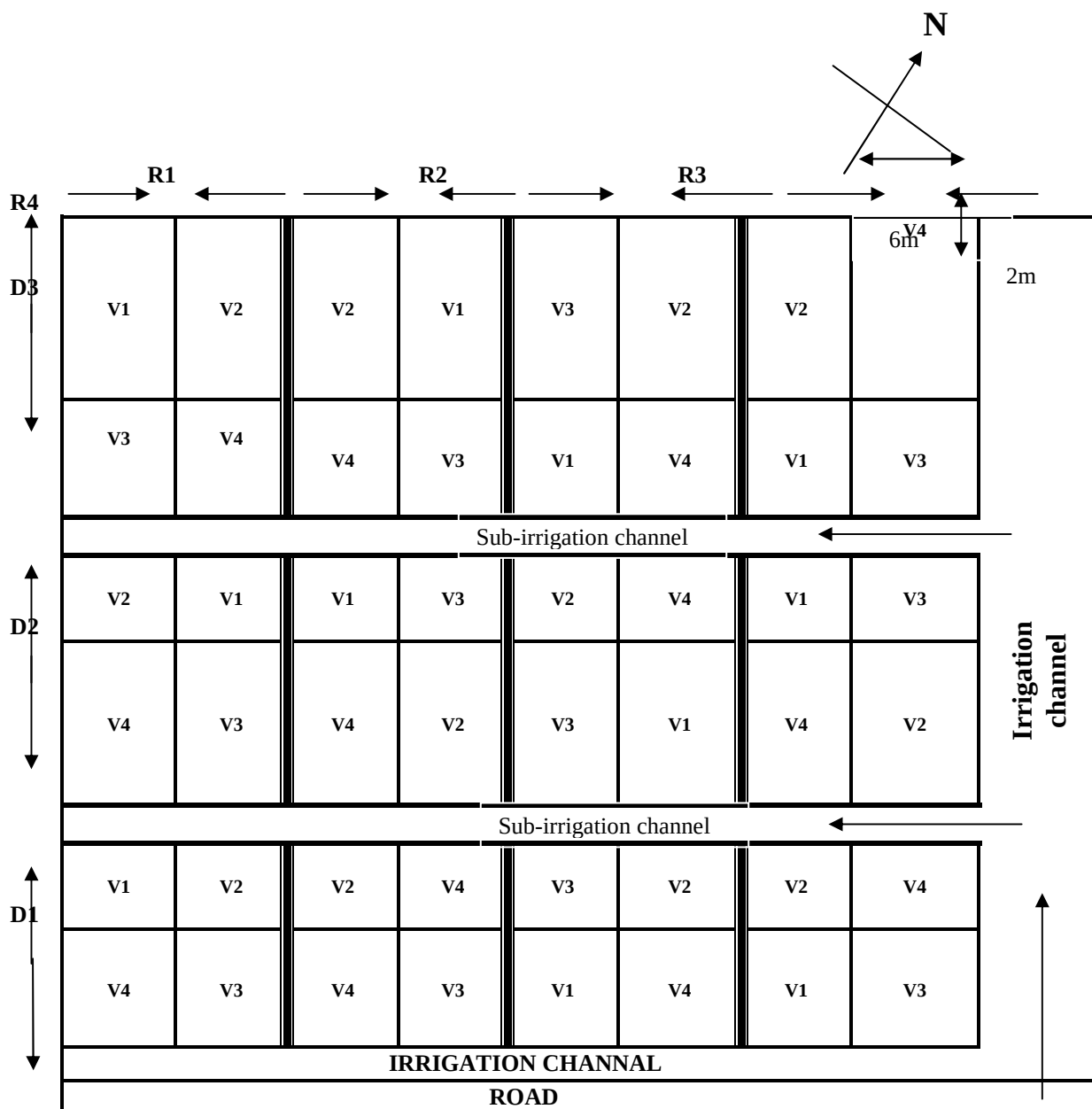


Fig. 2: Layout of rice varieties at different transplanting dates at Shalimar

Main plot : Date of Transplanting

D₁ = 25 May

D₂ = 10 June

D₃ = 25 June

Sub Plot : Varieties

V₁ = Shalimar rice-1

V₂ = Jhelum

V₃ = SKAU-382

V₄ = SKAU-341

Design : Split plot design; Replication : 4

Design	:	Split plot design
Replications	:	04
No. of treatment combinations	:	$3 \times 4 = 12$
No. of plots	:	$3 \times 4 \times 4 = 48$
Spacing	:	15x15 cm
Gross plot size	:	$6 \times 2 = 12 \text{ m}^2$
Net plot size	:	$5.40 \times 1.4 = 7.56 \text{ m}^2$

3.6 Brief description of cultivars

3.6.1 Shalimar rice-1

This variety is derived from a cross between “CH 1007” and “IET 1444” released in 2004. Its average plant height is 115 cm. It is highly tolerant to blast and matures in 145-150 days. Grains are short and slender. Its average yield is 72-78 q ha⁻¹.

3.6.2 Jhelum

It is a semi-dwarf high yielding rice variety released in 1996. The pedigree of this cultivar is “Jakkoku x IET 1444”. The average plant height is 117 cm. Its grains are medium bold with a good cooking quality. It matures in about 128-135 days and is recommended for cultivation up to an altitude of 1650 masl. Its average yield is 60-65 q ha⁻¹.

3.6.3 SKAU-382

It is a semi-dwarf rice variety released in 2012. The pedigree of this cultivar is “IR 32429-47-3-2 x K 438”. The average plant height is 117 cm. Its grains are medium bold with a good cooking quality. It matures in about 126-133 days. Its average yield is 58-63 q ha⁻¹. It is susceptible to helimenthosprium Brown spot disease caused by *Cochliobolus miyabeanus*.

3.6.4 SKAU-341

It is a tall rice variety. This variety is derived from a cross between “VL Dhan 221” and “K 39” released in 2012. Its average plant height is 125 cm. It matures in about 135-140 days.

3.7 Details of cultural operations

The details of various field operations during both years are given in Table 3.

Table 3: Details of cultural operations

Operation	2011			2012		
	25 May	10 June	25 June	25 May	10 June	25 June
Tractor ploughing	20 th May	-	-	20 th May	-	-
Tilling	22 nd May	-	-	22 nd May	-	-
Layout	23 rd May	-	-	23 rd May	-	-
Seed soaking for sprouting	20 th April	10 th May	26 st May	21 th April	10 th May	26 st May
Seed sowing in nursery	25 rd April	15 th May	30 th May	25 th April	15 th May	30 th May
Making irrigation channels, borders and levelling	23 rd May	-	-	22 nd May	-	-
Puddling	23 rd May	8 th June	23 rd June	22 nd May	8 th June	23 rd June
Fertilizer application	24 th May	9 th June	24 th June	24 th May	9 th June	24 th June
Transplanting	25 th May	10 th June	25 th June	25 th May	10 th June	25 th June
<u>Top dressing of urea:</u>						
I dose	14 th June	25 th June	8 th July	19 th June	26 th July	10 th July
II dose	6 th July	19 th July	1 st August	8 th July	18 st July	2 nd August
Herbicide application (Butachlor)	30 th May	14 th June	29 th June	30 th May	14 th June	29 th June
<u>Hand weeding:</u>						
1 st	13 th June	23 rd June	6 th July	17 th June	24 th June	8 th July
2 nd	4 th July	17 th July	31 st July	5 th July	16 th July	30 th July
Harvesting	13-21 Sept.	18-23 Sept.	28 Sep.- 02 Oct.	15-22 Sept.	22-27 Sept.	31 Sep.- 07 Oct.
Threshing	16-24 Sept.	20-25 Sept.	31 Sept.- 05 Oct.	18-25 Sept.	25-30 Sept.	02-10 Oct.

3.7.1 Nursery raising

The rice seedlings were raised through wet nursery method using protected nursery technique. The nursery plot was ploughed first by soil turning plough followed by cross ploughing with cultivator. The nursery beds with proper irrigation and drainage facility were puddled to a fine colloidal condition. The beds were leveled and bunds were properly plastered. Seeds of four varieties were used @ 80 kg/ha. Seeds were soaked in water for 12 hours and stored in wet gunny bags in dark for 24 hours to hasten sprouting. The sprouted seeds were evenly broadcasted in the nursery beds measuring 3m x 1m each. Nursery beds were irrigated as and when required indirectly through a buffer plot to avoid cold injury to the seedlings by exposure to direct cold water from running stream. Seedlings were top dressed @ 0.5 kg N 100 m² 20 days after sowing. The nursery beds were kept covered with polyethylene during period of low temperature (< 10 °C) (Plate-1).

3.7.2 Preparation of experimental field

The experimental field was thoroughly ploughed by tractor. It was followed by clod breaking and then tilling. Field was laid out in treatment beds as per the layout (Fig. 2) by making replication borders, paths and irrigation channels manually. Experimental beds were irrigated and puddled. The treatment and replication bunds of the plots were plastered properly to prevent seepage of water and nutrients from one plot to another.

3.7.3 Transplanting of seedlings

Thirty days old in the first date of transplanting and 25 days old seedlings in the 2nd and 3rd date of transplanting were uprooted from the nursery bed on the day of transplanting. Three seedlings per hill were transplanted at a spacing of 15x15 cm on the defined dates of transplanting during both the years (Plate 2).



Plate 1 : Nursery raised successfully for transplanting



Plate 2 : Transplanting operation under variable dates

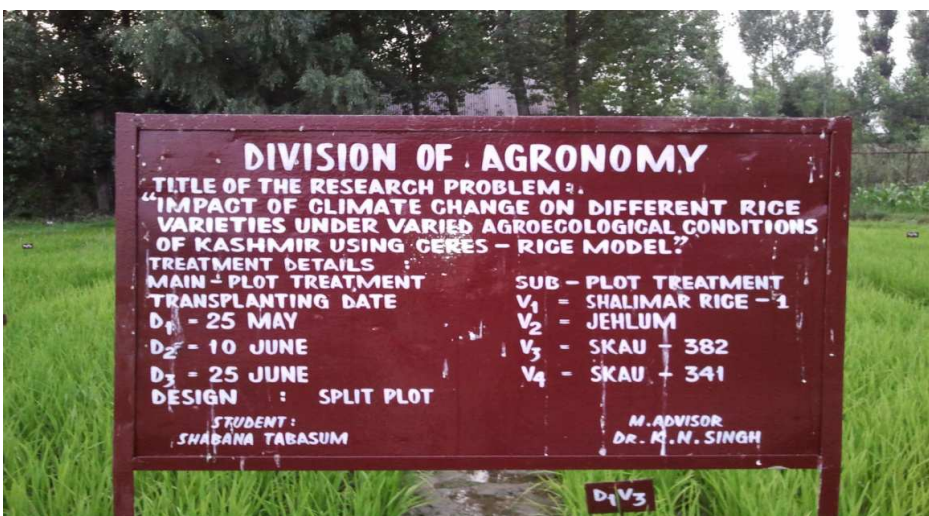


Plate 3 : View of experimental field

3.7.4 Fertilizer application

Fertilizer with a uniform dose of 120: 60: 40 kg per hectare N, P and K through urea, DAP and MOP was applied in all the plots. Half dose (50%) of nitrogen and full dose phosphorus and potassium were applied as basal application just before transplanting. The remaining half dose of nitrogen was applied in two equal splits at maximum tillering and panicle initiation stages. Zinc was applied through zinc sulphate at the rate of 20 kg ZnSO₄ per ha as basal application before transplanting.

3.7.5 Herbicide

To control weeds, butachlor (5%) was applied @ 3 g m², 3-4 days after transplanting.

3.7.6 Irrigation

A thin film of water was maintained at the time of transplanting. Then after transplanting till dough stage 5.0±2 cm of water was maintained except at tillering (20 DAT) and panicle initiation stage (45-50 DAT), where plots were drained to apply urea. Alternate wetting and drying was followed after semi dough stage till physiological maturity.

3.7.7 Intercultural operations

The first manual weeding was done at suitable soil moisture condition just before first top dressing and second weeding was done before second top dressing to remove weeds from the field.

3.7.8 Plant protection measures

Two sprays of Hinosan 50 EC @ 0.1% were sprayed at panicle initiation and 50% flowering stages to protect the crop from blast.

3.7.9 Harvesting

Harvesting was done at physiological maturity, judged visually when about 95 per cent grains were turned into golden colour. First of all, the border rows were harvest quite close to the ground around the individual plot leaving only the net plot area. The two border rows from each side were removed as border and the remaining net plot area was harvested and kept separately for recording the yield. The produce after harvesting was allowed in the plots for sun drying.

3.7.10 Threshing

Sun dried produce treatment wise was tied in bundles, tagged and weighed for recording the biological yield per plot. The weighted material was threshed manually by beating the bundles against the wooden log. and the grain produce of individual plot was cleaned and grain yield per plot was recorded in kgs. The produce of individual plot was converted into q/ha. Grain yield was subtracted from the biological yield to get straw yield kg per plot and was converted into t/ha.

3.8 Details of observation recorded

Leaving the border and penultimate rows from 4 sides of each plot constituted net plot. The penultimate rows of each plot were selected for destructive sampling. Ten hills were marked 5 from one side and 5 from another side by using sticks and pegs in the plots. Periodic observation on various plants characteristics were taken from these ten hills in each plot.

3.8.1 Pre-harvest observations

3.8.1.1 Plant height

Plant height was measured at 15 days interval up to harvesting stage of crop in cm with the help of meter scale. The height of plant measured from the ground level up to the auricle of fully open leaf till the emergence of panicle and up to the neck of panicle after emergence of panicle.

3.8.1.2 Tiller count

Number of tillers was counted periodically at 15 days interval after transplanting onwards up to harvest and expressed as tillers m⁻²

3.8.1.3 Leaf area index

Leaf area index was recorded from each plot at 15 days interval from the date of transplanting till harvesting with the canopy analyser Accupar LP-80 (Decagon Devices USA) (Plate 4).

Leaf area index (LAI) can be calculated by using the following formula:

$$LAI = \frac{\text{Total leaf area per unit area (cm}^2\text{)}}{\text{Land area per unit area (cm}^2\text{)}}$$

3.8.1.4 Relative growth rate (RGR) in kg/kg/day

Determined according to Watson`s (1958).

$$RGR = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1}$$

3.8.1.5 Specific leaf weight (SLW) in g cm⁻²

Ratio of leaf dry weight and leaf area:

$$SLW = \frac{\text{Dry weight of leaf}}{\text{Leaf area}}$$

3.8.1.6 Dead leaf weight

Dead leaves that have fallen off were collected and added to the other dead and yellow leaves.

3.8.1.7 Leaf number per Culm

The number of leaves on the culm was recorded periodically at 15 days interval after transplanting onwards up to harvesting.



Plate 4 : Periodic LAI recording by canopy analyzer Accupar LP-80

3.8.1.8 Dry matter production

Randomly selected three hills from penultimate rows of each plot at 15 days interval up to harvesting stage were removed from ground level. All plant samples were separated into leaf blades (leaf), Culm plus sheath (stem), and panicles when present. These samples were allowed firstly complete sun drying for 2 to 3 days followed by oven drying at 70°C till constant weight. The oven dried weight were recorded in g/hill and averaged and was converted in to $t\ ha^{-1}$.

3.8.1.9 Phenology

Number of days taken by crop to reach various phenological stages till harvest was recorded from each plot at each phenological stage viz. Transplanting shock over tillering start, maximum tillering, panicle initiation, booting, panicle exertion, anthesis, 50% flowering, milking, dough stage and physiological maturity. Panicle initiation was determined by dissecting five main stem in each plot every other day. The date was recorded as panicle initiation for the variety when at least 90% of examined main stems had visible primordia. Anthesis was determined when first flower was visible in the plot. The crop reached physiological maturity when 95% of spikelets had turned from green to golden yellow colour that means when translocation from leaves to source (leaves) to sink (grain) stops.

3.8.2.10 Nitrogen uptake

Nitrogen was calculated by multiplying the dry matter (oven dry) accumulated at anthesis in leaves and straw and at maturity in straw and grain yield of rice by respective percentage of nitrogen.

3.8.2 Post harvest observations

3.8.2.1 Panicle weight

Panicles of pegged hills were taken and weight was calculated and averaged as weight in $g\ panicle^{-1}$.

3.8.2.2 Spikelets panicle⁻¹

Number of spikelets from randomly pegged hills were threshed and counted hill wise. The average number of spikelets panicle⁻¹ was calculated.

3.8.2.3 Number of grains per panicle

The grain received from the sampled panicle was counted separately and their average number was recorded.

3.8.2.4 Filled grain per panicle

The total number of filled grains per panicle was separately counted from the sample, which was earlier used for recording the number of grains per panicle and average for statistical analysis.

3.8.2.5 Grains panicle⁻¹ and spikelet sterility

$$\text{Sterility percentage} = \frac{\text{Number of spikelets} - \text{Number of grains}}{\text{Number of spikelets}} \times 100$$

Out of total number of spikelets counted, the number of fully developed grains as well as sterile spikelets (unfilled) were counted and averaged as grains panicle⁻¹. The differentiation of filled and unfilled spikelets was made by pressing grains with fingers. The sterility percentage was calculated as a ratio of unfilled to total number of spikelets

3.8.2.6 1000-grain weight

Cleaned sample of grains was taken from each plot at 14% moisture and 1000-grain was counted from seed counter from each sample and weighed in grams.

3.8.2.7 Straw yield

The bundle weight of each net plot was recorded just before and after threshing and difference reported as straw yield in t ha⁻¹.

3.8.2.8 Grain yield

The straw yield was subtracted from the biological yield per plot to record the grain yield kg per plot, which was converted in to t/ha.

3.8.2.9 Biological yield

The total produce of net plot was allowed to dry in the field for three days and after drying biological produce tied in to bundles and weighed in kg and converted in to t/ha.

3.8.2.10 Harvest index

The harvest index was calculated by using the following formula and expressed in percentage.

$$\text{Harvest Index (H.I.)} = \frac{\text{Grain yield per plot}}{\text{Biological yield per plot}} \times 100$$

3.8.2.11 Nitrogen content

N content of the ground plant samples of wheat collected at harvest was estimated by modified Kjeldahl's method (Jackson, 1973). Plant samples collected for grain and straw were oven dried at 60 ± 1 °C for 24 hours and then grounded separately. The samples were subjected to chemical analysis.

3.8.2.12 Nitrogen uptake

Nitrogen was calculated by multiplying the dry matter (oven dry) accumulated at maturity in grain and straw yields of rice by respective percentage of nitrogen. Total uptake was calculated by adding uptake by grain and straw.

3.9 Statistical analysis and interpretation

All the biometric data recorded from crop during two consecutive years of investigation were compiled in appropriate tables and analyzed statistically as per the procedure prescribed for split plot design The data collected were analysed statistically by using analysis of variance technique as discussed by Gomez and

Gomez (1984). The results are presented at 5% significance. Software package used for analysis was “Indostat”. Wherever, the ‘F’ test was found significant at 5% probability, critical difference value was used to compare the treatment means, including interaction effects.

3.10 Crop models

A model is a set of mathematical equations describing a physical system. The model simulates/imitates the behavior of a real crop by predicting the growth of its components. Crop growth is a very complex phenomenon and a product of a series of complicated interactions of soil, plant and weather. A crop growth model synthesizes our insights into the physiological and ecological processes that govern crop growth into mathematical equations.

3.10.1 Evaluation of the model

The Decision Support System for Agro-technology Transfer (DSSAT) models, developed by an international network of scientists, cooperating in the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project (Jones *et al.*, 1998), was designed for researchers to easily create “experiments” to simulate the soil-plant-atmospheric system on computers. The outcomes of the complex interactions between various agricultural practices, soil and weather conditions are simulated to suggest appropriate solutions to site-specific problems. DSSAT relies heavily on simulation crop models to predict the performance of crops for making a wide range of decisions follow a systems approach to agronomic research. The Cropping System Model (CSM) released with DSSAT v 4.5 was used in this study, represents a major departure from previously released DSSAT crop model (Jones *et al.*, 2003; Porter *et al.*, 2003).

One of the main changes and improvements in DSSAT v 4.5 is that it has been completely redesigned and is MS Windows-based. A suite of tools is supplied for data management and analysis. X Build is used to create and modify experiment files (X-Files). The suite of tools include AT Create (observed data),

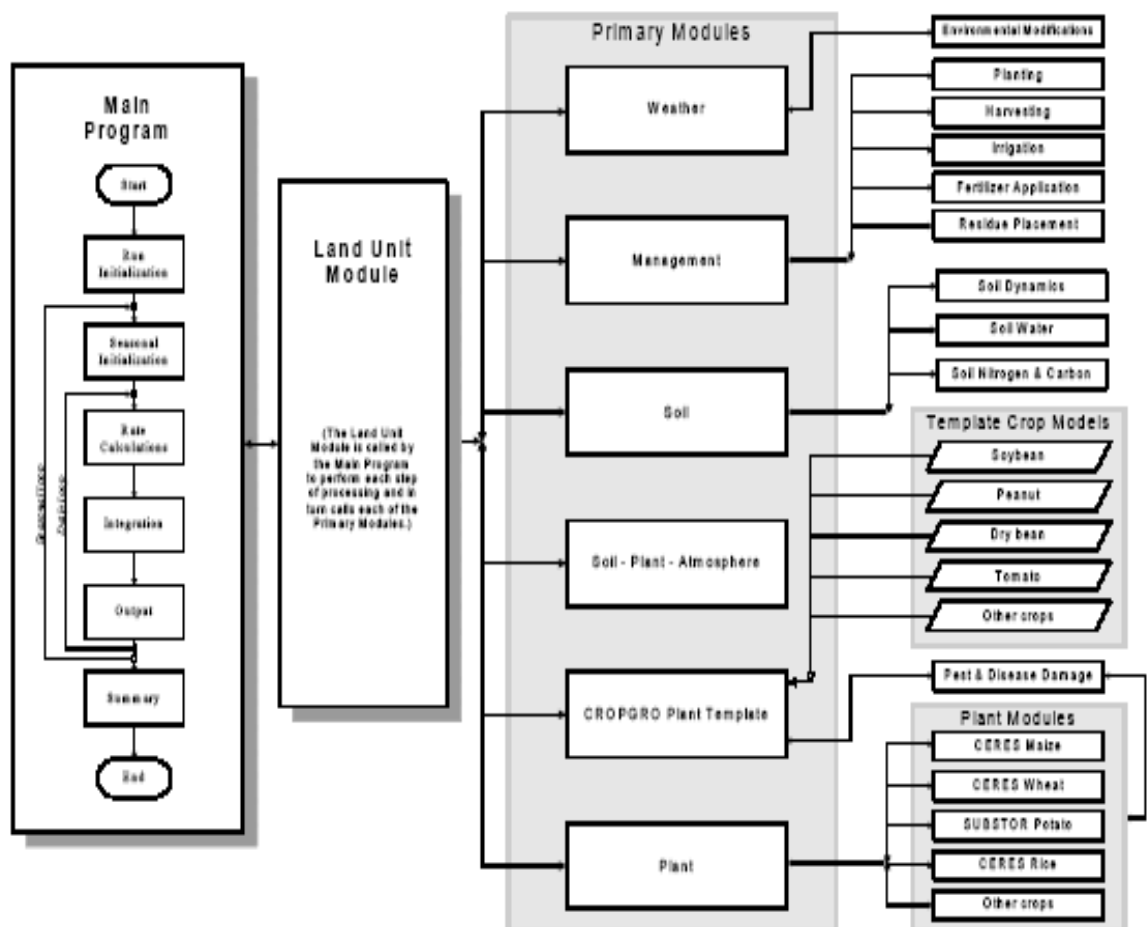


Fig. 3 : Overview of the components and modular structure of DSSAT-CSM

Weatherman (Weather data), G Build (Graphics of outputs), and S Build (Soil data base). The new cropping system model now contains model of 17 crops derived from the old DSSAT CROPGRO and CERES model. The DSSAT Cropping System Model (CSM) simulates growth and development of a crop over time, as well as the soil water, carbon and nitrogen processes and management practices. CSM now incorporates all crops as modules using a single soil model and a single weather module and a single weather module. Figure 3 shows the main components of CSM (rate calculations, integration, daily output, and summary output) lists the primary and sub modules that are currently used in the cropping system model and summarizes their functions. The major modules in the new version (Batchelor, 2003; Jones *et al.*, 2003; Porter *et al.*, 2003) are:

- Soil module-includes a soil water balance sub-module and two soil nitrogen/organic matter modules.
- CROPGRO plant growth template module-simulates different crops by defining species characteristics in input files.
- Plant growth interface for adding additional individual crop models, which are not included in the CROPGRO template approach. Currently this includes rice, maize, millet, sorghum, wheat, barley and potato.
- Weather module-reads or generates daily weather data.
- Soil-plant-Atmosphere module-deals with competition for light and water among the soil, plant and atmosphere.
- New components and capabilities that have been added to the CSM system of modules include (Porter *et al.*, 2003):
- Two additional ET routines (FAO Penman Monteith PET-FAO-56 and Penman Monteith PET using dynamic canopy height and LAI).

- Addition of the CENTURY SOM simulation as an option for modeling SON and SOC processes.
- A soil-plant-atmosphere module.
- Pest damage simulation for maize, millet and sorghum.
- A soil fertility factor for maize, millet and sorghum.
- Combination of several crop growth routines into a single model.

The main programme controls the timing of events: the start and stop of simulation, beginning and end of crop season, as well as daily time loops.

3.10.1.1 CERES-Rice model description

The CERES-Rice (Crop environment and resource synthesis) model simulates crop growth with a daily time step from sowing to maturity based on physiological processes that describe the crops response to soil and aerial environmental conditions. Figure 4 shows a schematic diagram of CERES-Rice model. The model consider the effects of weather, genetics, soil water, soil C and N, and management in single or multiple seasons and in crop rotations at any location where minimum inputs are provided. The input data required to run the CERES-Rice of DSSAT shell include daily weather information (maximum, minimum temperature, rainfall and solar radiation); soil characterization data (data by soil layer on extractable nitrogen and phosphorus and soil water content) a set of genetic coefficients characterizing the variety being grown; and crop management information, such as emerged plant population, row spacing and fertilizer and irrigation schedules. The minimum data sets for operations, calibration and validation of rice are provided by Hunt and Boote (1994) and are summarized as below:

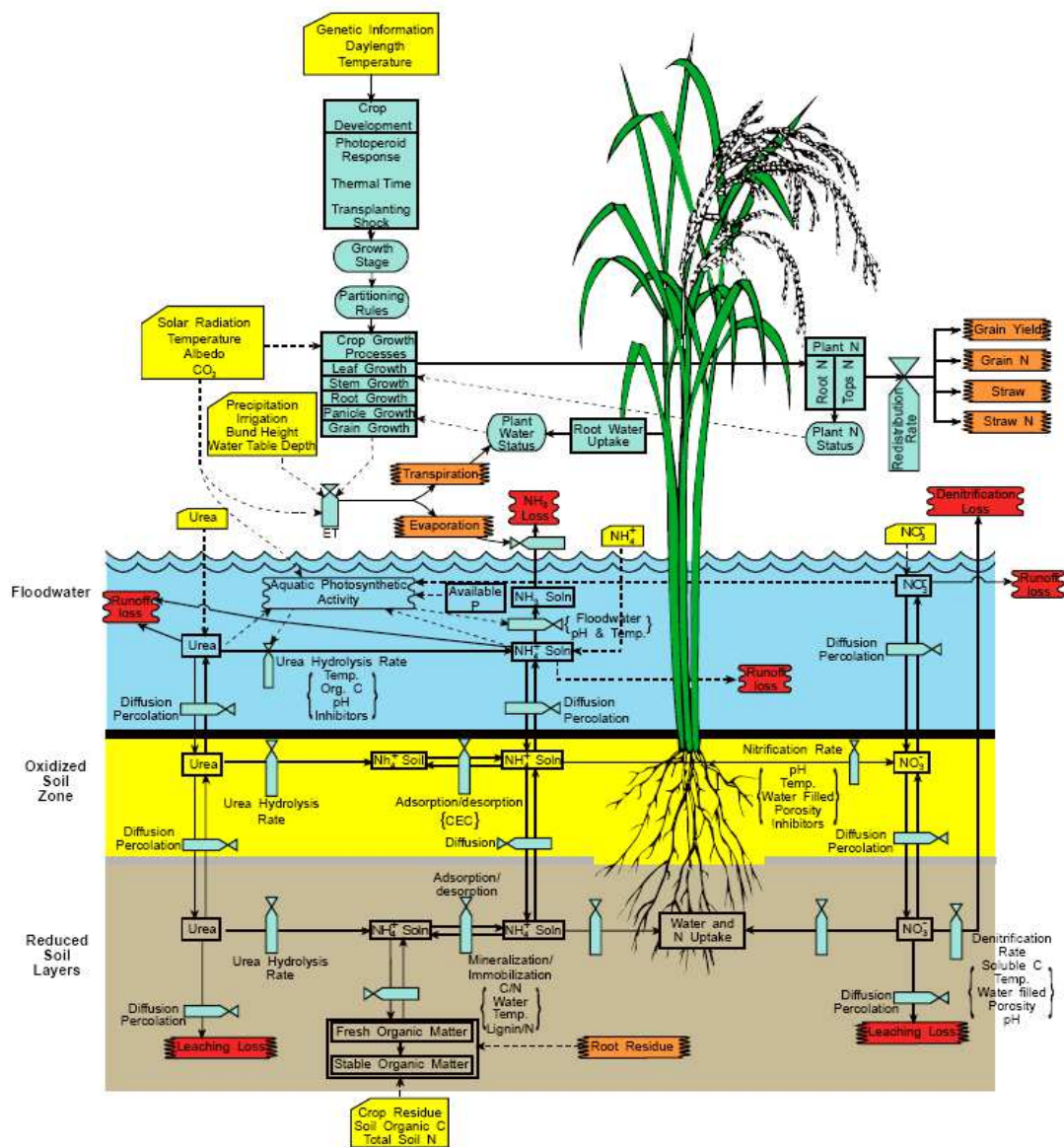


Fig. 4 : Schematic diagram of the CERES-rice model

Minimum data requirement for operation and evaluation of CERES-Rice model

- ➔ **Site** (latitude, longitude, elevation, slope, aspect, water table depth)
- ➔ **Weather** (daily maximum and minimum temperature, global solar radiation, rainfall, wind dew point temperature or relative humidity)
- ➔ **Soil** (classification using the local system and (to family level) the USDA-NRCS taxonomic system), root growth factor, drainage coefficient.
- ➔ **Physical properties-** Depths of layers; percentages of sand, silt and clay and bulk density at various depths; moisture content at lower limit (LL, 15 bars), drained upper limit (DUL, 1/3 bar), and at saturation (SAT) for various depths (if they are not available, they could be estimated from percentages of sand, silt, and clay and bulk density).
- ➔ **Chemical properties-** pH; organic C; total N; CEC
- ➔ **Initial conditions-** C:N ratio and weight of root and shoot residues of previous crop incorporated or retained in field; date and depth of residue (material type, amount and N concentration) incorporation; soil water, and KCl-extractable ammonium and nitrate N by soil layer); in-crop season (ammonium and nitrate N); between phases (organic C and total N); tillage practice.

Management

- ➔ **Establishment-** Dates of planting/transplanting; age of transplants; seedling (seed bed) environment temperature; plant population (number of plants for DSR; number of seedlings per hill for TRR).
- ➔ **Water-** Bunding (date and depth); flood water depth (date and depth); depth of furrows and of flood water (for beds); irrigation amount and dates; date of water removal; percolation rate (beds-

from bed surface and furrows); perched water table depth (beds-
from bed surface and furrows)

- ➔ **Calibration and validation** (data from separate experiments): All of the above plus:
- ➔ **Phenology** Date of emergence, PI, 50% heading, 50% flowering, physiological maturity (as identified by nodes and constant weight of grain) and harvest.
- ➔ **Performance at harvest** Grain and straw yields, panicles or spikes per unit area, grain number per panicle, grain weight, and N concentrations of grain and straw.
- ➔ **Number of leaves** produced in main stem; LAI, canopy dry weight (also leaf, stem, and panicle weight separately), solar radiation interception, and N concentration in above-ground biomass at key stages such as end of tillering, 50% flowering and maturity (bed-radiation interception at edges and in crops).
- ➔ **Soil water content** at various depth with time (beds-in bed centers and edges, and in furrows; during rice season-depth of water in furrows measured daily and immediately after and before irrigation).
- ➔ **Soil nitrate and ammonium** content at various depths with time (beds-in bed centres and edges, and in furrows).

Genetic coefficients of four varieties were estimated using crop data of all varieties (Table 5). The available data included emergence date, anthesis date, maturity date, aboveground crop biomass, grain number per unit of ground area, individual grain weight, maximum LAI, and final grain yield.

Table 4: Phenology and growth coefficients used in CERES-Rice model

Genetic coefficients	Definitions and unit
Phenology coefficients	
P1	Time period (expressed as growing degree days [GDD] in °C above a base temperature of 9°C) from seedling emergence during which the rice plant is not responsive to changes in photoperiod. This period is also referred to as the basic vegetative phase of the plant.
P2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P20
P5	(Time period in GDD in °C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with the base temperature of 9°C.
P20	Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P20 development rate is slowed, hence there is delay due to longer day lengths.
Growth Coefficients	
G1	Potential spikelet number coefficient as estimated from the number of spikelets per g of main culm dry weight (less leaf blades and sheaths plus spikes) at anthesis. A typical value is 55.
G2	Single grain weight (g) under ideal growing conditions, i.e. non-limiting light, water, nutrients, and absence of pests and diseases.
G3	Tillering coefficient (scalar value) relative to IR64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.0.
G4	Temperature tolerance coefficient. Usually 1.0 for varieties grown in normal environments. G4 for japonica type rice growing in a warmer environment would be 1.0 or greater. Likewise, the G4 value for indica type rice in very cool environments or season would be less than 1.0.

Table 5: Genetic coefficients of cultivars

Genetic parameter	Description*	Jhelum	Shalimar rice-1	SKAU-382	SKAU-341
P1	Time period (GDD) of basic vegetative phase	440.0	510.0	430.0	510.0
P2R	Extent phasic development (GDD)	10.0	10.0	10.0	10.0
P5	Time period (GDD) of grain filling phase	400.0	405.0	400.0	405.0
P20	Critical photo period (hour)	12.0	12.0	12.0	12.0
G1	Potential spikelet number	60.0	59.0	60.0	60.0
G2	Single grain weight	0.240	0.250	0.238	0.250
G3	Tillering coefficient	1.00	1.00	1.01	1.10
G4	Temperature tolerance coefficient	1.00	1.25	1.00	1.00

3.10.1.2 Phenology

The phenology components of CERES Rice have been described by Ritchie and NeSmith (1991), Singh (1994) and Ritchie *et al.* (1998). The models describe the progress through the crop life cycle using degree-day accumulation (heat sum). The duration of growth stages in response to temperature and photoperiod varies between species and cultivars, and genetic coefficients are used as model inputs to describe these differences (Table 2; Hunt and Boote, 1994; Singh *et al.*, 2002). In wheat, the duration from emergence to terminal spikelet formation is influenced by the vernalization (chilling) requirement and photoperiod. In rice, a developmental phase (juvenile stage) occurs when the crop is not sensitive to photoperiod. After this stage sensitivity to both photoperiod and temperature determine the time to panicle initiation. The phenology component also simulates the effect of water or N deficit on the rate of life cycle progress

(Singh *et al.*, 1999). These effects may vary with life cycle phase; for example, water deficit may slow the onset of reproductive growth but accelerate reproductive growth after the beginning of grain filling

3.10.1.3 Growth

The model predict daily photosynthesis using the radiation-use efficiency approach as a function of daily irradiance for a full canopy, which is then multiplied by factors ranging from 0 to 1 for light interception, temperature, leaf N status and water deficit. There are additional adjustments for CO₂ concentration, specific leaf weight, row spacing and cultivar (Ritchie *et al.*, 1998). Growth of new tissues depends on daily available carbohydrate and partitioning to different tissues as a function of phenological stage and modified by water deficit and N deficiency.

Leaf area expansion is depends on leaf appearance rate, photosynthesis and specific leaf area. Leaf area expansion is more sensitive to temperature, water deficit and N stress. During seed fill, N is mobilized from vegetative tissues. As a result, vegetative tissue N concentration declines and this in turn lowers photosynthesis and causes leaf senescence to increase protein and carbohydrate mobilized from vegetative tissues contribute to seed growth while photosynthesis declines (Godwin and Singh 1998). Cultivar differences in yield components, tillering, and temperature tolerance are captured by the model using a suite of coefficient specific to a cultivar.

3.10.1.4 Soil water balance

The soil water balance model of DSSAT is a one-dimensional model and computes the daily changes in soil water content by soil layer due to infiltration of rainfall and irrigation, vertical drainage, unsaturated flow, soil evaporation, and root water uptake processes (Jones *et al.*, 2003). The soil has parameters that describe its surface conditions and layer-by-layer soil water holding and conductivity characteristics. The model use a ‘tipping bucket’ approach for

computing soil water drainage when a layer's water content is above a drained upper limit parameter. Upward unsaturated flow is also computed using a conservative estimate of the soil water diffusivity and differences in volumetric soil water content of adjacent layers (Ritchie, 1998). Soil water infiltration during a day is computed by subtracting surface runoff from rainfall that occurs on that day. The SCS method (Soil Conservation Service, 1972) is used to partition rainfall into runoff and infiltration, based on a 'curve number' that was developed by Williams *et al.* (1984) used in the model accounts for layered soils and soil water content at the time when rainfall occurs. When irrigation is applied, the amount applied is added to the amount of rainfall for the day to compute infiltration and runoff. Drainage of water through the profile is first calculated based on an overall soil drainage parameter assumed to be constant with depth. The amount of water passing through any layer is then compared with the saturated hydraulic conductivity of that layer, if this parameter is provided. If the saturated hydraulic conductivity of any layer is less than computed vertical drainage through that layer, actual drainage is limited to the conductivity value, and water accumulates above that layer. The details of soil water balance sub-module are given in Ritchie (1998) and Jones *et al.* (2003).

3.10.1.5 Nitrogen dynamics

In the DSSSAT 4.0 N sub model, the major processes simulated are mineralization and immobilization (influenced by soil temperature, soil water, C/N ratio), nitrification (influenced by soil temperature, soil water pH, NH_4 concentration), denitrification (influenced by soil temperature, soil water pH, Soil C, and NO_3 concentration), NO_3 leaching (influenced by drainage and NO_3 concentration), ammonia volatilization (influenced by soil temperature, soil pH, surface evaporation, NH_4 concentration), and crop uptake (influenced by soil water, inorganic N, crop demand, root length density). In the model mineralization of N is linked to the routines describing the decomposition of organic matter. The soil profile is characterized by its initial organic matter and N layers are based on

water-holding properties and texture. Transport of N through the soil to lower layers is based on water movement obtained from the soil water balanced module. Details of nitrogen sub-module are given by Godwin and Jones (1991) and Godwin and Singh (1998).

3.10.2 Validation and Calibration of the Model

3.10.2.1 Calibration

Calibration refers to adjustments made to model parameters so as to give the “most accurate” comparison between simulated results and results obtained from field measurements. In other words calibration involves the adjustment of certain model parameters by systematically comparing simulated results to field observations of state variables.

Observed weather data of Shalimar main campus of the University for growing seasons 2011 and 2012 was used for calibrating the coefficients of four rice cultivars using set of data of one treatment of field experiment (25 May transplanting). The coefficients for varieties were estimated from field experiment by adjusting coefficients until close match were achieved between simulated and observed phenology and yield (Table 5).

The available data included emergence date, anthesis date, maturity date, grain yield, and aboveground crop biomass, grain number per unit of ground area, individual grain weight, maximum LAI, and final grain yield.

3.10.2.2 Validation

Validation is the process by which a simulation model is compared to field data not used previously in the development of calibration process. Simulated state variables are compared with measured values of state variables. For example, measured leaf area is compared with simulated values.

To assess the accuracy of the model simulation compared with the observations, data generated from three transplanting dates (25 May, 10 June and

25 June) and four varieties of rice over the year 2012 was used for validating the performance of CERES-rice model. Prediction capabilities of the model were tested by judging the performance of the crop in terms of grain yield, phenology (days to anthesis and maturity), N- uptake and top weight (biological weight).

3.11 Simulation runs for climate change

Crop models are assisting tools for assessing the vulnerability and adaptation to climate change. A simulation study was carried out using CERES-rice model embedded in DSSAT (V 4.5) (Jones et al, 2003, 2004) to evaluate the potential consequences of climate change on the four different cultivars of rice i.e. Shalimar- rice 1, Jhelum, SKAU-341 and SKAU-382 in terms of yield in different locations (Kokernag, Kupwara, Srinagar, Badgam and Anantnag) of Kashmir valley. Base line data for climate change scenario were obtained from the thesis (P.hd Environmental Science) of SKUAST-K in which the climatic scenario for 2011-2090 under AIB was extracted from a PRECIS run obtained from IITM which showed that in the year 2040 the maximum temperature will increase by 2°C, minimum temperature increases by 2.3°C, CO₂ concentration will increase by 80 ppm and the projected precipitation is likely to decrease by 90mm.

Table-6 : Combination of weather parameters selected for climate change scenario

Climatic parameters	Kokernag	Kupwara	Anantnag	Srinagar	Budgam
Normal	Normal	Normal	Normal	Normal	Normal
Maximum temperature (C ₁)	+2 °C	+2 °C	+2 °C	+2 °C	+2 °C
Minimum temperature (C ₂)	+2.3°C	+2.3°C	+2.3°C	+2.3°C	+2.3°C
Precipitation (C ₃)	-90mm	-90mm	-90mm	-90mm	-90mm
CO ₂ (C ₄)	+80ppm	+80ppm	+80ppm	+80ppm	+80ppm
ALL	(C ₁ +C ₂ +C ₃ +C ₄)	(C ₁ +C ₂ +C ₃ +C ₄)	(C ₁ +C ₂ +C ₃ +C ₄)	C ₁ +C ₂ +C ₃ +C ₄)	C ₁ +C ₂ +C ₃ +C ₄)

Chapter – 4

EXPERIMENTAL FINDINGS

This chapter includes the interpretation of data generated during the course of this investigation and simulation results of the model.

The experimental findings are summarized in tables and figures and described in the following text under separate heads.

4.1 Growth characters

4.1.1 Plant height

Data presented in Table 7 and Fig. 5 revealed that irrespective of years, transplanting dates and cultivars plant height increased consistently up to 75DAT, thereafter, increase was marginal. 25 May transplanting recorded significantly taller plants than 10 and 25 June transplanting at complete bearing stage of crop during both the years.

Similarly, Plant height of all cultivars increased up to 75DAT, beyond that increase was marginal (Table 7 and Fig. 6). Cultivars behaved differently with regard to plant height at different periods. Cultivar SKAU-341 recorded significantly taller plants than other varieties at 60 DAT till maturity during both the years, though Jhelum and SKAU-382 were at par at all the recorded periodic stages. After SKAU- 341, Shalimar rice-1 significantly recorded more height than other cultivars. Cultivar SKAU-341 gained more height after panicle initiation (45DAT) (Plate 5 6 and 7).

4.1.2 Tillers m⁻²

Tillers number m⁻² (Table 8 and Fig. 7) increased up to 45 DAT, thereafter decreased gradually up to maturity during both the years. Transplanting on 25 June significantly produced maximum tiller number at 15 DAT and 30 DAT than 25 May and 10 June transplanting during both the years. At 45,60,75,90 and 105 DAT 25 May transplanting recorded significantly highest tiller number than

Table 7: Periodic plant height (cm) of rice cultivars as influenced by transplanting dates

Treatment	15 DAT		30 DAT		45 DAT		60 DAT		75 DAT		90 DAT		105 DAT (Maturity)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting date														
25 th May	21.51	25.54	40.75	42.87	60.55	62.33	91.23	98.72	123.45	124.98	130.14	127.56	130.28	127.58
10 th June	33.14	33.85	51.32	55.63	76.68	78.43	108.08	111.70	122.81	123.27	125.69	124.65	125.73	124.79
25 th July	35.53	37.97	54.32	58.43	74.51	75.52	107.94	108.23	116.94	118.85	121.29	122.81	121.99	123.14
SE(m)±	1.15	0.68	0.48	0.64	0.25	0.39	1.01	0.54	0.51	0.73	0.74	0.40	0.82	0.58
CD (0.05)	4.51	2.65	1.87	2.52	1.01	1.56	3.91	2.13	1.99	2.84	2.92	1.56	3.24	2.27
Cultivars														
Shalimar rice-1	29.93	33.38	49.91	54.68	73.19	75.16	102.42	106.59	120.60	121.78	123.51	122.54	123.74	122.59
Jhelum	30.50	33.68	47.08	51.29	70.14	71.14	99.91	103.58	118.54	119.97	121.93	121.17	122.12	121.32
SKAU-382	30.98	33.88	49.08	52.93	68.58	69.78	98.47	101.21	115.81	118.42	119.87	119.60	119.91	119.86
SKAU- 341	28.82	28.86	49.11	50.23	70.39	72.28	108.89	113.52	129.42	129.32	137.46	136.51	137.53	136.84
SE(m)±	0.72	1.58	0.94	0.75	0.81	1.19	0.88	0.90	0.82	1.08	1.15	1.57	1.24	1.87
CD(0.05)	NS	NS	NS	2.24	2.42	3.54	2.62	2.66	2.45	3.22	3.42	4.65	3.71	5.56

Table 8: Periodic tillers m⁻² of rice cultivars as influenced by transplanting dates

Treatment	15 DAT		30 DAT		45 DAT		60 DAT		75 DAT		90 DAT		105 DAT (Maturity)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting date														
25 th May	148.33	168.72	240.27	253.33	484.54	494.02	449.52	458.32	428.82	433.91	387.16	392.44	373.21	381.61
10 th June	154.87	172.43	263.24	261.91	470.82	486.91	425.03	430.48	375.14	381.63	333.53	339.92	302.52	314.92
25 th July	160.64	185.58	279.03	283.17	418.36	423.53	387.14	394.26	343.09	369.42	326.08	331.58	265.30	271.44
SE(m)±	3.53	4.12	5.11	3.76	5.24	3.84	2.96	2.84	3.48	5.31	4.16	5.95	6.34	7.14
CD (0.05)	12.04	14.93	16.03	12.72	16.09	13.62	11.12	10.43	12.15	16.11	14.13	19.94	20.68	23.12
Cultivars														
Shalimar rice-1	155.82	165.35	268.65	272.53	465.11	471.73	424.44	426.29	356.46	364.33	323.42	337.29	318.53	322.83
Jhelum	162.69	167.21	271.43	278.41	449.13	442.92	430.02	417.91	363.02	370.31	340.37	352.23	331.71	343.58
SKAU-382	177.55	182.04	273.08	284.23	432.72	426.68	412.75	399.04	348.14	339.42	317.81	310.84	296.54	288.94
SKAU- 341	148.31	156.62	258.52	261.28	395.24	404.34	374.48	387.42	332.42	328.47	304.14	295.75	278.62	257.03
SE(m)±	1.26	3.14	2.93	1.51	1.09	2.48	2.21	3.41	4.01	2.41	2.53	2.79	2.04	3.23
CD(0.05)	NS	NS	8.05	6.92	5.34	7.86	6.48	9.70	10.83	7.33	7.57	7.58	6.52	8.54

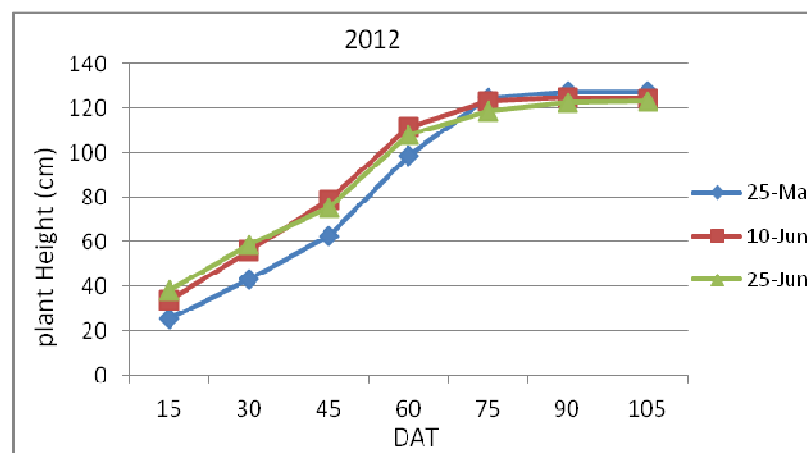
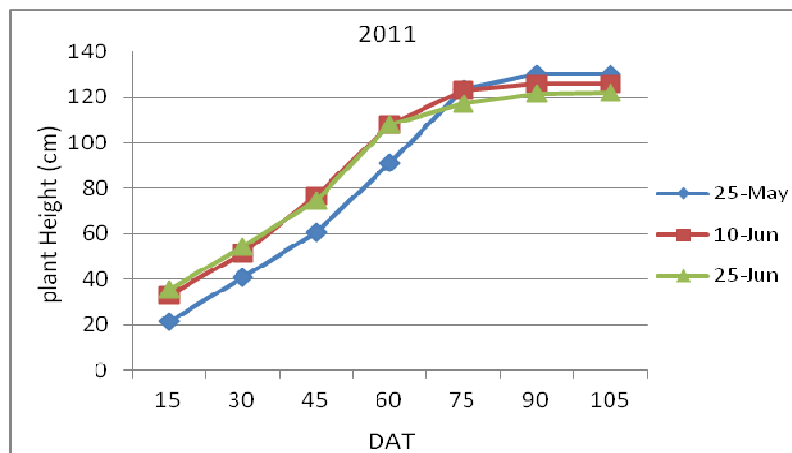


Fig. 5: Periodic Plant height as affected by transplanting dates

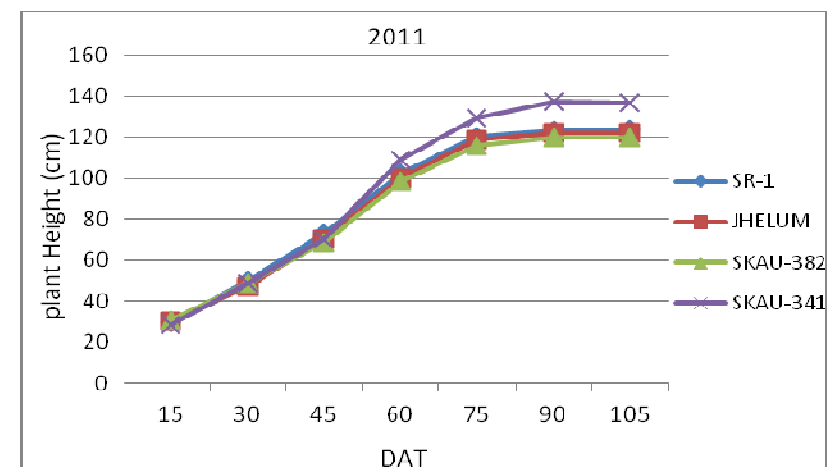
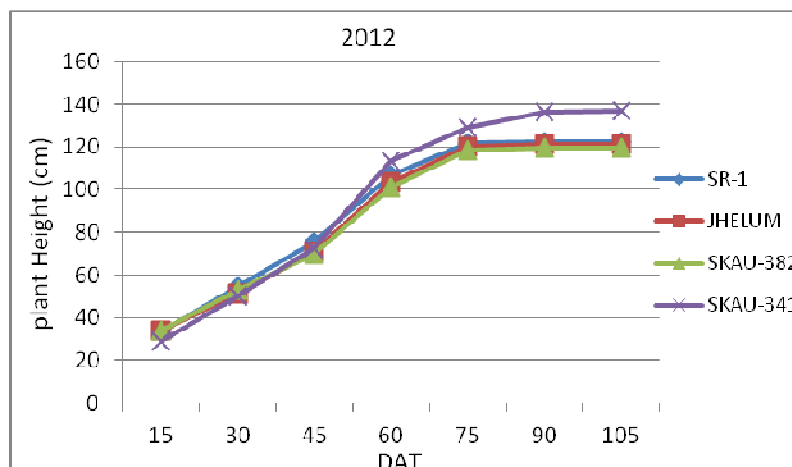


Fig. 6 : Periodic Plant height as affected by rice cultivars

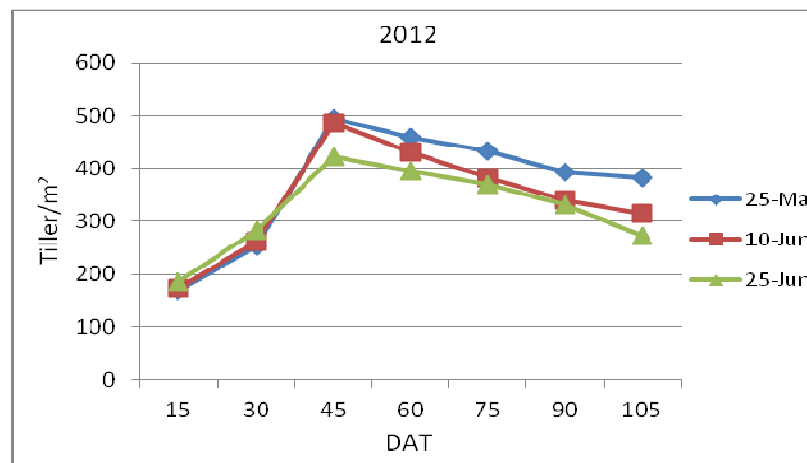
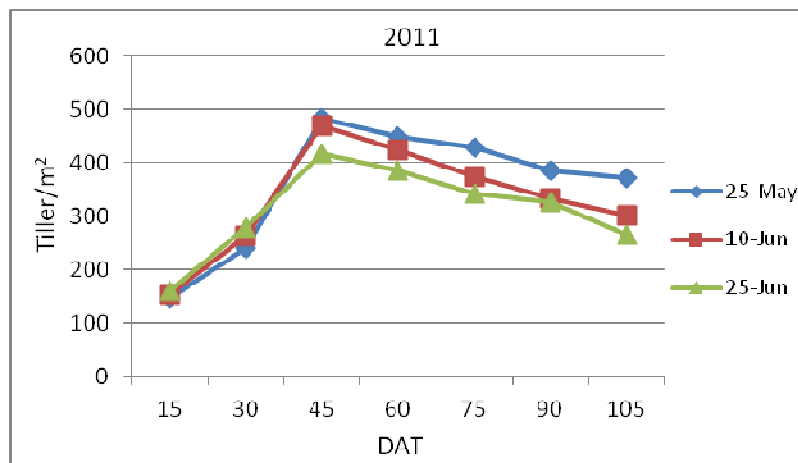


Fig. 7: Periodic tiller no. as affected by transplanting dates

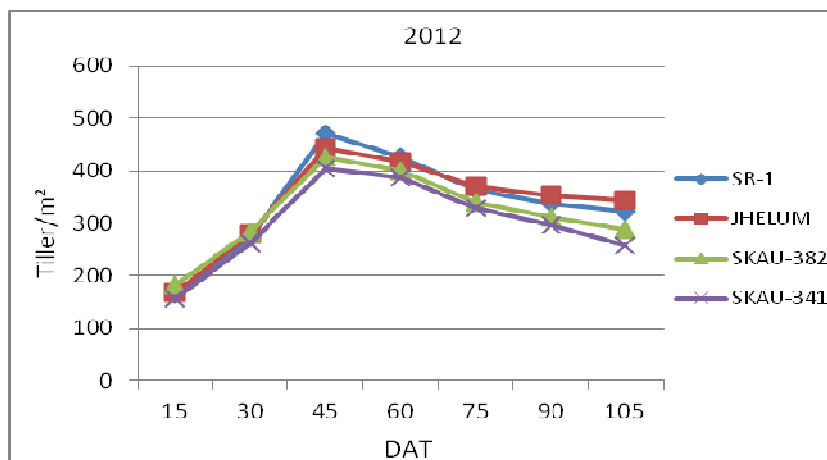
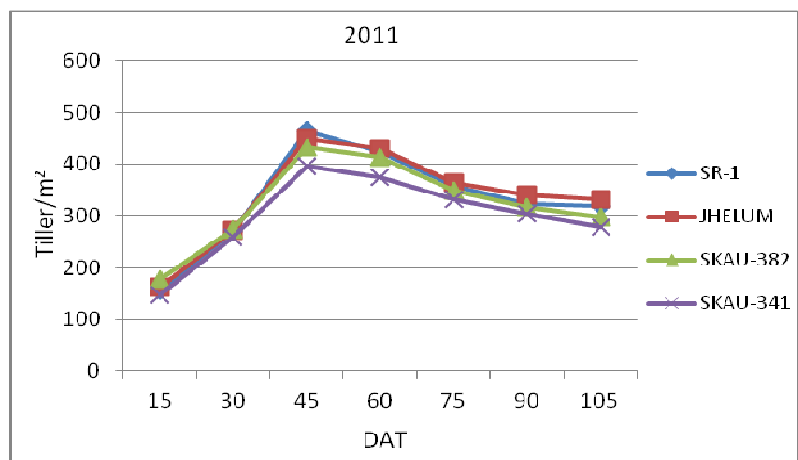


Fig. 8 : Periodic tiller No. as affected by rice cultivars



SKAU-341 (V4) gained more height compared to SKAU-382 (V₃)



SKAU-341 (V4) gained more height compared to Jhelum (V₂)



SKAU-341 (V4) gained more height compared to Shalimar rice-1 (V₁)

Plate 5 : Comparison of plant height among cultivars

10 and 25 June transplanting. The difference between transplanting dates at 15 and 30 DAT was significant between 25 May and 25 June during both the years except 2012 where 10 June and 25 June at 30 DAT also shows significant difference. At 45 DAT 10 June and 25 May recorded non-significant difference during both the years. Further difference between transplanting dates at 60, 75, 90 and 105 DAT was significant during both the years except 75 DAT (2012) 90 DAT (2011 and 12) 10 June and 25 June was not significant.

As far as cultivars are concerned there was no significant difference in the tiller production m^{-2} at 15 DAT, after this period tiller production m^{-2} increased consistently in all cultivars upto 45 DAT after this period till maturity all the cultivars showed decreasing trend. SKAU-382 produced higher tiller production m^{-2} upto 30 DAT. From 45 DAT till maturity Jhelum significantly produced highest number of tiller m^{-2} followed by Shalimar rice-1, SKAU-382, and SKAU-341 (Table 8 and Fig. 8)

4.1.3 Leaf area index

LAI is the component of crop growth analysis that accounts for the ability of the crop to capture light energy and is critical to understand the function of many crop management practices. Leaf area index can have importance in many areas of agronomy and crop production through its influence: light interception, crop growth, weed control, crop-competition, crop water use and soil erosion.

Data pertaining to leaf area index is presented in Table 9 and Fig. 9, irrespective of years, transplanting dates and cultivars, LAI showed an increasing trend upto 60 DAT where maximum values are recorded, there after LAI values gradually start decreasing with the advancement of rice age.

At all the recorded periodic stages, LAI was significantly influenced by transplanting dates and cultivars except due to cultivars at 15 DAT and 30 DAT. 25 July transplanted rice recorded higher LAI upto 45 DAT followed by 10 June and then 25 May during both the years. Thereafter i.e. upto 90 DAT, LAI

Table 9: Periodic leaf area index of rice cultivars as influenced by transplanting dates

Treatment	I5 DAT		30 DAT		45 DAT		60 DAT		75 DAT		90 DAT		I05 DAT (Maturity)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting date														
25 th May	0.14	0.16	0.26	0.27	1.84	2.16	4.54	4.66	3.84	3.96	2.55	2.80	1.58	1.75
10 th June	0.22	0.23	0.51	0.56	2.36	2.52	4.26	4.32	3.65	3.75	2.39	2.69	1.74	1.96
25 th July	0.31	0.30	0.74	0.81	2.72	2.81	4.15	4.18	3.29	3.40	2.28	2.51	1.95	2.15
SE(m)±	0.01	0.01	0.02	0.1	0.02	0.08	0.01	0.08	0.02	0.06	0.04	0.08	0.02	0.01
CD (0.05)	0.03	0.05	0.06	0.3	0.09	0.30	0.05	0.30	0.07	0.22	0.17	0.32	0.06	0.05
Cultivars														
Shalimar rice-1	0.21	0.22	0.49	0.51	2.31	2.51	4.15	4.25	3.65	3.78	2.43	2.70	1.76	2.02
Jhelum	0.25	0.26	0.55	0.61	2.49	2.70	4.28	4.34	3.46	3.63	2.38	2.36	1.63	1.86
SKAU-382	0.23	0.24	0.53	0.60	2.44	2.63	4.24	4.28	3.32	3.34	2.17	2.32	1.48	1.63
SKAU- 341	0.20	0.20	0.46	0.45	2.00	2.16	4.60	4.68	3.95	4.08	2.64	3.27	2.15	2.30
SE(m)±	0.01	0.01	0.01	0.05	0.02	0.05	0.02	0.07	0.02	0.09	0.02	0.06	0.02	0.03
CD(0.05)	NS	NS	NS	NS	0.06	0.13	0.07	0.22	0.07	0.27	0.05	0.17	0.07	0.08

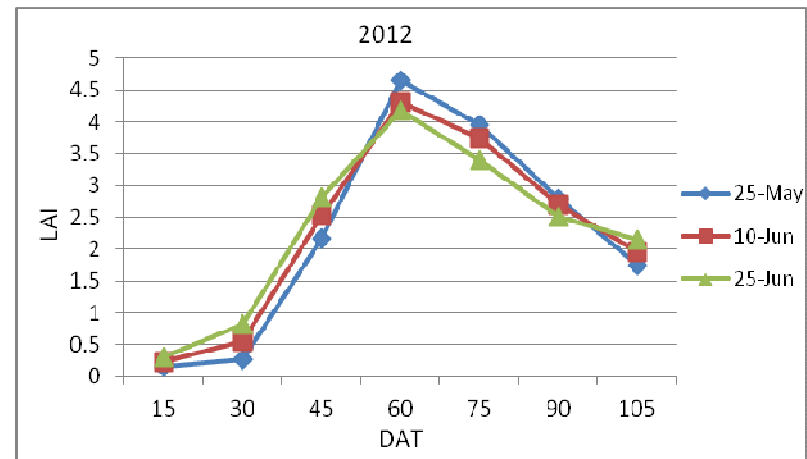
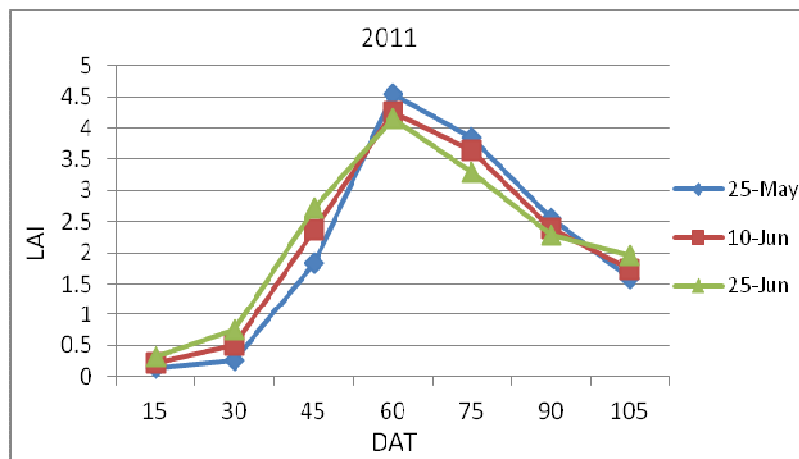


Fig. 9 : Periodic Leaf area index as affected by transplanting dates

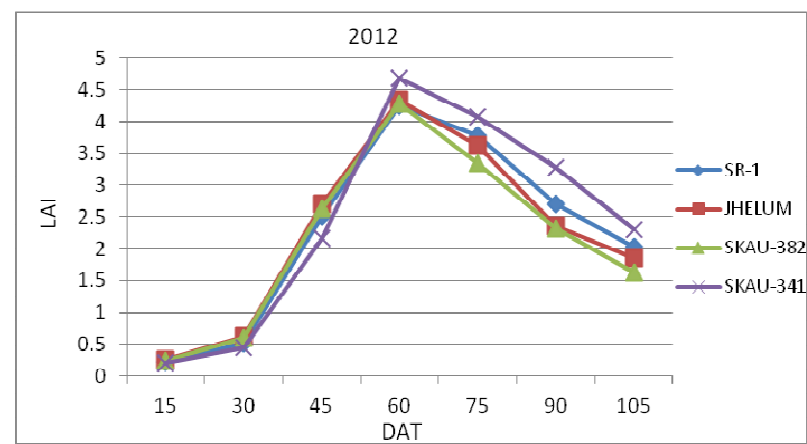
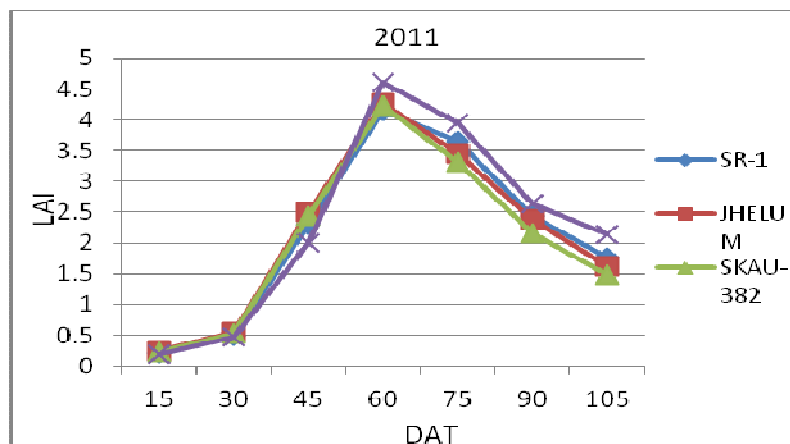


Fig. 10 : Periodic Leaf area index as affected by rice cultivars

registration was in the order of 25 May > 10 June > 25 June. At maturity i.e. 105 DAT, LAI was again in the reverse order. At 60 DAT, 25May transplanting was significantly superior over 10 June which in turn is significantly superior over 25 June transplanting. However, at later stages of crop i.e. 75 DAT during 2012 and 90 DAT during both the years 25 May and 10 June transplanted crop recorded at par leaf area index.

Among cultivars, Jehlum and SKAU-382 were statistically at par and significantly superior over Shalimar rice1 and SKAU-341 in LAI upto 60 DAT. Except during 2012 where Shalimar rice 1 and SKAU-341 were statistically at par. Rest on all recorded periodic stages i.e. 60, 75, 90 and 105 DAT SKAU-341 was significantly superior over all the cultivars under study (Table 9 and Fig. 10).

4.1.4 Dry matter accumulation

Dry matter production was significantly influenced by transplanting date during both the years (Table 10 and Fig. 11). 25 June transplanting was significantly superior over 10 June transplanting which in turn was superior over 25 May transplanting during both the years at all the periodic stages upto 60 DAT. However, at 75 DAT, dates could not produce significantly varied dry matter. At 90 DAT, 25 May and 10 June transplanting were at par and significantly superior over 25 June transplanting, but at maturity i.e. 105 DAT 25 May transplanting yield significantly higher dry matter followed by 10 June and then 25 June transplanting.

Cultivars under study responded significantly to dry matter accumulation at all the periodic stages during both the years. At 15 DAT, all the cultivars were at par in registering dry matter accumulation during both the years. Shalimar rice-1 accumulated significantly higher dry matter over all the cultivars at 30 and 45 DAT. However, rest all the stages Jehlum recorded significantly superior dry matter followed by Shalimar rice 1 (Table 10 and Fig. 12).

Table10: Periodic dry matter (q ha⁻¹) of rice cultivars influenced by transplanting dates

Treatment	15 DAT		30 DAT		45 DAT		60 DAT		75 DAT		90 DAT		105 DAT (Maturity)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting date														
25 th May	1.42	1.51	12.6	12.23	22.6	23.71	51.71	53.33	89.41	90.53	129.92	131.55	137.22	145.04
10 th June	2.36	2.41	13.0	13.15	29.1	31.14	56.63	53.54	90.31	94.01	126.53	129.46	123.64	129.12
25 th July	2.52	2.51	13.6	13.98	35.7	37.19	63.50	60.55	89.64	93.84	111.21	111.68	104.21	109.01
SE(m)±	0.01	0.29	0.16	0.08	0.70	0.88	2.31	0.48	1.52	3.54	2.32	2.13	2.60	2.76
CD (0.05)	0.05	0.11	0.64	0.33	2.71	0.35	9.04	0.02	6.01	13.86	8.73	8.33	10.17	10.81
Cultivars														
Shalimar rice-1	2.06	2.10	15.0	15.14	31.69	35.20	56.62	55.04	85.5	91.40	122.0	122.26	125.04	131.11
Jhelum	2.27	2.40	13.3	13.09	29.48	32.23	56.81	54.53	94.5	97.82	131.9	132.23	128.91	134.54
SKAU-382	2.16	2.12	12.5	12.54	28.13	28.06	51.24	50.5	93.9	92.81	115.8	118.49	114.24	119.41
SKAU- 341	1.89	1.96	11.3	11.71	27.32	27.22	64.51	63.15	85.1	89.13	120.4	123.94	108.53	115.82
SE(m)±	0.05	0.08	0.41	0.74	1.87	1.38	3.21	1.91	1.9	3.77	2.04	3.33	1.74	2.45
CD(0.05)	NS	NS	1.21	2.19	5.60	4.13	9.53	5.68	5.50	11.21	6.03	9.91	5.07	7.28

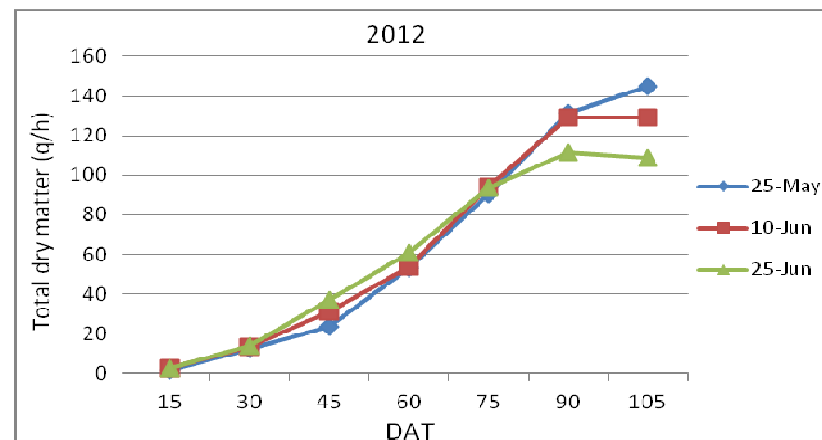
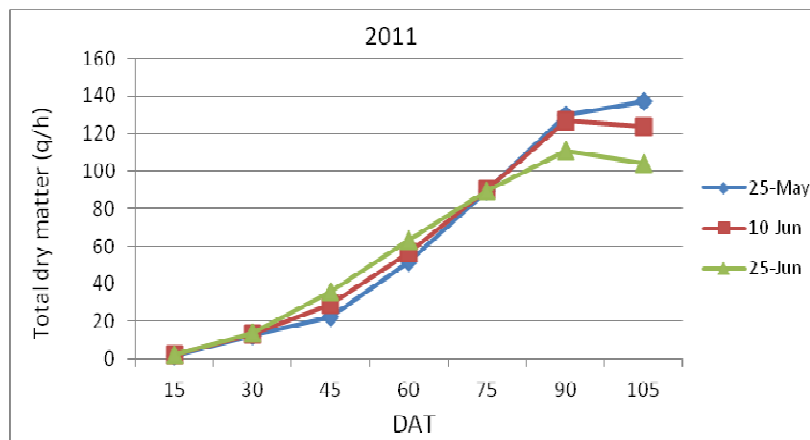


Fig. 11 : Periodic dry matter as affected by transplanting dates

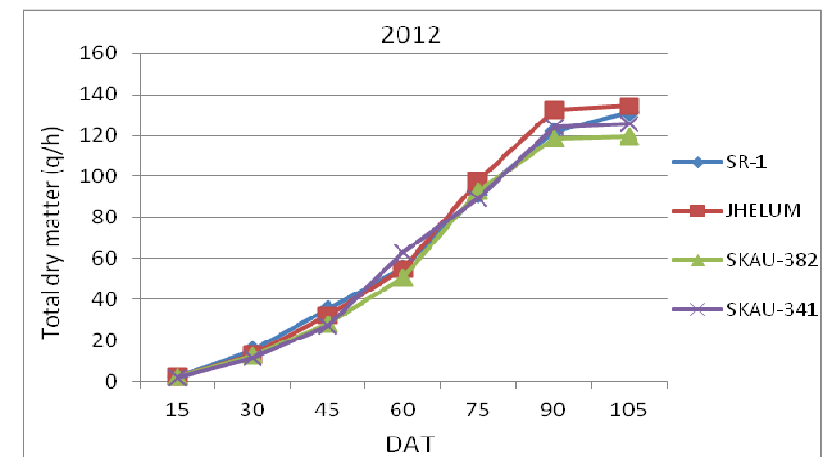
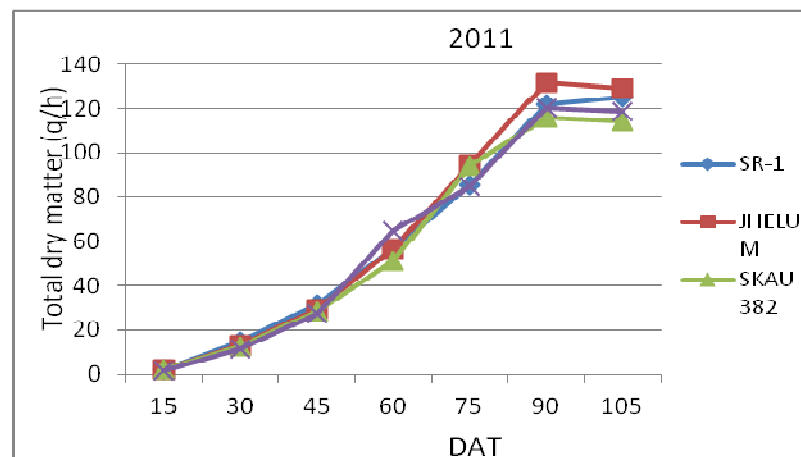


Fig. 12 : Periodic dry matter as affected by rice cultivars

4.1.5 Leaf dry matter accumulation

Leaf dry matter varied significantly by transplanting dates (Table 11 and Fig. 13). 25 June and 10 June transplanting were at par and significantly superior to 25 May transplanting at 15 DAT during both the years. At 30 DAT 25 May transplanting was significantly superior over 10 June and 25 June transplanting except 2011 where 25 May and 10 June transplanting were at par. At 45 DAT 10 June transplanting significantly produces more leaf dry matter over 25 May and 25 June transplanting except 2012 where 25 May and 10 June were at par. At 60 DAT till maturity (105 DAT) 25 May transplanting was superior to 10 and 25 June transplanting during both years.

Cultivars under study responded significantly to leaf dry matter at all periodic stages. At 15 DAT, Cultivar Jhelum was significantly superior to other cultivars where Shalimar rice 1 and SKAU-382 were at par. At 30 and 45 DAT Shalimar rice 1 significantly produced more leaf dry matter except 45 DAT during 2011 where Shalimar rice 1 and SKAU-341 were at par. At 60 DAT (anthesis) till 105 DAT (maturity) the leaf dry matter was in the order of SKAU-341 > Shalimar rice 1 > SKAU-382 > Jhelum, SKAU-341 was significantly superior to other cultivars and Shalimar rice-1 was also superior then Jhelum and SKAU-382 (Table 11 and Fig. 14).

4.1.6 Stem dry matter accumulation

Stem dry matter production was significantly affected by transplanting date during both the years (Table 12 and Fig. 15). At 15, 30, 45 and 60 DAT transplanting 25 June significantly produced more stem dry matter compared to 10 June and 25 May transplanting, where 10 and 25 June were statistically at par with each other at 15 DAT and 60 DAT during 2011. At 75 DAT till maturity (105 DAT) 25 May transplanting was statistically significant then 10 and 25 June transplanting during both the years.

With regard to stem dry matter production cultivars significantly varied

Table11: Periodic leaf dry matter (q ha⁻¹) of rice cultivars as influenced by transplanting dates

Treatment	15 DAT		30 DAT		45 DAT		60 DAT		75 DAT		90 DAT		105 DAT (Maturity)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting date														
25 th May	1.11	1.21	8.11	8.04	12.73	13.38	29.31	30.26	21.71	24.59	20.59	19.67	17.41	18.74
10 th June	1.63	1.60	7.60	7.16	14.87	16.31	24.38	23.42	20.09	22.39	19.32	18.52	15.89	15.47
25 th July	1.69	1.58	7.28	6.96	12.21	12.10	20.42	19.42	17.48	18.97	15.51	15.34	12.82	12.58
SE(m)±	0.02	0.03	0.15	0.09	0.25	0.32	2.35	1.46	0.56	0.81	0.33	0.95	0.88	0.95
CD (0.05)	0.08	0.11	0.60	0.35	0.99	1.25	9.01	5.73	2.32	3.16	0.13	3.70	3.52	3.73
Cultivars														
Shalimar rice-1	1.43	1.47	9.10	9.17	13.82	15.23	24.41	24.82	18.82	20.82	18.68	16.74	16.32	16.27
Jhelum	1.63	1.67	8.04	7.78	12.71	14.07	23.03	22.90	18.01	19.91	17.61	16.08	11.71	13.00
SKAU-382	1.53	1.50	7.20	6.75	12.29	12.05	19.76	20.57	16.42	18.06	15.52	14.74	12.62	13.77
SKAU- 341	1.25	1.23	6.31	5.86	14.22	14.36	31.72	29.18	25.67	29.13	22.14	23.82	20.81	21.50
SE(m)±	0.04	0.05	0.21	0.22	0.36	0.23	2.12	1.17	0.99	1.39	1.03	1.22	0.93	1.14
CD(0.05)	0.11	0.15	0.62	0.64	1.06	0.64	6.13	3.48	0.30	4.12	0.31	3.56	2.80	3.38

Table12: Periodic stem dry matter (q ha⁻¹) of rice cultivars as influenced by transplanting dates

Treatment	I5 DAT		30 DAT		45 DAT		60 DAT		75 DAT		90 DAT		I05 DAT (Maturity)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting date														
25 th May	0.29	0.30	4.52	4.21	9.93	10.33	22.42	24.41	52.50	53.68	54.67	54.83	48.62	50.35
10 th June	0.78	0.81	5.41	5.99	14.31	14.83	29.71	30.12	43.52	43.66	46.88	47.54	41.86	42.11
25 th July	0.85	0.93	6.33	7.01	23.30	25.09	32.41	36.80	37.91	38.42	39.92	39.41	36.32	38.14
SE(m)±	0.03	0.01	0.20	0.26	0.63	0.60	1.91	0.98	1.62	1.99	1.25	0.68	1.27	1.68
CD (0.05)	0.11	0.03	0.79	1.01	2.51	2.34	7.42	3.83	6.24	7.79	4.61	2.65	4.92	6.56
Cultivars														
Shalimar rice-1	0.63	0.64	5.93	5.97	17.92	19.98	29.33	30.45	44.72	47.00	46.83	47.82	42.11	43.54
Jhelum	0.64	0.73	5.31	5.31	16.81	18.15	26.61	28.47	43.41	45.14	45.02	46.04	38.14	41.06
SKAU-382	0.65	0.63	5.34	5.79	15.83	16.02	24.14	27.78	41.61	41.48	43.31	42.44	38.82	39.57
SKAU- 341	0.64	0.73	5.08	5.86	12.80	12.85	32.73	35.11	49.13	47.38	53.42	52.74	55.13	57.96
SE(m)±	0.03	0.04	0.17	0.16	0.48	0.69	2.24	1.57	1.73	2.56	1.92	2.31	1.25	1.50
CD(0.05)	NS	NS	0.52	0.47	1.43	2.04	6.61	4.67	5.04	7.60	5.53	6.85	3.62	4.47

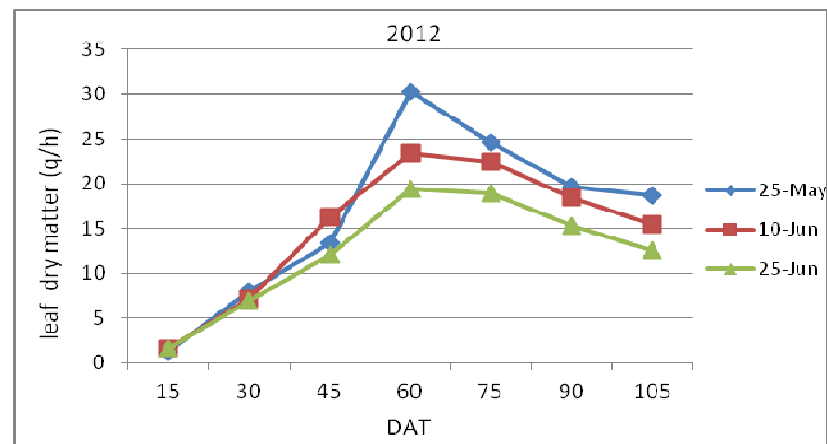
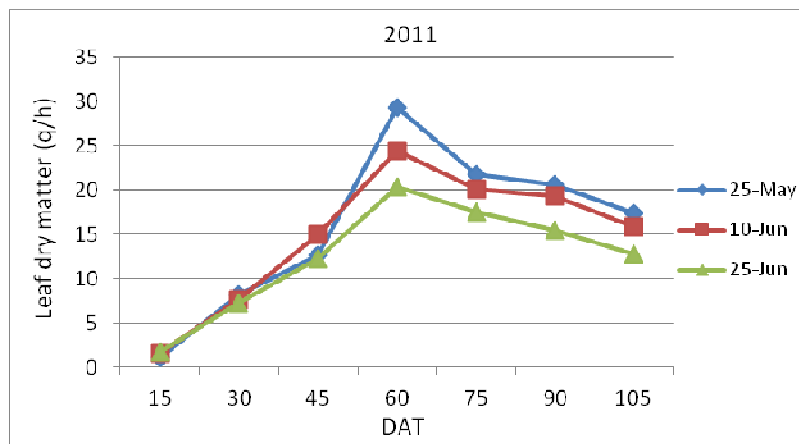


Fig. 13 : Periodic leaf dry matter as affected by transplanting dates

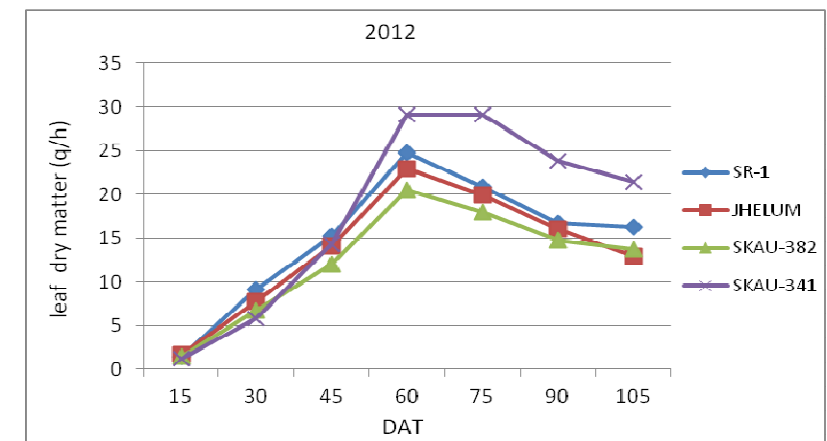
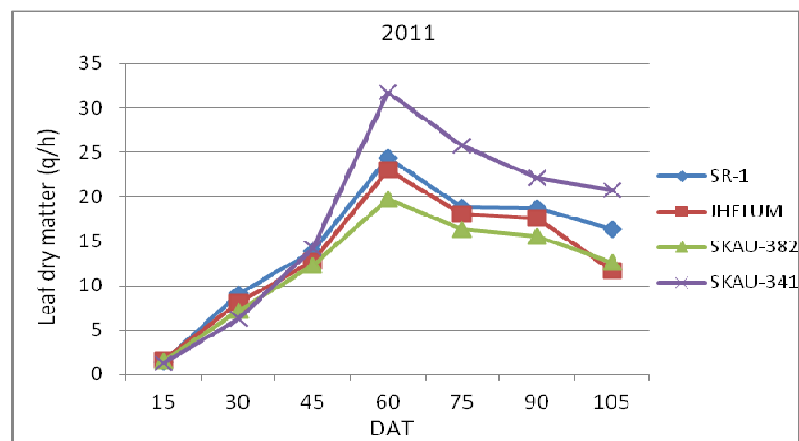


Fig. 14 : Periodic leaf dry matter as affected by rice cultivars

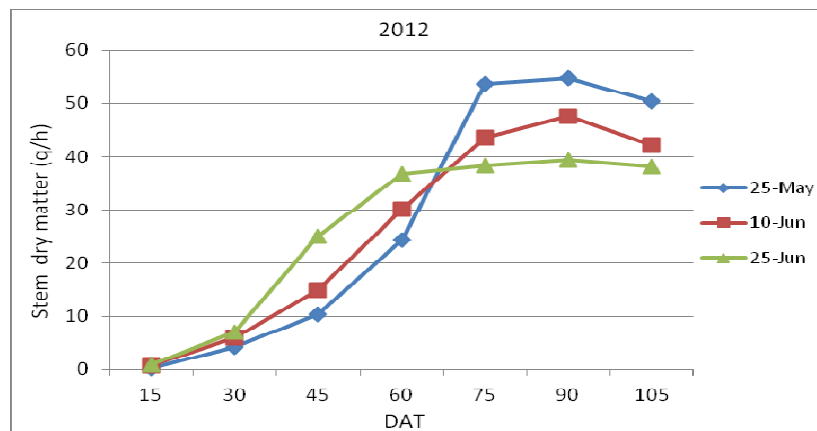
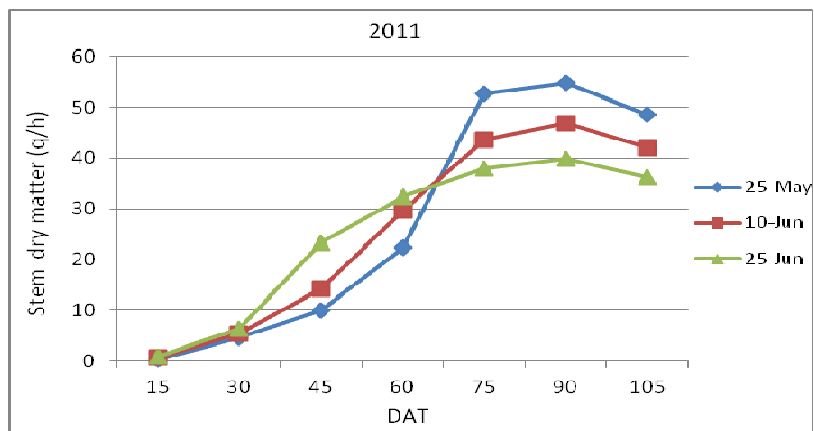


Fig. 15: Periodic stem dry matter as affected by transplanting dates

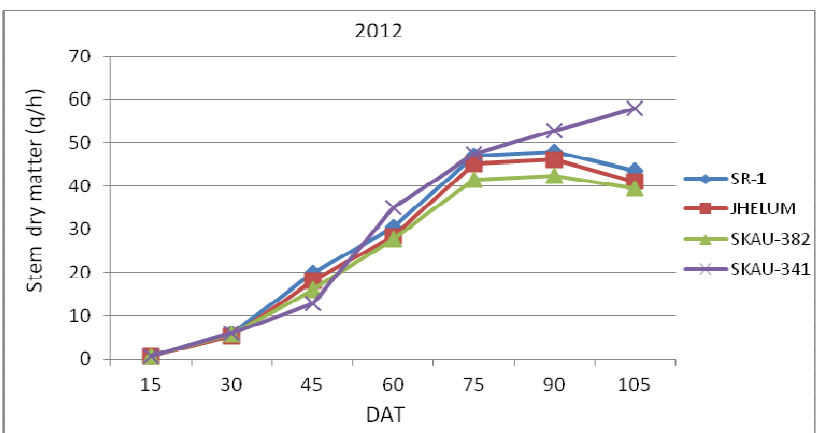
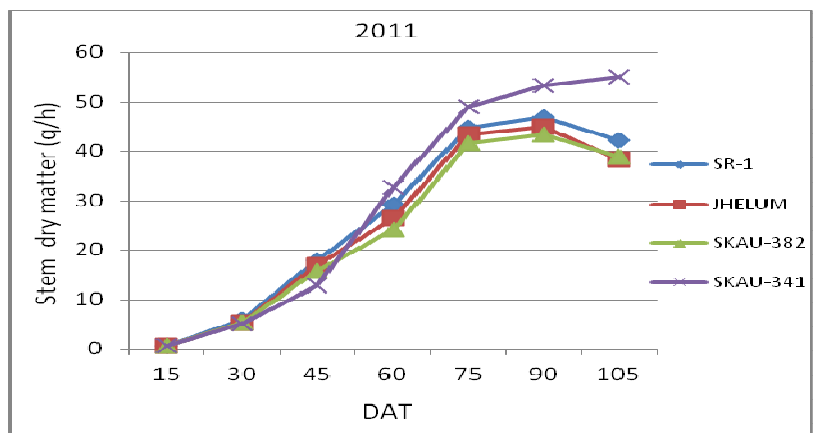


Fig. 16 : Periodic stem dry matter as affected by rice cultivars

during both the years (Table 12 and Fig. 16). At 15 DAT there was no significant difference among cultivars. At 30 and 45 DAT Shalimar rice-1 accumulated significantly more stem dry matter than other cultivars. At 60 DAT till maturity SKAU-341 recorded significantly more stem dry matter followed by SR-1 than Jhelum and than SKAU- 382 during both the years. Shalimar rice-1, Jhelum and SKAU-382 were statistically at par with each other at 45 DAT till maturity (105 DAT) during both the years.

4.1.7 Panicle dry matter accumulation

Panicle dry matter production was significantly affected by transplanting date during both the years (Table 13 and Fig. 17). At 75 DAT transplanting 25 June significantly produced more panicle dry matter compared to 10 June and 25 May transplanting except during 2011 where 10 and 25 June were statistically at par. At maturity (105 DAT) 25 May was statistically significant than 10 and 25 June transplanting and 10 June was superior than 25 June during both the years.

With regard to panicle dry matter production cultivars significantly varied during both the years (Table 13 and Fig. 18). At 60 and 75 DAT Jhelum and SKAU-382 were significantly superior among cultivars. At maturity Jhelum recorded significantly more Jhelum dry matter followed by Shalimar rice-1, SKAU- 382 and SKAU-341 during both the years.

4.1.8 Leaf number per Culm

Data presented in Table 14 and Fig. 19 revealed that leaf number per culm increased up to 60 DAT (anthesis) and the highest value was found at 60 DAT, thereafter the number gradually decreased in all the treatments during both the years. At 15 days after transplanting there was no significant difference between 3 dates of transplanting during both the years. At 30DAT highest leaf number was found on 25 June transplanting followed by 10 June and then 25 May transplanting there was significant difference between all the dates of

Table 13: Periodic panicle dry matter (q ha⁻¹) of rice cultivars influenced by transplanting dates

Treatment	15 DAT		30 DAT		45 DAT		60 DAT		75 DAT		90 DAT		105 DAT (Maturity)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting date														
25 th May	-	-	-	-	-	-	0.01	0.02	15.31	12.32	54.61	57.13	79.50	84.22
10 th June	-	-	-	-	-	-	2.53	0.01	26.62	28.01	60.32	63.42	65.83	68.61
25 th July	-	-	-	-	-	-	0.61	4.23	33.84	36.41	55.74	56.94	55.21	58.31
SE(m)±	-	-	-	-	-	-	0.48	0.02	2.72	2.34	1.52	1.42	1.19	1.28
CD (0.05)	-	-	-	-	-	-	1.92	0.07	10.31	9.14	5.82	5.33	4.11	4.62
Cultivars														
Shalimar rice-1	-	-	-	-	-	-	0.32	0.02	22.02	23.64	56.54	57.74	66.62	71.24
Jhelum	-	-	-	-	-	-	3.81	3.41	33.11	32.71	59.32	58.13	69.24	70.61
SKAU-382	-	-	-	-	-	-	2.43	2.24	35.52	33.32	57.01	61.31	62.81	65.03
SKAU- 341	-	-	-	-	-	-	0.01	0.02	10.31	12.64	44.82	47.41	59.68	62.42
SE(m)±	-	-	-	-	-	-	0.34	0.33	1.67	1.68	1.99	2.73	1.88	2.51
CD(0.05)	-	-	-	-	-	-	1.0	0.97	4.73	4.81	5.52	8.04	5.34	7.46

Table 14: Periodic leaf No. per culm of rice cultivars as influenced by transplanting dates

Treatment	15 DAT		30 DAT		45 DAT		60 DAT		75 DAT		90 DAT		105 DAT (Maturity)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting date														
25 th May	2.43	2.57	3.02	3.12	3.92	3.98	4.47	4.35	4.24	4.17	3.63	3.97	2.86	2.79
10 th June	2.91	2.96	3.23	3.29	3.67	3.79	4.26	4.22	3.60	3.79	2.95	3.13	2.57	2.63
25 th July	3.22	3.10	3.41	3.53	3.56	3.61	4.24	4.29	3.24	3.18	2.44	2.50	2.17	2.05
SE(m)±	0.04	0.07	0.05	0.03	0.03	0.07	0.03	0.06	0.11	0.09	0.04	0.04	0.04	0.07
CD (0.05)	NS	NS	0.20	0.12	0.13	0.27	0.11	0.23	0.42	0.35	0.28	0.16	0.15	0.27
Cultivars														
Shalimar rice-1	2.95	3.03	3.92	3.82	3.59	3.86	4.64	4.71	4.07	3.92	3.09	3.15	2.37	2.55
Jhelum	2.75	2.86	3.21	3.49	3.74	3.71	3.76	3.89	3.60	3.71	2.91	2.84	2.18	2.29
SKAU-382	3.01	3.11	3.31	3.61	3.82	3.90	3.69	3.88	3.17	3.29	2.35	2.66	2.22	2.14
SKAU- 341	2.82	2.76	2.90	3.33	3.35	3.38	5.07	4.97	4.68	4.38	4.02	3.87	3.07	3.57
SE(m)±	0.06	0.07	0.09	0.06	0.06	0.06	0.07	0.08	0.11	0.08	0.05	0.07	0.05	0.12
CD(0.05)	NS	NS	NS	NS	0.18	0.17	0.22	0.23	0.33	0.23	0.14	0.22	0.14	0.35

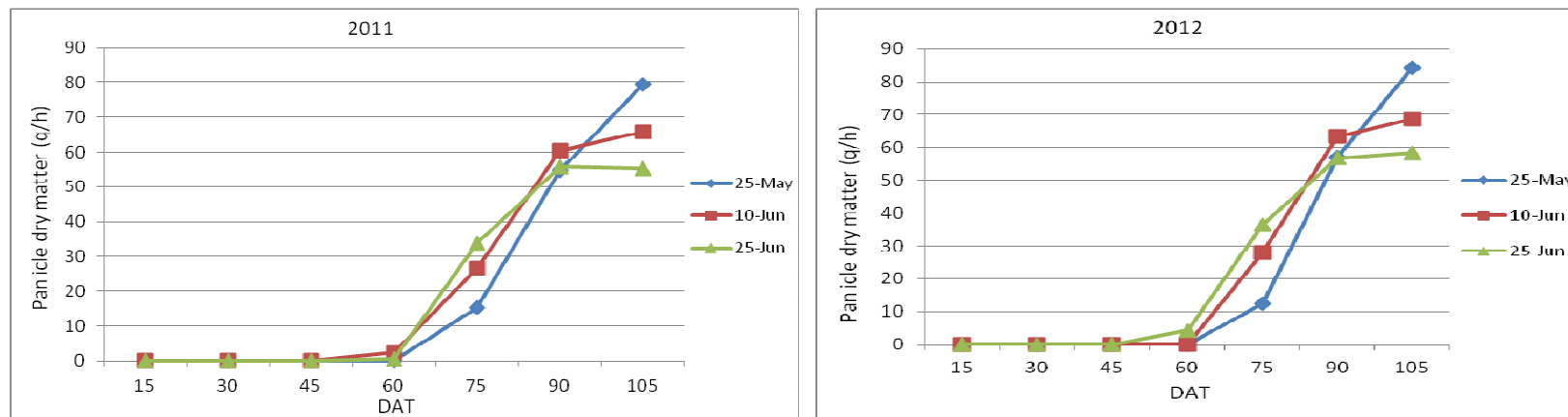


Fig. 17 : Periodic panicle dry matter as affected by transplanting dates

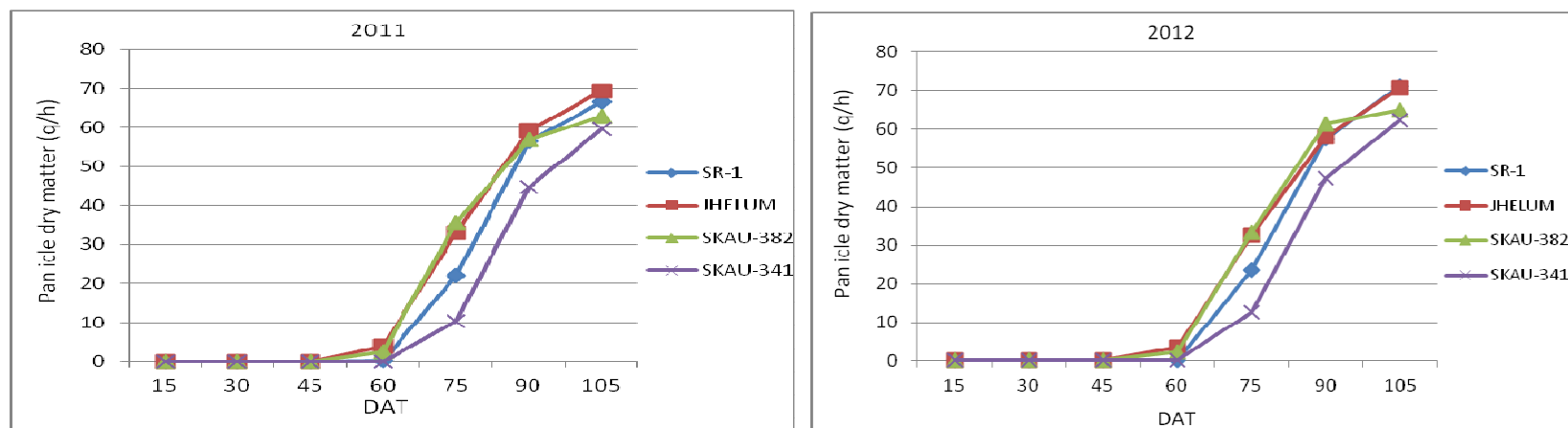


Fig. 18 : Periodic panicle dry matter as affected by rice cultivars

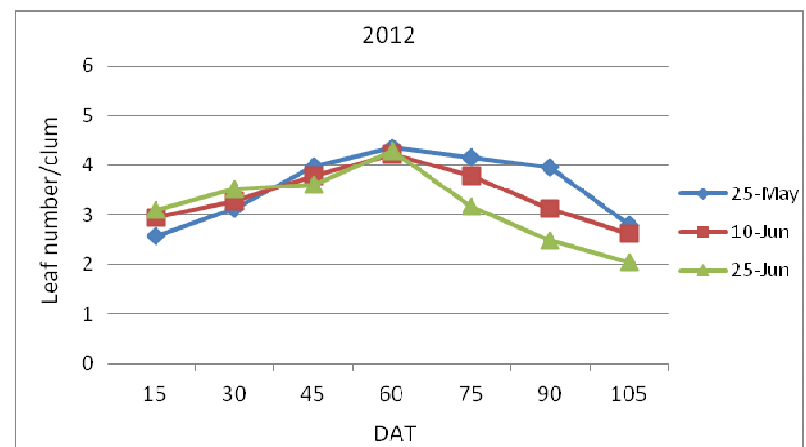
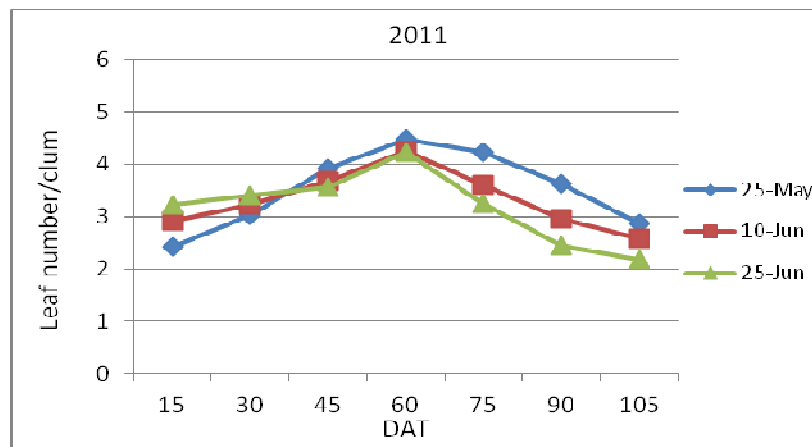


Fig. 19 : Periodic leaf number as affected by transplanting dates

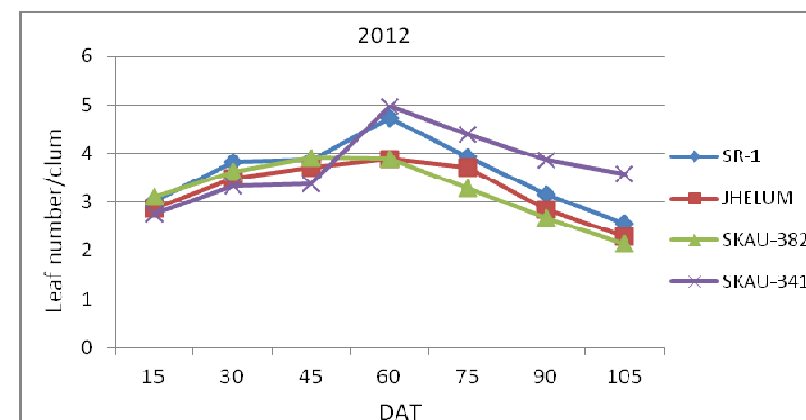
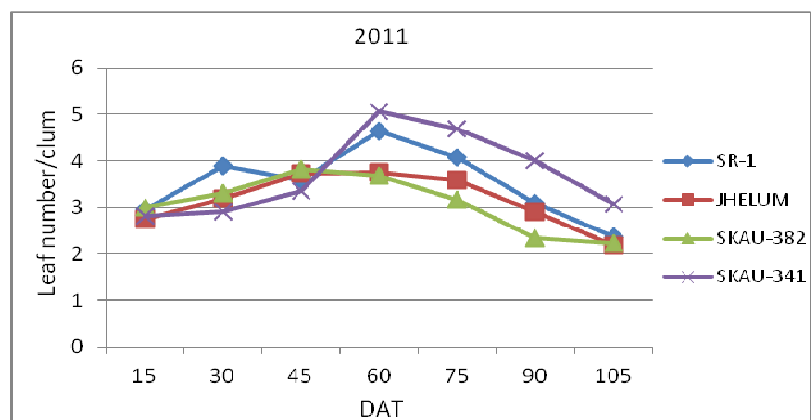


Fig. 20 : Periodic leaf number as affected by rice cultivars

transplanting. At 45 DAT till maturity highest leaf number was recorded on 25 may transplanting followed by 10 June and then 25 June during both the years.

During 2011 and 2012 at 15 and 30 DAT all cultivars show no significant difference (Table 14 and Fig. 20). At 45 DAT Jhelum and SKAU-382 were superior to Shalimar rice-1 and SKAU-341. SKAU-341 recorded significantly higher leaf number followed by Shalimar rice-1 at 60, 75, 90 and 105 DAT. Jhelum and SKAU-382 were statistically similar almost whole crop period except 45DAT 2011, 75 DAT during both years and 90DAT in year 2011.

4.1.9 Specific Leaf Weight

Data presented in Table 15 and Fig. 21, was significantly affected by transplanting dates during both the years. At 15 DAT the specific leaf weight of 25 June transplanting was significantly superior over 10 June transplanting and 10 June transplanting was superior over 25 may transplanting during 2011 but during 2012, 25 June transplanting was superior over 25 May transplanting and 10 June transplanting was at par with 25 May and 25 June transplanting. At 60 DAT (anthesis) 25 May transplanting significantly accumulated more specific leaf weight than 10 and 25 June transplanting; however 10 and 25 June transplanting were statistically at par. At maturity (105DAT) the 25 May transplanting recorded significantly highest specific leaf weight than 25 June but 10 June was at par with 25 May and 25 June during 2011. During 2012 the highest specific leaf weight was recorded by 25 May transplanting but there was no significant difference among transplanting dates. The highest specific leaf weight was recorded at 60 DAT.

During 2011 and 2012 at 15 and 30 DAT all cultivars show no significant difference. At 60 DAT (anthesis) the cultivar SKAU-341 had highest specific leaf weight and was significantly superior than SKAU-382 but there was no significant difference among other cultivars during 2011, but during 2012 cultivar SKAU-341 was significantly superior over other cultivars and Shalimar rice-1 was

Table 15: Periodic specific leaf weight (g / cm²) of rice cultivars as influenced by transplanting dates

Treatment	15 DAT		30 DAT		45 DAT		60 DAT		75 DAT		90 DAT		105 DAT (Maturity)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting date														
25 th May	3.01	3.04	3.44	3.53	3.60	4.05	5.63	5.91	5.22	5.42	3.91	4.14	3.81	3.91
10 th June	3.83	3.62	4.06	3.91	4.04	4.04	4.21	4.59	4.14	4.43	3.25	3.62	3.35	3.50
25 th July	4.60	4.51	4.81	4.82	5.05	5.13	4.73	4.91	4.53	4.71	3.04	3.31	2.93	3.52
SE(m)±	0.13	0.24	0.26	0.26	0.16	0.23	0.54	0.32	0.10	0.20	0.05	0.35	0.23	0.24
CD (0.05)	0.52	0.93	0.97	0.81	0.43	0.87	1.16	0.91	0.61	1.41	0.23	1.84	0.88	NS
Cultivars														
Shalimar rice-1	3.64	3.82	4.24	4.43	5.25	5.05	5.45	5.33	5.01	5.15	4.53	4.31	4.14	4.01
Jhelum	3.71	3.93	4.02	4.23	4.40	4.33	4.72	4.50	4.44	4.33	3.84	3.64	3.05	3.22
SKAU-382	3.73	3.74	3.85	3.94	4.32	4.14	4.51	4.41	4.23	4.10	3.51	3.25	3.23	2.95
SKAU- 341	3.52	3.81	3.83	4.01	5.14	5.41	5.94	6.04	5.52	5.73	5.04	5.30	4.54	4.73
SE(m)±	0.12	0.23	0.51	0.22	0.14	0.11	0.52	0.24	0.35	0.33	0.24	0.36	0.26	0.28
CD(0.05)	NS	NS	NS	0.65	0.41	0.34	1.32	0.63	0.81	0.81	0.54	1.11	0.76	0.82

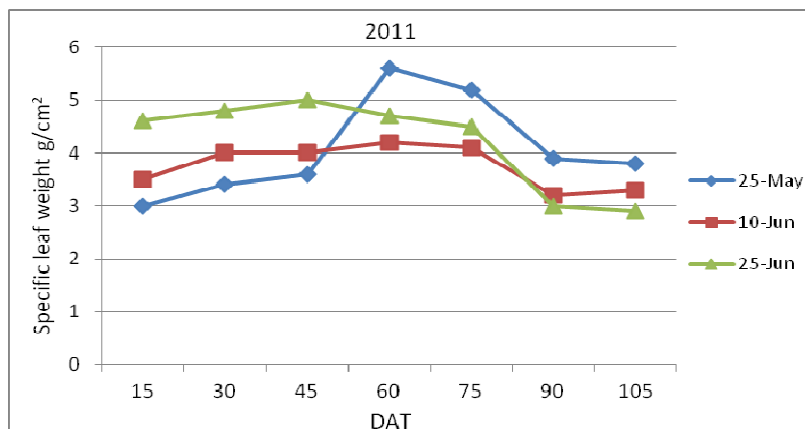


Fig. 21 : Periodic specific leaf weight as affected by transplanting dates

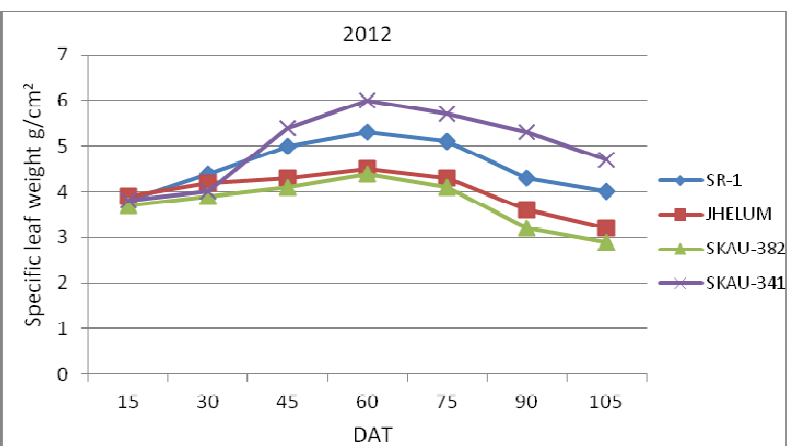
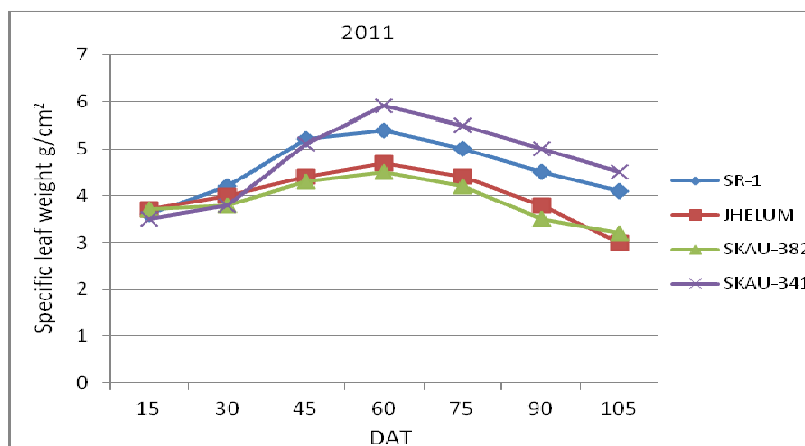


Fig. 22 : Periodic specific leaf weight as affected by rice cultivars

significantly superior over SKAU-382, but there was no significant difference between SKAU-382 and Jhelum. At 105 DAT (maturity) cultivar SKAU-341 recorded highest specific leaf weight and was significantly superior over Jhelum and SKAU-382, cultivar SKAU-341 and Shalimar rice-1 were at par and Shalimar rice-1 was also significantly superior over Jhelum and SKAU-382 during both the years (Table 15 and Fig. 22).

4.1.10 Relative growth rate

Relative growth rate was significantly affected by transplanting dates during both the years (Table 16 and Fig. 23). At 15-30 DAT transplanting on 25 June recorded more relative growth compared to 10 June and 25 May transplanting, 25 June was significantly superior than 25 May transplanting, where 10 June were statistically at par with 25 May and 25 June transplanting during both the years. At 60-75 DAT (flowering) 25 May transplanting was significantly superior to 25 June transplanting, 10 June being at par with 25 May and 25 June during both the years. At 90-105 DAT (maturity) 25 May transplanting had higher relative growth rate than 10 and 25 June transplanting but there was no significant difference during both the years.

With regard to relative growth rate of different cultivars it varied significantly during both the years (Table 16 Fig. 24). At 15-30 DAT SR-1 significantly had higher relative growth rate than other cultivars during both the years. At 60 (flowering) till maturity 105 DAT cultivar SKAU-341 significantly superior than other cultivars. At maturity SKAU-341 recorded highest value of relative growth rate than other cultivars, but there was no significant difference among cultivars. At most of the growing periods SR-1, Jhelum and SKAU 382 were statistically at par during both the years.

4.1.11 Dead leaf weight

Data presented in Table 17 and Fig. 25 revealed that during the period of 2011 and 2012 at 15 and 30 DAT there was no significant difference between

Table 16: Periodic relative growth rate (kg/kg/day) of rice cultivars as influenced by transplanting dates

Treatment	15 DAT		30 DAT		45 DAT		60 DAT		75 DAT		90 DAT		105 DAT (Maturity)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting date														
25 th May	4.32	4.45	3.71	3.92	2.35	2.39	1.59	1.53	1.08	1.10	0.16	0.28	3.8	3.9
10 th June	4.94	4.91	3.88	3.90	1.93	1.57	1.35	1.33	0.98	0.93	0.07	0.03	3.3	3.5
25 th July	5.88	5.97	3.80	3.83	1.70	1.41	1.01	1.27	0.63	0.51	0.03	0.05	2.9	3.5
SE(m)±	0.37	0.48	0.94	1.10	0.18	0.31	0.17	0.21	0.05	0.10	0.55	0.40	0.23	0.24
CD (0.05)	1.45	1.90	NS	NS	0.61	0.92	0.56	NS	0.18	0.30	NS	NS	0.88	NS
Cultivars														
Shalimar rice-1	5.87	5.71	2.17	2.44	1.69	1.29	1.30	1.33	1.03	1.07	0.09	0.13	4.1	4.0
Jhelum	5.20	5.32	2.31	2.61	1.90	1.52	1.17	1.15	0.97	0.87	0.07	0.05	3.0	3.2
SKAU-382	5.28	5.39	2.35	2.33	1.74	1.70	1.19	1.10	0.61	0.71	0.04	0.02	3.2	2.9
SKAU- 341	5.18	5.26	2.55	2.44	2.49	2.44	1.80	1.94	1.23	1.11	0.15	0.29	4.5	4.7
SE(m)±	1.14	1.90	0.24	0.20	0.17	0.21	0.11	0.19	0.08	0.05	0.65	0.68	0.26	0.28
CD(0.05)	NS	NS	NS	NS	0.54	0.68	0.39	0.54	0.24	0.19	NS	NS	0.76	0.82

Table 17: Periodic dead leaf weight production (q ha⁻¹) of rice cultivars influenced by transplanting dates

Treatment	I5 DAT		30 DAT		45 DAT		60 DAT		75 DAT		90 DAT		I05 DAT (Maturity)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting date														
25 th May	0.25	0.26	0.56	0.57	3.40	3.25	5.64	5.52	8.46	7.57	11.75	12.47	17.01	18.05
10 th June	0.33	0.32	0.56	0.60	3.71	3.50	7.87	7.13	9.49	8.70	12.63	12.95	4.68	14.85
25 th July	0.38	0.35	0.61	0.62	4.79	4.70	8.93	8.02	9.72	9.24	12.16	11.88	12.71	12.29
SE(m)±	0.01	0.11	0.02	0.02	0.03	0.05	0.03	0.01	0.02	0.02	0.03	0.01	.02	0.05
CD (0.05)	NS	NS	NS	NS	0.13	0.19	0.12	0.05	0.07	0.09	0.13	0.03	0.08	0.21
Cultivars														
Shalimar rice-1	0.41	0.38	0.57	0.61	4.50	3.74	5.95	5.25	8.85	8.12	13.70	12.51	5.69	14.59
Jhelum	0.22	0.25	0.59	0.58	4.72	4.08	5.72	5.38	9.09	8.73	13.41	13.66	13.26	14.15
SKAU-382	0.38	0.32	0.64	0.65	4.95	4.47	5.64	5.60	9.18	9.11	12.17	12.04	12.24	12.43
SKAU- 341	0.26	0.30	0.49	0.55	2.95	2.99	4.62	4.33	8.11	7.43	12.36	12.59	3.01	13.11
SE(m)±	0.01	0.02	0.01	0.02	0.02	0.06	0.03	0.03	0.03	0.02	0.02	0.02	0.03	0.07
CD(0.05)	NS	NS	NS	NS	0.06	0.19	0.09	0.08	0.08	0.06	0.06	0.07	0.09	0.19

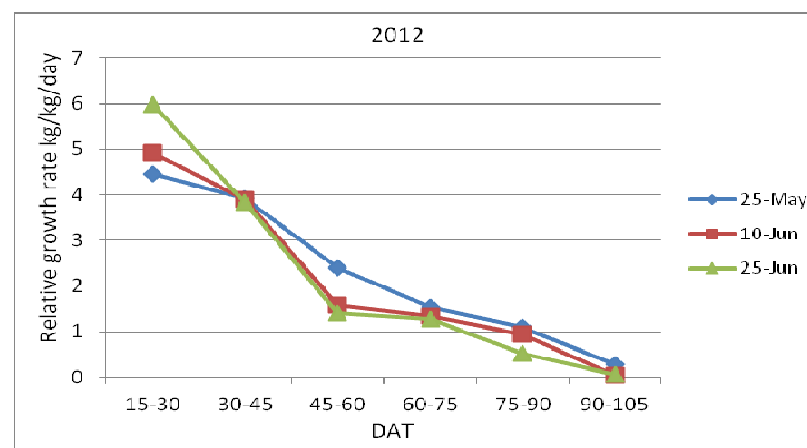
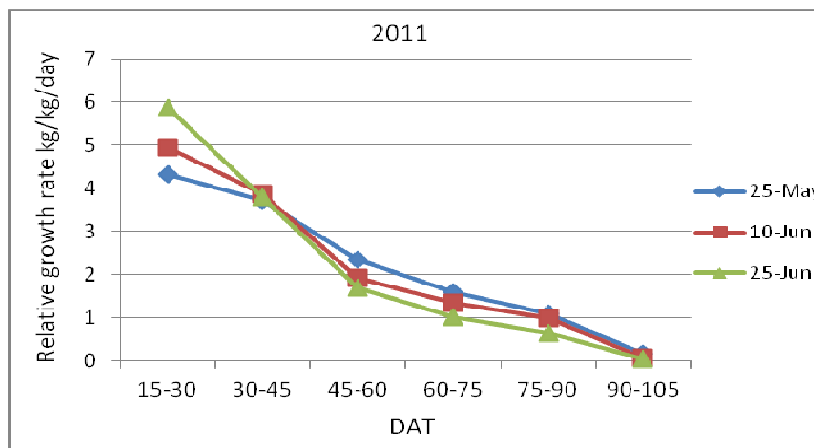


Fig. 23 : Periodic Relative growth rate as affected by transplanting dates

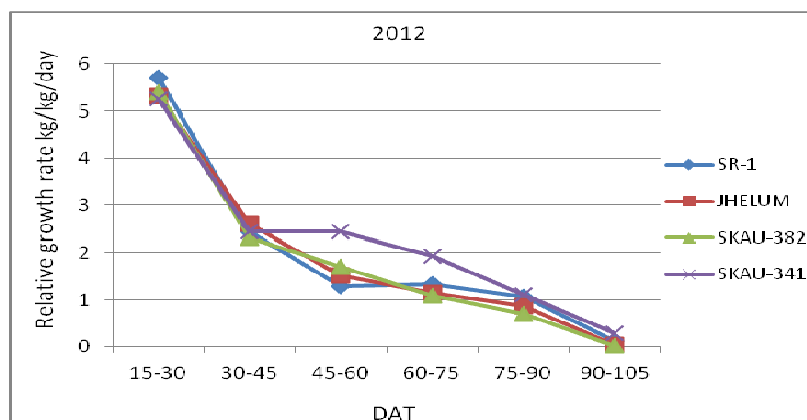
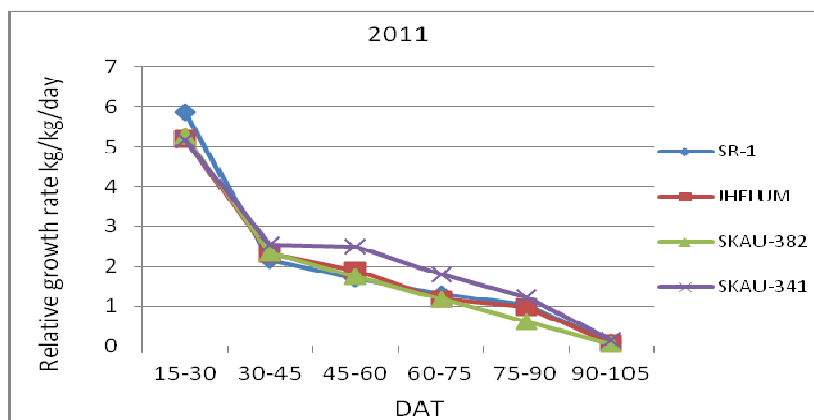


Fig. 24: Periodic Relative growth rate as affected by rice cultivars

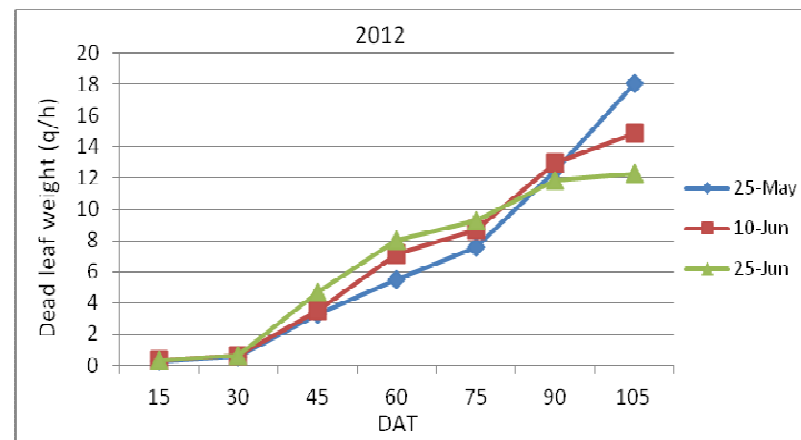
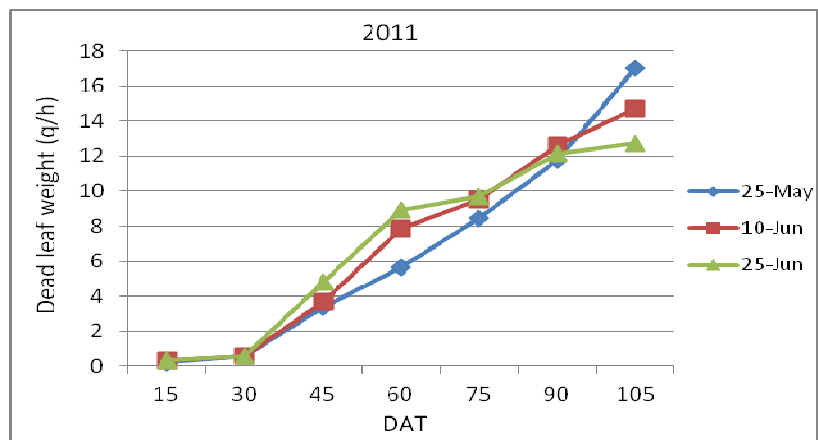


Fig. 25 : Periodic Dead leaf weight as affected by transplanting dates

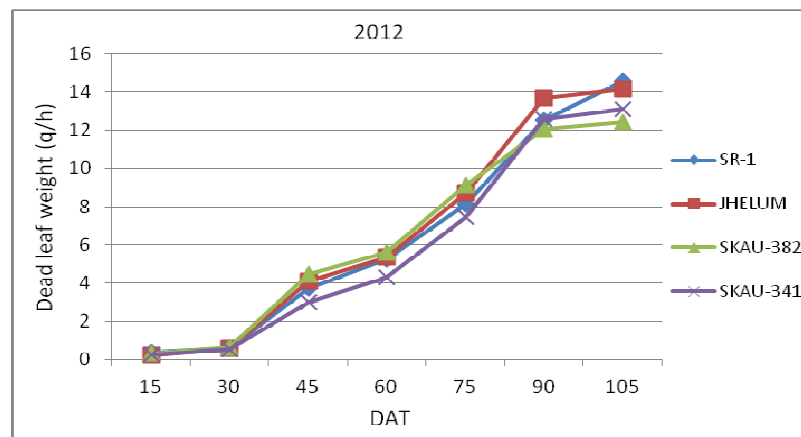
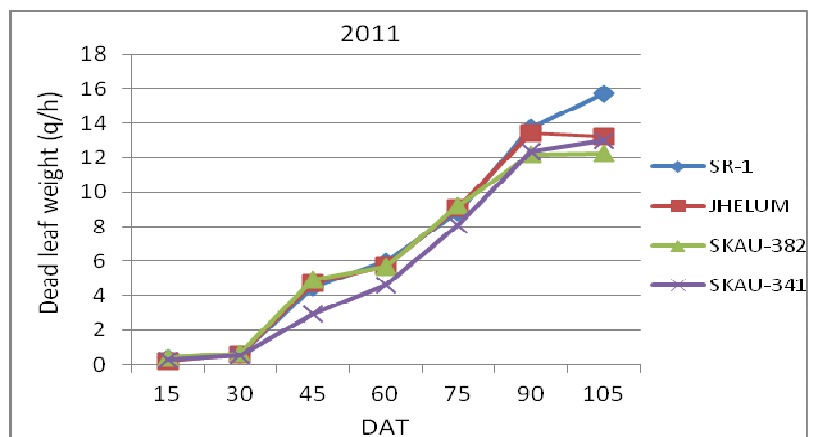


Fig. 26 : Periodic Dead leaf weight as affected by rice cultivars

25 May, 10 June and 25 May transplanting. At 45 DAT, 60 DAT and 75 DAT (anthesis) 25 June recorded significantly highest dead leaf weight followed by 10 June and then 25 May transplanting during both the years. At 90 DAT 10 June significantly recorded more dead leaf weight than 25 May and 25 June transplanting. At maturity (105 DAT) 25 May significantly had more dead leaf weight compared to 10 and 25 June transplanting during both the years.

During 2011 and 2012 at 15 and 30 DAT all cultivars show no significant difference. At 45 DAT Jhelum and SKAU-382 were superior to Shalimar rice-1 and SKAU-341. At 60 DAT (anthesis) during 2011 SR-1 significantly recorded more dead leaf weight than other cultivars and during 2012 SKAU-382 recorded significantly higher dead leaf weight. At 75 DAT SKAU-382 significantly recorded more dead leaf weight followed by Jhelum then Shalimar Rice-1 and then SKAU-341. At 90 DAT during 2011 SR-1 recorded significantly highest dead leaf weight and there was significant difference among all the cultivars, during 2012 at 90 DAT Jhelum significantly recorded highest dead leaf weight. At maturity (105 DAT) SR-1 significantly recorded more dead leaf weight followed by Jhelum then SKAU-341 and then SKAU-382 (Table 17 and Fig. 26).

4.2 Phenological stages and growth duration.

Table 18 and Fig. 27 indicated that various phenological stages viz. transplanting shock over, tillering, panicle initiation, anthesis 50% flowering milking and maturity were affected due to various treatments. Transplanting shock was over in 5 days in most of the treatments during both the years except 10 June transplanting in 2012 which took only 4 days for all cultivars and 25 May transplanted SR-1 took 6 days in both the years. Crop transplanted on 25 May took more days to reach tillering, panicle initiation, anthesis and maturity compared to 10 June which in turn took more days than 25 June. Days taken to reach anthesis were 99.5 and 100.8, 92.0 and 92.5, 83.3 and 83.8 for 25 May, 10

Table 18: Phenology of rice cultivars as influenced by transplanting dates

Treatment	Transplanting shock over		Tillering		Panicle initiation		Anthesis		50 % flowering		Milking		Dough		Physiological maturity		Harvesting	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
25 th May SR-1	6	6	19	20	39	40	64	66	75	75	73	72	87	88	104	107	110	112
25 th May Jhelum	5	5	19	20	39	39	62	63	74	73	73	71	84	85	102	104	110	112
25 th May SKAU-382	5	5	19	20	39	39	61	62	73	72	72	71	83	83	102	102	110	112
25 th May SKAU-341	5	5	20	20	45	43	71	72	81	82	79	79	93	94	112	115	118	119
10 th June SR-1	5	4	13	14	37	36	61	62	65	66	66	65	80	83	95	98	100	104
10 th June Jhelum	5	4	15	13	36	35	60	60	65	65	64	64	78	80	93	95	100	104
10 th June SKAU-382	4	4	12	12	36	35	60	61	66	65	64	63	76	78	92	93	100	104
10 th June SKAU-341	5	4	15	15	42	41	67	67	72	73	71	72	88	89	102	106	105	109
25 th June SR-1	5	5	13	14	36	34	56	58	61	64	61	62	77	76	89	91	95	98
25 th June Jhelum	5	5	14	14	36	35	56	56	60	62	59	58	74	73	86	88	95	98
25 th June SKAU-382	5	5	13	14	36	34	58	57	62	63	61	62	73	73	84	86	95	98
25 th June SKAU-341	5	5	15	14	40	41	63	64	67	70	69	71	82	81	95	99	100	105

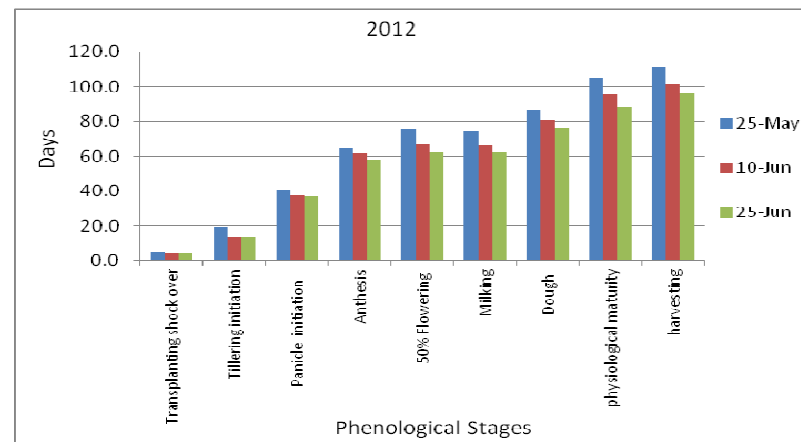
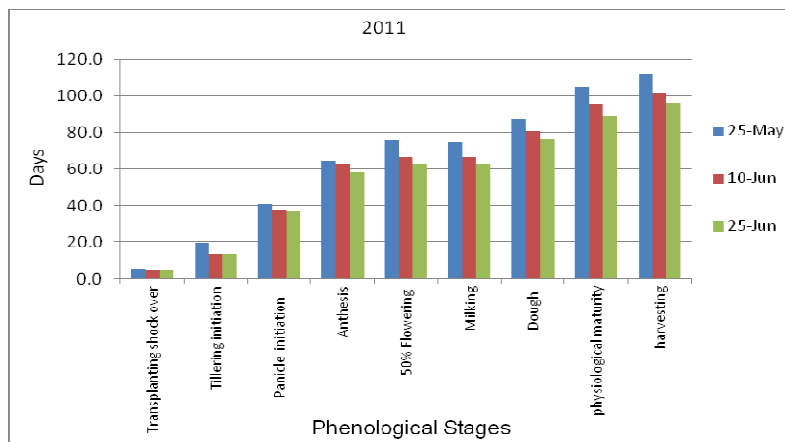


Fig. 27 : Days taken to various phenological stages as affected by transplanting dates

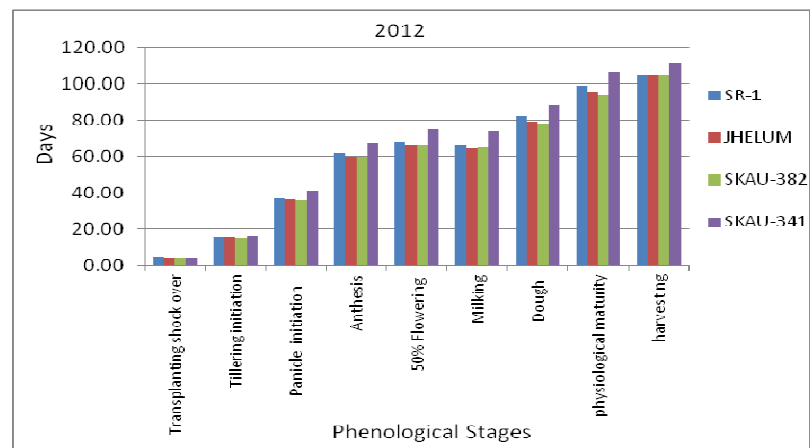
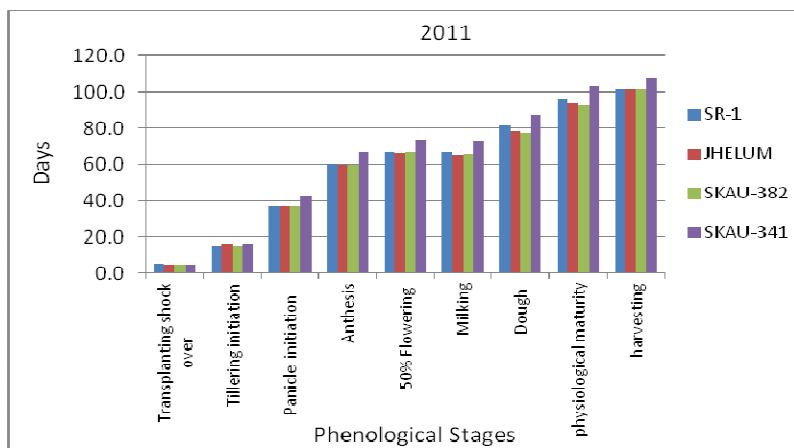


Fig. 28: Days taken to various phenological stages as affected by cultivars

June and 25 June transplanting dates during 2011 and 2012, respectively. Days taken to reach maturity were 141.8 and 142.3, 32.0 and 133.1, 123.0 and 124.8 for 25 May, 10 June and 25 June transplanting dates during 2011 and 2012, respectively.

Cultivars also behaved differently with regard to number of days taken to reach various phenological stages. Variety SKAU-341 after panicle initiation required more number of days to reach various stages, where as all other varieties almost took same days during both years. Days taken to reach anthesis stage for SKAU-341 were 97 and 98.7, Shalimar rice-1 were 90.3 and 92.3, Jhelum were 89.3 and 92.2 and SKAU-382 were 88.3 and 89.4 during 2011 and 2012, respectively. Days taken to reach maturity for all cultivars SKAU-341 were 139.0 and 138.2, Shalimar rice-1 were 131.3 and 132.3, Jhelum were 129.7 and 131.3 and SKAU-382 were 130.0 and 131.6 days during 2011 and 2012, respectively (Table 18 and Fig. 28).

4.3 Yield attributing characters

4.3.1 Spikelets panicle⁻¹

Spikelets panicle⁻¹ was influenced by transplanting dates during both the years (Table 19). Transplanting on 25 May being at par with 10 June recorded significantly more spikelet number than 25 June transplanting during both years. The maximum number of spikelets 114.08 and 115.04 from 25 May transplanting and minimum 92.61 and 91.70 from 25 June transplanting were recorded during 2011 and 2012, respectively.

The data (Table 19) revealed that during 2011 and 2012, cultivar SKAU-341 (116.7 and 119.2) respectively, had significantly highest spikelets number than other varieties. Varieties Jhelum (104.8 and 102.2), SKAU-382 (102.6 and 102.4) and Shalimar rice-1 (97.5 and 98.7) were statistically at par during 2011 and 2012 respectively, where Shalimar rice-1 recorded lowest spikelet number per panicle during both the years.

Table 19: Test weight (g), grains/panicle, spikelets/panicle and spikelet sterility of rice cultivars as affected by transplanting dates

Treatments	Yield attributes							
	Grains/panicle		Spikelets/panicle		Spikelet sterility		Test weight (g)	
	2011	2012	2011	2012	2011	2012	2011	2012
25 th May	92.31	93.25	114.08	115.04	19.08	18.18	25.02	25.01
10 th June	85.76	86.89	109.49	110.06	20.21	20.62	24.99	24.92
25 th July	64.76	60.48	92.61	91.70	29.67	33.84	24.87	24.91
SE(m)±	4.94	3.29	3.36	2.19	2.67	4.81	0.84	0.23
CD (0.05)	19.33	12.82	13.14	8.56	10.41	14.29	NS	NS
Cultivars								
Shalimar rice-1	83.59	83.41	97.49	98.72	15.07	17.08	24.88	24.91
Jhelum	88.69	87.04	104.80	102.18	15.73	15.43	24.28	24.42
SKAU-382	85.81	84.36	102.56	102.35	16.04	18.61	23.58	23.56
SKAU- 341	64.36	66.01	116.7	119.16	45.85	45.75	25.60	25.44
SE(m)±	5.59	6.19	6.3	5.73	2.34	2.74	0.29	0.45
CD(0.05)	16.62	18.40	19.08	17.03	6.91	8.13	0.86	1.33

4.3.2 Grains panicle⁻¹

Number of grains panicle⁻¹ decreased with successive delay in transplanting date during both years (Table 19). The 25 May (91.3 and 93.3) transplanting being at par with 10 June (85.8 and 86.9) recorded significantly highest number of grains panicle⁻¹ than 25 June (64.8 and 60.5) transplanting during 2011 and 2012 respectively.

Rice variety Jhelum being at par with SKAU-382 and Shalimar Rice-1 produced significantly more number of grains panicle⁻¹ than SKAU-341 during both the years. Data (Table 19) revealed that during 2011 and 2012, cultivar Jhelum (88.7 and 87.1), SKAU-382 (85.8.7 and 84.4) and Shalimar rice-1 (83.6 and 83.4) had significantly highest spikelets number than SKAU-341 (64.4 and 66.0) where Jhelum recorded highest and SKAU-341 recorded lowest spikelet number per panicle during both the years.

4.3.3 1000-grain weight

Differences between transplanting dates (Table 19) with regard to 1000-grain weight varied. Heavier 1000-grain was recorded with 25 May (25.02 and 25.01) and 10 June (24.99 and 24.92) transplanting than 25 June (24.87 and 24.91) during both years 2011 and 2012, respectively. The weight of 1000-grain was not significant between transplanting dates both years.

The data (Table 22) revealed that during 2011, 1000-grain weight remained significantly higher in SKAU-341 compared to Jhelum and SKAU-382. SKAU-341 was statistically at par with Shalimar rice-1 and Shalimar rice-1 was also at par with Jhelum. Shalimar rice-1 had significantly higher 1000 –seed weight than SKAU-382, Jhelum and SKAU-382 were at par. During 2012, SKAU-341 and Shalimar rice-1 had significantly higher 1000-seed weight than SKAU-382. There was no significant difference between SKAU-341, Shalimar rice-1 and Jhelum. Jhelum was also at par with SKAU-382.

4.3.4 Sterility percentage

The result inferred that Sterility percentage increased significantly with delay in transplanting from 25 May to 25 June during both years (Table 19). Significantly maximum sterility (%) were recorded with 25 June transplanting date compared to 25 May where 10 June had no significantly more sterility (%) than 25 May transplanting and 10 June transplanting was at par with 25 May and 25 June transplanting during both years. The value of sterility was in the order: 19.1 and 20.2, 29.7 and 18.8, 20.6 and 33.98 with 25 May, 10 June and 25 June transplanting during 2011 and 2012, respectively.

Among different cultivars during 2011 and 2012 significantly highest sterility was recorded in SKAU-341 than other cultivars. During 2011, the sterility was in the order: SKAU-341 (45.85) > SKAU-382 (16.0) > Jhelum (15.7) > Shalimar rice-1 (15.1). During 2012, sterility was in the order: SKAU-341 (45.8) > SKAU-382 (18.6) > Shalimar rice-1 (17.1) > Jhelum (15.4). Though cultivar Shalimar rice-1, SKAU-382 and Jhelum were statistically at par during both the years (Table 22).

4.4 Yield index

4.4.1 Grain yield

Grain yield of rice varieties differed significantly due to different transplanting dates (Table 20 and Fig. 29).

Significantly highest grain yield of rice varieties was obtained by transplanting on 25 May than 10 June and 25 June transplanting dates. Whereas, transplanting on 10 June also recorded significantly higher yield than 25 June transplanting during both the years. The reduction in grain yield by transplanting on 25 June (31.1 q ha^{-1}) was 58.0 and 45.7 per cent than 25 May (74.0 q ha^{-1}) and 10 June (57.3 q ha^{-1}), respectively, during 2011. However, during 2012, decrease in grain yield on 25 June transplanting (32.2 q ha^{-1}) was 59.2 and 43.6 per cent than 25 May (79.0 q ha^{-1}) and 10 June (57.1 q ha^{-1}), respectively.

Table 20: Grain yield, straw yield, biological yield and harvest index of rice Cultivars as influenced by transplanting dates

Treatments	Grain yield (q ha ⁻¹)		Straw yield (q ha ⁻¹)		Biological yield (qha ⁻¹)		Harvest index (%)	
	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting Date								
25 th May	74.00	79.00	84.10	87.10	158.10	166.10	46.81	47.56
10 th June	57.30	57.10	79.20	81.70	136.59	138.80	41.97	41.14
25 th June	31.10	32.20	72.50	73.50	103.69	105.70	30.02	30.46
SE(m)±	2.50	2.70	2.10	2.50	6.99	05.90	01.50	2.10
CD (0.05)	9.70	10.40	6.90	7.40	26.99	23.00	06.20	7.00
Cultivars								
Shalimar rice-1	56.20	58.40	78.50	81.30	134.70	139.70	41.72	41.80
Jhelum	58.30	60.40	74.20	76.40	132.50	136.80	44.00	44.15
SKAU-382	53.00	54.00	73.50	74.10	126.50	128.10	41.89	42.16
SKAU- 341	49.00	51.60	88.20	91.30	137.20	142.90	35.71	36.11
SE(m)±	2.79	3.01	2.40	2.10	9.29	10.70	1.90	2.00
CD(0.05)	8.32	9.12	7.60	6.70	NS	NS	3.60	5.70

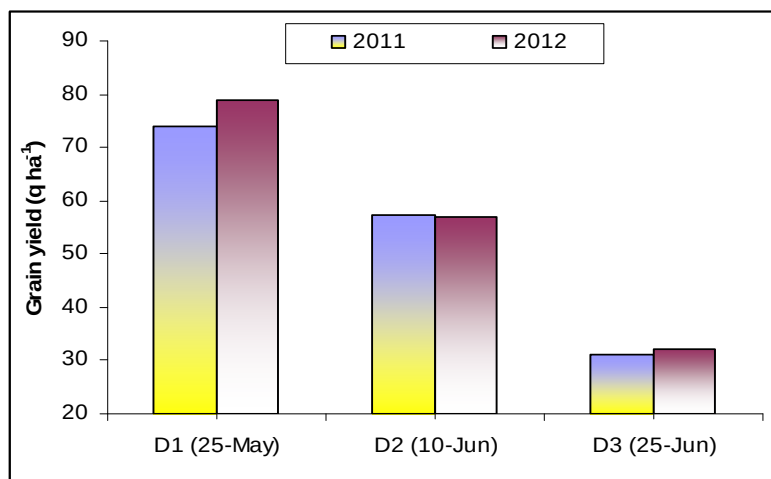


Fig. 29 : Grain yield of rice as affected by transplanting dates

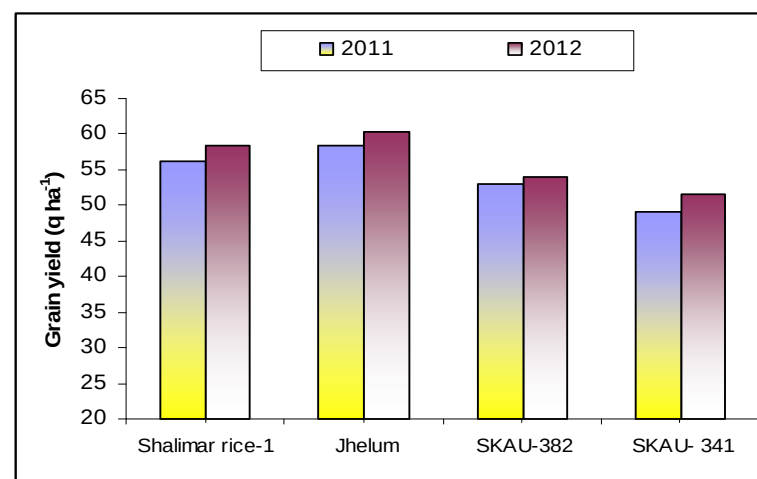


Fig. 30 : Grain yield as affected by rice cultivars

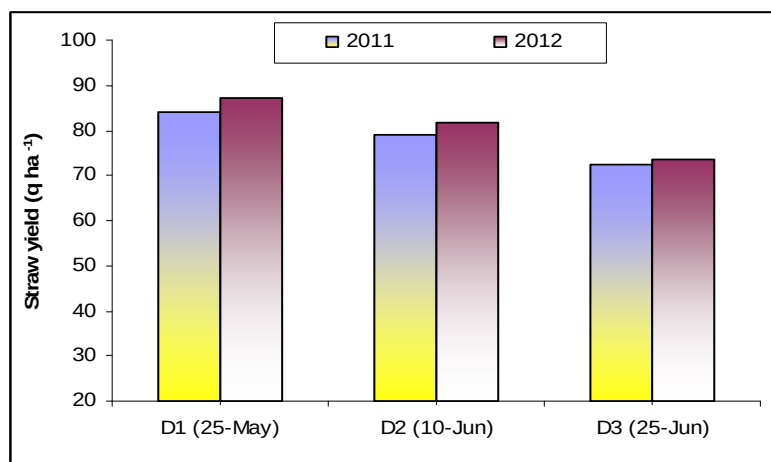


Fig. 31: Straw yield of rice as affected by transplanting dates

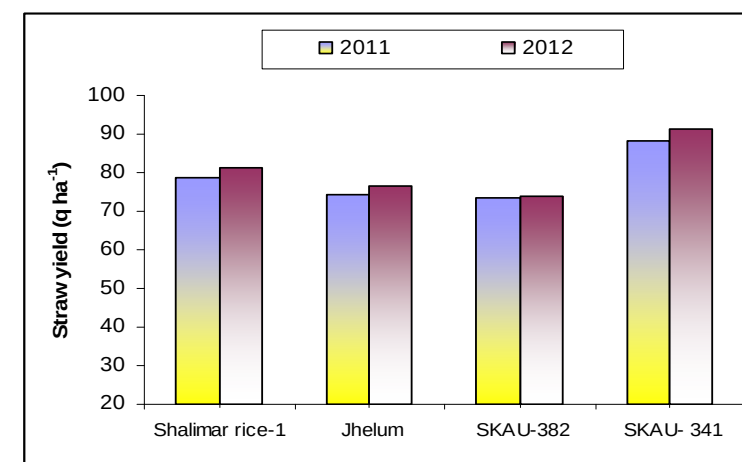


Fig. 32: Straw yield as affected by rice cultivars

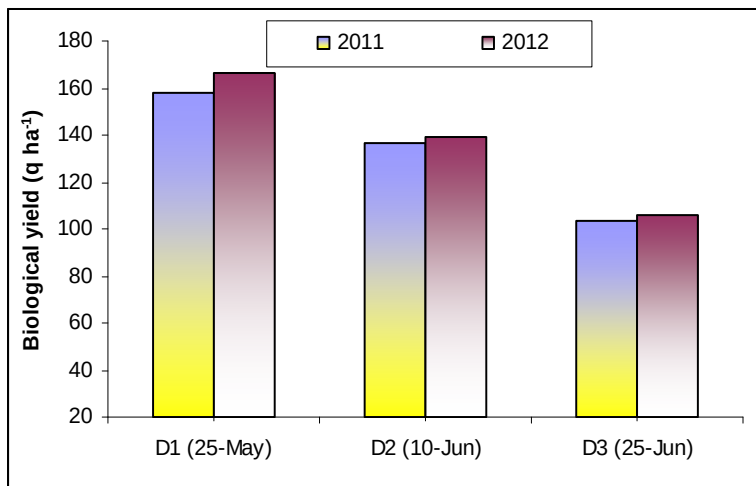


Fig. 33: Biological yield of rice as affected by transplanting dates

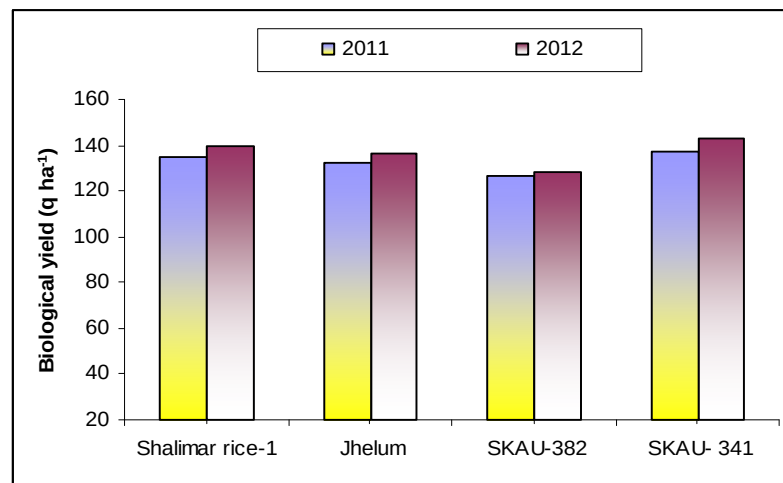


Fig. 34: Biological yield as affected by rice cultivars

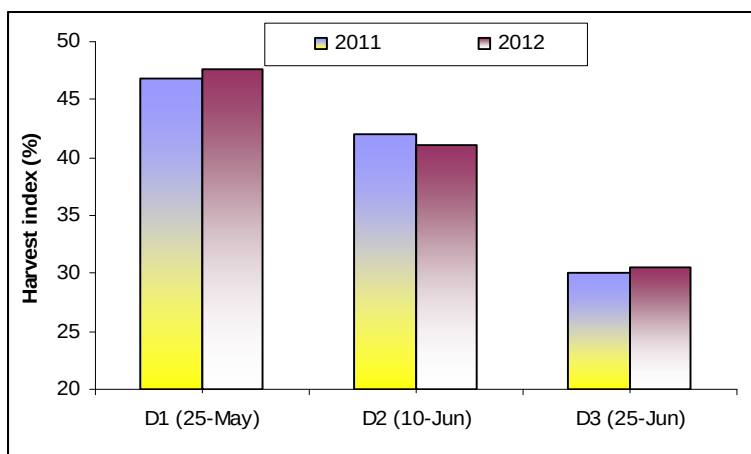


Fig. 35: Harvest index of rice as affected by transplanting dates

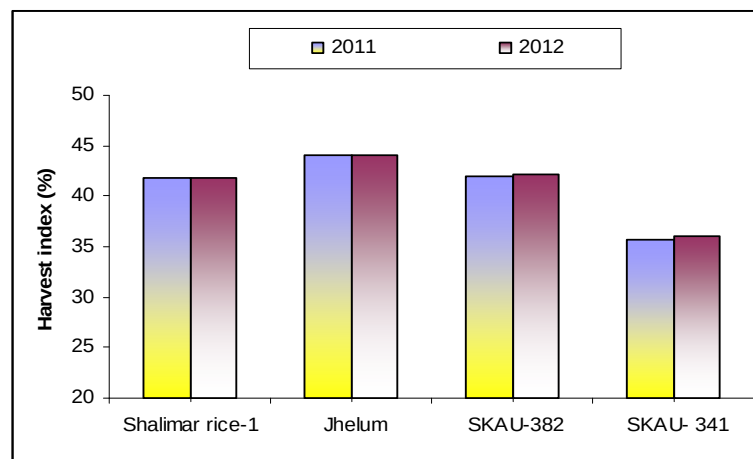


Fig. 36: Harvest index as affected by rice cultivars

Variety Jhelum produced highest seed yield than other varieties during both the years. Jhelum being at par with Shalimar rice-1 and SKAU-382 significantly produced higher grain yield than cultivar SKAU-341 during 2011 and 2012. The superiority of Jhelum over Shalimar rice-1, SKAU-382 and SKAU-341 was 3.9, 9.1 and 15.9 per cent, respectively during 2011 and corresponding values for year 2012 were 1.7, 8.5 and 14.7 per cent, respectively (Table 20 Fig. 30).

4.4.2 Straw yield

Variation in transplanting dates did not influence the straw yield between 25 May and 10 June transplanting but significantly out yielded 25 June transplanting during both the years 2011 and 2012 (Table 20 and Fig. 31). During 2011 earlier transplanting date 25 May produced (84.1 q ha^{-1}) straw, which was being at par with 10 June (79.2 q ha^{-1}) significantly superior to 25 June (72.5 q ha^{-1}). In 2012 transplanting on 25 May produced (87.1 q ha^{-1}) straw, which was being at par with 10 June (81.7 q ha^{-1}) significantly superior to 25 June (73.5 q ha^{-1}). However, the difference between 10 and 25 June transplanting was not significant during both the years.

Among varieties, SKAU-341 recorded significantly higher straw yield than Shalimar rice-1, Jhelum and SKAU-382 in 2011 and 2012. The differences among Shalimar rice-1, Jhelum and SKAU-382 were not significant during both the years (Table 20 and Fig. 32).

4.4.3 Biological yield

Data presented in Table 20 and Fig. 33 shows that early transplanted crop on 25 May being at par with 10 June recorded significantly highest yield than 25 June transplanting in the year 2011. During 2012, 25 May recorded significantly highest yield than 10 June and 25 June whereas 10 June also recorded significantly highest yield than 25 June transplanting. The decrease in biological

yield was 14.1 and 34.8 per cent by transplanting on 10 June and 25 June, respectively than 25 May transplanting during 2011, the corresponding value for 2012 was 16.4 and 36.4 per cent, respectively.

Cultivar SKAU-341 recorded highest and SKAU-382 recorded lowest biological yield than rest of varieties during 2011 and 2012. During 2011, biological yield (q ha^{-1}) of cultivars were in the order: SKAU-341 (137.20) > Shalimar rice-1 (134.70) > Jhelum (132.50) > SKAU-382 (126.50). However, during 2012 the cultivars were in the order : SKAU-341 (142.90) > Shalimar rice-1 (139.70) > Jhelum (136.80) > SKAU-382 (128.10). During both the years there was no significant difference in the biological yield of all the cultivars (Table 20 Fig. 34).

4.4.4 Harvest index

Harvest index which denotes the capacity of metabolites to translocate from source to sink indicated significant variation due to transplanting dates. 25 May transplanting being at par with 10 June significantly recorded higher harvest index than 25 June transplanting during both the years. Harvest index decreased from 46.4 to 30.0% and 41.9 to 30.0% by delaying transplanting dates from 25 May to 25 June and 10 June to 25 June, respectively during 2011. The corresponding value for 2012 was 47.6 to 30.5% and 41.1 to 30.5%, respectively (Table 20 and Fig. 35).

Variety Jhelum being at par with Shalimar rice-1 and SKAU-382 significantly recorded highest harvest index than SKAU-341 during both the years. The highest value of harvest index 44.00 and 46.15% with Jhelum and lowest 35.71 and 36.11% with SKAU-341 was recorded during 2011 and 2012, respectively (Table 20 and Fig. 36).

4.5 Nitrogen content and uptake

4.5.1 Nitrogen content of grain and straw

Rice cultivars transplanted on 25 May recorded significantly higher values of N content in grain and straw than 10 and 25 June transplanting during both the years and 15 June transplanting was significantly superior than 25 June transplanting.

Cultivar SKAU-341 recorded significantly highest grain N content followed by SKAU-382, Shalimar rice-1 and Jhelum. The difference between the cultivars Shalimar rice-1 and SKAU-382 was not significant during 2011 but there was significant difference between these two cultivars during 2012. Jhelum was at par with Shalimar rice-1 during both the years but there was significant difference between Jhelum and SKAU-382 during both the years.

Cultivar SKAU-341 significantly recorded highest N content in straw followed by Shalimar rice-1, Jhelum and SKAU-382 during both the years.

4.5.2 N uptake

Data pertaining to N-uptake (Table 21) revealed that early transplanted crops (25 May) being recorded significantly higher grain uptake during both the years. 10 June transplanting was also significantly superior to 25 June with respect to grain N-uptake.

Total N-uptake and uptake by straw during both the years followed the similar trend as grain nitrogen where significant decrease was recorded by delayed in transplanting from 25 May to 25 June.

Nitrogen uptake with respect to grain (Table 21) revealed that SKAU -341 significantly recorded higher N-uptake followed by Shalimar rice-1, Jhelum and SKAU -382. However the difference between the cultivars Shalimar rice-1, Jhelum and SKAU -382 was not significant.

Table 21: N content and nitrogen uptake of rice cultivars as affected by transplanting dates

Treatment	N content (%)				N uptake (kg ha ⁻¹)					
	Grain		Straw		Grain		Straw		Total	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Transplanting date										
25 th May	1.31	1.34	0.31	0.37	96.60	105.91	26.12	32.20	122.71	138.11
10 th June	1.29	1.31	0.30	0.35	73.92	74.84	23.76	28.64	97.66	103.42
25 th June	1.20	1.26	0.26	0.26	37.31	40.21	18.75	19.32	53.75	59.54
SE(m)±	0.01	0.02	0.01	0.01	0.85	0.92	0.79	0.85	1.51	1.54
CD(0.05)	0.05	0.05	0.02	0.02	2.95	3.18	2.77	2.93	4.87	5.13
Cultivars										
Shalimar rice-1	1.23	1.24	0.32	0.39	69.13	72.45	25.12	31.71	94.25	104.16
Jhelum	1.18	1.20	0.30	0.33	68.41	72.48	22.26	25.21	90.67	97.69
SKAU-382	1.29	1.27	0.27	0.32	68.50	68.52	19.85	23.71	88.26	92.20
SKAU-341	1.31	1.39	0.47	0.44	71.42	71.72	41.45	40.17	112.87	111.89
SE(m)±	0.02	0.02	0.01	0.01	2.04	2.50	1.07	1.09	2.96	3.05
CD (0.05)	0.06	0.05	0.03	0.03	6.35	7.44	2.99	3.17	9.11	9.36

N uptake of straw revealed that SKAU-341 recorded significantly higher N-uptake than other cultivars. Shalimar rice-1 was at par with Jhelum during 2011, but was significantly higher than SKAU -382 during both the years.

With regard to total N uptake, SKAU-341 recorded higher N-uptake followed by Shalimar rice-1, Jhelum and SKAU-382 during both the years. However there was no significant difference between Shalimar rice-1, Jhelum and SKAU-382 during both the years.

4.6 Crop modeling

Crop models play an important role in not only estimating rice yield but also for impact of climate change, best management practices, recommending suitable technology etc. at regional level. Validating and fine tuning the model is important before using for predictions. Integrating crop models with spatial data improve the model performance and give additional strength of finding the outputs at pixel level. This will be helpful for effective decision making and to recommend technologies at farm level. The crop growth simulation models can replace the need for years of costly multi-location, on station and on farm trials to select rice varieties. There is ample scope for application of the calibrated model to identify better cultivars and management practices for different rice growing environments

4.6.1 Validation studies

In general the model is modified in order to make model applicable in the new location, the process is known as calibration. Nevertheless, model cannot be considered fully functional unless model performance is evaluated against the independent data set. The process of evaluating model performance on the data, which have not been used for the model development or modification, is called as Validation.

4.6.2 Validation of CERES- rice model

The validation of CERES-rice model was done in the year 2011 and 2012 at three different locations (Srinagar, Badgam, and Anantnag) using the observed field data. The model was validated for four rice varieties (Shalimar rice-1, Jhelum and SKAU-382 and SKAU-341) transplanted on 25 May, 10 June and 25 June. Simulated phenology (days to anthesis and maturity), grain yield, tops wt. at maturity, tops N, were compared with actual observed values.

a) Srinagar station

4.6.3 Phenological observations

Crop phenological stages play a great role in defining crop growth duration, biomass partitioning and finally crop production. Two major crop phenological stages viz. anthesis and physiological maturity were compared.

The simulated duration to anthesis (first flower) is shown in Table 22 and Fig. 37. The per cent variation in simulated duration to anthesis over observed value ranged from -7.87 to 4.40 days. Duration to anthesis varied between sowing dates and varieties under both simulated and observed values. The range was between 81 to 107 days and 77 to 104 days for observed and simulated data, respectively. The RMSE (Root Mean Square Error) obtained between the actual and predicted anthesis was 3.72 days with a MAE (Mean Absolute Error) of 3.50 days and D-index (Index of agreement) 0.94. The simulated anthesis dates were overestimated by slight difference on the 25 May transplanting and underestimated on 10 June and 25 June transplanting, however RMSE and D-index values suggest that the pattern of anthesis dates could be well captured.

Simulated data showed that 25 May recorded highest number of days to reach anthesis and 25 June transplanting took least number of days to anthesis. The crop transplanted on 25 May had least difference in anthesis data between observed and simulated values and it was little more with 25 June transplanting.

Simulated data showed cultivar Jhelum and SKAU-382 transplanted on

Table 22: Validation results of rice cultivars for, days to anthesis and maturity and yield (kg ha⁻¹) under different transplanting dates at Srinagar during 2011 and 2012

Treatment	Days to anthesis				Days to maturity				Yield			
	Obs	Sim	Devi	% Devi	Obs	Sim	Devi	% Devi	Obs	Sim	Devi	%Devi
25 th May SR-1	99	102	-3	3.03	141	145	-4	2.84	7710	7408	302	-3.92
25 th May Jhelum	97	100	-3	3.09	139	141	-2	1.44	7653	7298	355	-4.64
25 th May SKAU-382	96	100	-4	4.17	138	141	-3	2.17	7219	7298	-79	1.09
25 th May SKAU-341	106	103	3	-2.83	149	145	4	-2.68	6889	7464	-575	8.35
10 th June SR-1	91	89	2	-2.20	131	128	3	-2.29	5876	5321	555	-9.45
10 th June Jhelum	90	87	3	-3.33	129	126	3	-2.33	6310	5790	520	-8.24
10 th June SKAU-382	90	87	3	-3.33	129	126	3	-2.33	5727	5790	-63	1.10
10 th June SKAU-341	97	93	4	-4.12	139	131	8	-5.76	4986	5354	-368	7.38
25 th June SR-1	81	79	2	-2.47	122	117	5	-4.10	3219	2874	345	-10.72
25 th June Jhelum	81	77	4	-4.94	121	116	5	-4.13	3522	2909	613	-17.40
25 th June SKAU-382	83	77	6	-7.23	123	116	7	-5.69	2916	2909	7	-0.24
25 th June SKAU-341	88	86	2	-2.27	129	125	4	-3.10	2763	2911	-148	5.36
25 th May SR-1	101	104	-3	2.97	142	145	-3	2.11	8140	8046	94	-1.15
25 th May Jhelum	98	101	-3	3.06	140	136	4	-2.86	8069	7743	326	-4.04
25 th May SKAU-382	99	101	-2	2.02	140	136	4	-2.86	7529	7743	-214	2.84
25 th May SKAU-341	107	102	5	-4.67	149	144	5	-3.36	7836	8085	-249	3.18
10 th June SR-1	91	95	-4	4.40	132	135	-3	2.27	5936	5536	400	-6.74
10 th June Jhelum	90	85	5	-5.56	132	128	4	-3.03	6127	5777	350	-5.71
10 th June SKAU-382	91	85	6	-6.59	120	128	-8	6.67	5523	5777	-254	4.60
10 th June SKAU-341	97	95	2	-2.06	138	133	5	-3.62	5240	5615	-375	7.16
25 th June SR-1	83	80	3	-3.61	123	126	-3	2.44	3217	2960	257	-7.99
25 th June Jhelum	82	77	5	-6.10	122	117	5	-4.10	3582	3195	387	-10.80
25 th June SKAU-382	83	77	6	-7.23	131	117	6	-4.88	3106	3195	-89	2.87
25 th June SKAU-341	89	82	7	-7.87	125	125	6	-4.58	2897	3042	-145	5.01
Male		275.00				4.46				294.58		
RMSE		4.02				4.73				338.13		

Obs=observed; Sim=simulated; devi=deviation; RMSE=Root mean square error; MAE=Mean absolute error

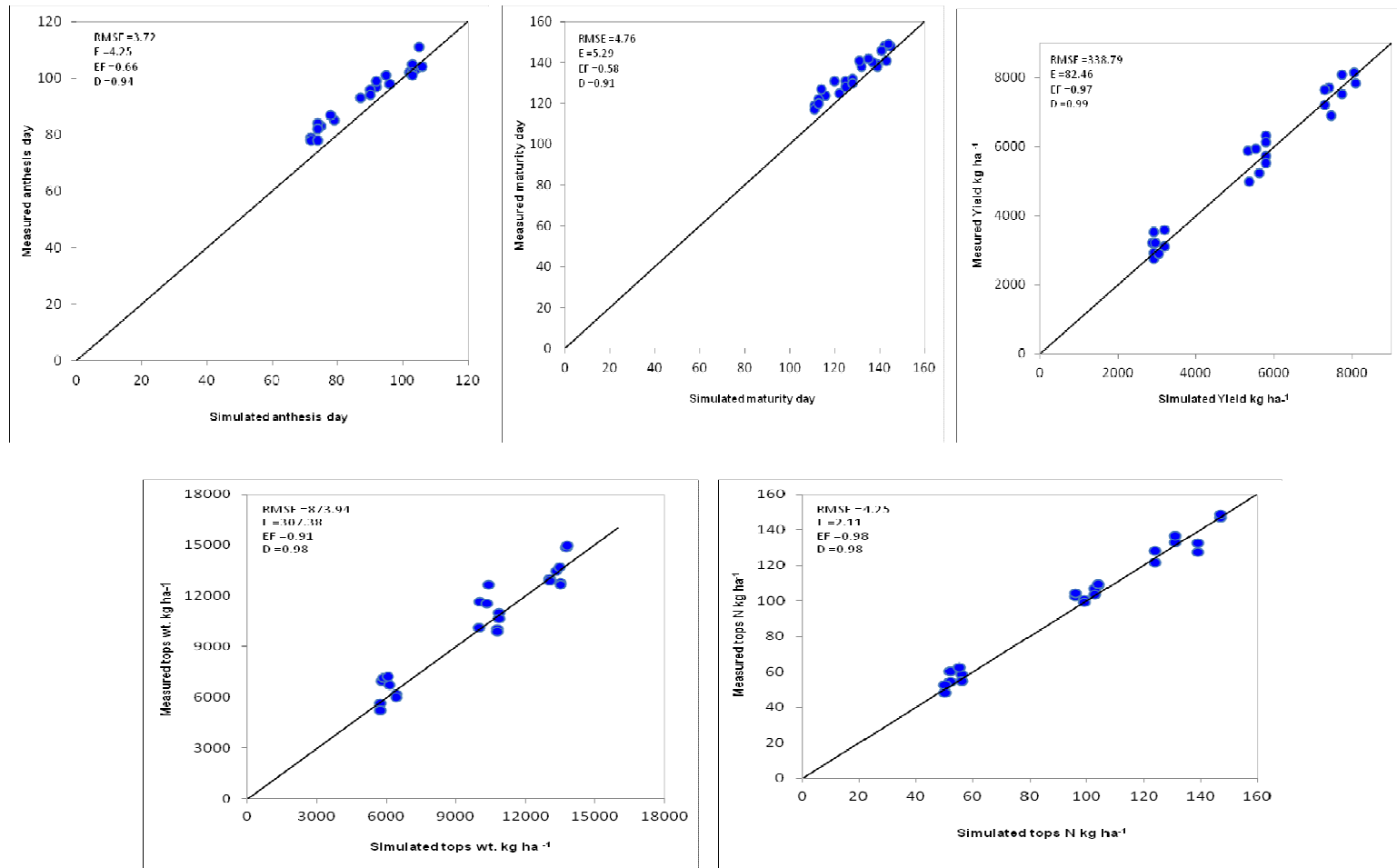


Fig. 37: Comparison between observed and simulated days to anthesis, maturity, grain yield, tops weight at maturity and N- uptake

25 June recorded least number of days to reach anthesis and cultivars SKAU-341 and Shalimar rice-1 transplanted on 25 May took maximum number of days to anthesis.

The patterns of simulated and observed physiological maturity days have been depicted in Fig. 37 and Table 22. Duration of maturity also varied between transplanting dates and varieties under both simulated and observed values. The per cent variation in simulated duration to maturity over observed value ranged from -7.3 to 2.8 days. Duration to maturity varied between sowing dates and varieties under both simulated and observed values. The range was between 121 to 149 days and 114 to 145 days for observed and simulated data, respectively. The RMSE (Root Mean Square Error) obtained between the actual and predicted maturity was 4.76 days with a MAE (Mean Absolute Error) of 4.42 days and D-index (Index of agreement) of 0.91. The table and graph showed that the genetic coefficients, which govern the physiological maturity in CERES-rice model (P5) developed by GENCALC software, over-predicted the physiological maturity of various rice cultivars on 25 May and underestimated on 10 and 25 June, however RMSE values suggest that the variation in physiological maturity arising due the varying dates of sowing could be very well captured.

Simulated data showed that 25 May recorded highest number of days to reach maturity and 25 June transplanting took least number of days to maturity.

Cultivars Shalimar rice-1 and SKAU-341 transplanted on 25 May recorded maximum number of days to mature for both predicted and observed values whereas cultivar Jhelum and SKAU-382 transplanted on 25 June took least number of days to mature for both simulated and observed values.

4.6.4 Grain yield

The grain yield is the main entity of the crop and is the prime concern for the model for forecasting acceptably. Under temperate conditions of Kashmir

validation of CERES-rice model revealed that the grain yield could be predicted with fairly good accuracy. Observed and Predicted yield have been presented in Table 22 and Fig. 37. The observed values of all treatments during both the years ranged from 2763 to 8140 kg ha⁻¹, as compared to simulated data ranging from 2805 to 8085 kg ha⁻¹. The predicted yield value varied between -17.40 to 8.35 per cent over observed values during both the years of validation. The RMSE for the grain yield was 338.79 kg ha⁻¹ with a MAE of 298.51 kg ha⁻¹ and D-index of 0.99. The RMSE and D-index suggests that simulated yields and observed yield are in very close collaboration not only in terms of the yield potential of different cultivars but also the pattern of yield in different transplanting dates.

The grain yield was maximum for the earliest transplanting (25 May) over the year and decreased progressively with delay in transplanting. The comparison of observed and predicted grain yields both over and underestimated by the model; however, the trend noted for the field observed and model simulated grain yields was similar.

The model predicted grain yields within -4.64 to 8.35 per cent for 25 May, -9.45 to + 7.20 for 10 June and -17.4 to 5.4 for 25 June transplanting across the years.

Cultivar SKAU-341 recorded lowest simulated and observed yield on all transplanting dates where as cultivar Jhelum and Shalimar rice-1 recorded highest predicted and observed grain yield.

4.6.5 Tops weight at maturity

The photosynthesis activity take place in the presence of sunlight and Carbon Dioxide (CO₂), which produces dry matters in the plant. The dry matter is partitioned in to various parts of the plants. The biomass of plant parts, which are above the soil surface, are called as above ground biomass, while biomass of plant parts below the soil surface are called below ground biomass. The above ground biomass has great bearing on the grain production. The tops wt. at maturity has

Table 23: Validation results of rice cultivars for tops N (kg ha⁻¹) and tops wt. at maturity (kg ha⁻¹) under different transplanting dates at Srinagar

Treatment	Tops N				Tops weight at maturity			
	Obs	Sim	Devi	% Devi	Obs	Sim	Devi	% Devi
25 th May SR-1	133	131	2	-1.50	13476	13314	162	-1.20
25 th May Jhelum	128.2	124	4.2	-3.28	13000	13014	-14	0.11
25 th May SKAU-382	121.5	124	-2.5	2.06	12876	13014	-138	1.07
25 th May SKAU-341	136.7	131	5.7	-4.17	13692	13495	197	-1.44
10 th June SR-1	102.4	96	6.4	-6.25	10124	9997	127	-1.25
10 th June Jhelum	100.8	99	1.8	-1.79	10038	10791	-753	7.50
10 th June SKAU-382	99	99	0.0	0.00	9873	10791	-918	9.30
10 th June SKAU-341	104.3	96	8.3	-7.96	11643	10013	1630	-14.00
25 th June SR-1	54.4	52	2.4	-4.41	6953	5797	1156	-16.63
25 th June Jhelum	52.5	50	2.5	-4.76	5632	5702	-70	1.24
25 th June SKAU-382	48	50	-2	4.17	5218	5702	-484	9.28
25 th June SKAU-341	60.1	52	8.1	-13.48	7192	5863	1329	-18.48
25 th May SR-1	146.9	147	-0.1	0.07	14837	13779	1058	-7.13
25 th May Jhelum	132.6	139	-6.4	4.83	12760	13499	-739	5.79
25 th May SKAU-382	127.4	139	-11.6	9.11	12653	13499	-846	6.69
25 th May SKAU-341	148.6	147	1.6	-1.08	14979	13814	1165	-7.78
10 th June SR-1	108.7	104	4.7	-4.32	11542	10323	1219	-10.56
10 th June Jhelum	106.7	103	3.7	-3.47	10986	10840	146	-1.33
10 th June SKAU-382	103.5	103	0.5	-0.48	10654	10840	-186	1.75
10 th June SKAU-341	109.5	104	5.5	-5.02	12658	10405	2253	-17.80
25 th June SR-1	62.5	55	7.5	-12.00	7237	6056	1181	-16.32
25 th June Jhelum	58.4	56	2.4	-4.11	6173	6404	-231	3.74
25 th June SKAU-382	54.7	56	-1.3	2.38	5987	6404	-417	6.97
25 th June SKAU-341	62.3	55	7.3	-11.72	6739	6126	613	-9.10
Male		4.10				709.67		
RMSE		5.07				900.71		

Obs=observed ; sim=simulated; devi=deviation; RMSE=Root mean square error; MAE=Mean Absolute Error

been presented in Table 23 and plotted in Fig.38. Observed tops weight at maturity ranged from 5218 to 14979 kg ha⁻¹, compared to 5702 to 13814 kg ha⁻¹ for simulated yield under different treatments. The per cent variation in simulated tops weight at anthesis over observed value ranged from -18.5 to 7.5. The model predicted top weight at maturity reasonably well with RMSE value of 873.94 kg ha⁻¹ along with MAE value of 642.88 kg ha⁻¹ and D-index value of 0.98. The data showed that there is good relationship between observed and predicted tops wt. at maturity and RMSE was within the expectable limit.

For both observed and simulated data 25 May transplanting gave the maximum tops weight at maturity, while lowest tops weight at maturity was recorded on 25 June transplanting.

Cultivars Shalimar rice-1 and SKAU-341 transplanted on 25 May recorded maximum tops wt at maturity for both predicted and observed values whereas cultivar Jhelum and SKAU-382 transplanted on 25 June recorded least tops wt at maturity for both simulated and observed values.

4.6.6 N-uptake

Nitrogen (N) is essential for rice, and usually it is the most yield-limiting nutrient in irrigated rice production around the world (Samonte *et al.*, 2006). Nitrogen use efficiency has been defined in various ways, but these definitions generally take into account quantity of N accumulated in the plant, known as uptake efficiency and quantity of N utilized in grain production known as utilization efficiency.

The tops nitrogen uptake ranged from 48 to 148 kg ha⁻¹, compared to 49 to 147 kg ha⁻¹ for simulated yield under different treatments (Table 23 and Fig. 37). The per cent variation in simulated N uptake over observed value ranged from -13.5 to 4.8. The model predicted N uptake reasonably well with RMSE value of 4.52 kg ha⁻¹ along with MAE value of 3.66 kg ha⁻¹ and D-index value of 0.98.

For both observed and simulated data 25 May transplanting gave the maximum nitrogen uptake and the lowest was recorded on 25 June transplanting.

Cultivars SKAU-341 transplanted on 25 May recorded maximum nitrogen uptake for observed values but for predicted values whereas cultivar Shalimar rice -1 and SKAU-341 recorded maximum nitrogen uptake. Cultivar SKAU-382 transplanted on 25 June recorded least nitrogen uptake.

b) Badgam station

4.6.7 Phenological observations

The simulated duration to anthesis is shown in Table 24 and Fig. 38. The per cent variation in simulated duration to anthesis over observed value ranged from -13.4 to 2.1 days. Duration to anthesis varied between sowing dates and varieties under both simulated and observed values. The range was between 70 to 110 days and 65 to 102 days for observed and simulated data, respectively. The RMSE (Root Mean Square Error) obtained between the actual and predicted anthesis was 6.26 days with a MAE (Mean Absolute Error) of 5.08 days and D-index (Index of agreement) 0.89.

Simulated data showed that 25 May recorded highest number of days to reach anthesis and 25 June transplanting took least number of days to anthesis.

Simulated data showed cultivar Jhelum and SKAU-382 transplanted on 25 June recorded least number of days to reach anthesis and cultivars SKAU-341 and Shalimar rice-1 transplanted on 25 May took maximum number of days to anthesis.

Duration of maturity also varied between transplanting dates and varieties under both simulated and observed values. The per cent variation in simulated duration to maturity over observed value ranged from -6.8 to 0 days. Duration to maturity varied between sowing dates and varieties under both simulated and observed values. The range was between 107 to 147 days and 105 to 141 days for observed and simulated data, respectively. The RMSE (Root Mean Square Error)

Table 24: Validation results of rice cultivars for, days to anthesis and maturity and yield (kg ha⁻¹) under different transplanting dates at Badgam

Treatment	Days to anthesis				Days to maturity				Yield			
	Obs	Sim	Devi	% Devi	Obs	Sim	Devi	% Devi	Obs	Sim	Devi	%Devi
25 th May SR-1	99	102	-3	3.03	141	145	-4	2.84	7352	7112	240	-3.26
25 th May Jhelum	97	100	-3	3.09	139	141	-2	1.44	7231	6981	250	-3.46
25 th May SKAU-382	96	100	-4	4.17	138	141	-3	2.17	7146	6981	165	-2.31
25 th May SKAU-341	106	103	3	-2.83	149	145	4	-2.68	7193	7255	-62	0.86
10 th June SR-1	91	89	2	-2.20	131	128	3	-2.29	5827	5598	229	-3.93
10 th June Jhelum	90	87	3	-3.33	129	126	3	-2.33	5943	5462	481	-8.09
10 th June SKAU-382	90	87	3	-3.33	129	126	3	-2.33	5675	5462	213	-3.75
10 th June SKAU-341	97	93	4	-4.12	139	131	8	-5.76	5813	5747	66	-1.14
25 th June SR-1	81	79	2	-2.47	122	117	5	-4.10	4117	3953	164	-3.98
25 th June Jhelum	81	77	4	-4.94	121	116	5	-4.13	3916	3745	171	-4.37
25 th June SKAU-382	83	77	6	-7.23	123	116	7	-5.69	3612	3745	-133	3.68
25 th June SKAU-341	88	86	2	-2.27	129	125	4	-3.10	3415	3852	-437	12.80
25 th May SR-1	101	104	-3	2.97	142	145	-3	2.11	6943	6767	176	-2.53
25 th May Jhelum	98	101	-3	3.06	140	136	4	-2.86	6893	6569	324	-4.70
25 th May SKAU-382	99	101	-2	2.02	140	136	4	-2.86	6320	6569	-249	3.94
25 th May SKAU-341	107	102	5	-4.67	149	144	5	-3.36	6725	6857	-132	1.96
10 th June SR-1	91	95	-4	4.40	132	135	-3	2.27	5568	5733	-165	2.96
10 th June Jhelum	90	85	5	-5.56	132	128	4	-3.03	5659	5778	-119	2.10
10 th June SKAU-382	91	85	6	-6.59	120	128	-8	6.67	5421	5778	-357	6.59
10 th June SKAU-341	97	95	2	-2.06	138	133	5	-3.62	5713	5840	-127	2.22
25 th June SR-1	83	80	3	-3.61	123	126	-3	2.44	3487	3659	-172	4.93
25 th June Jhelum	82	77	5	-6.10	122	117	5	-4.10	3876	3541	335	-8.64
25 th June SKAU-382	83	77	6	-7.23	131	117	6	-4.88	3312	3541	-229	6.91
25 th June SKAU-341	89	82	7	-7.87	125	125	6	-4.58	3019	3675	-656	21.73
Male		3.75				4.46				235.52		
RMSE		4.02				4.73				271.91		

Obs=observed ; sim=simulated; devi=deviation; RMSE=Root mean square error; MAE=Mean Absolute Error

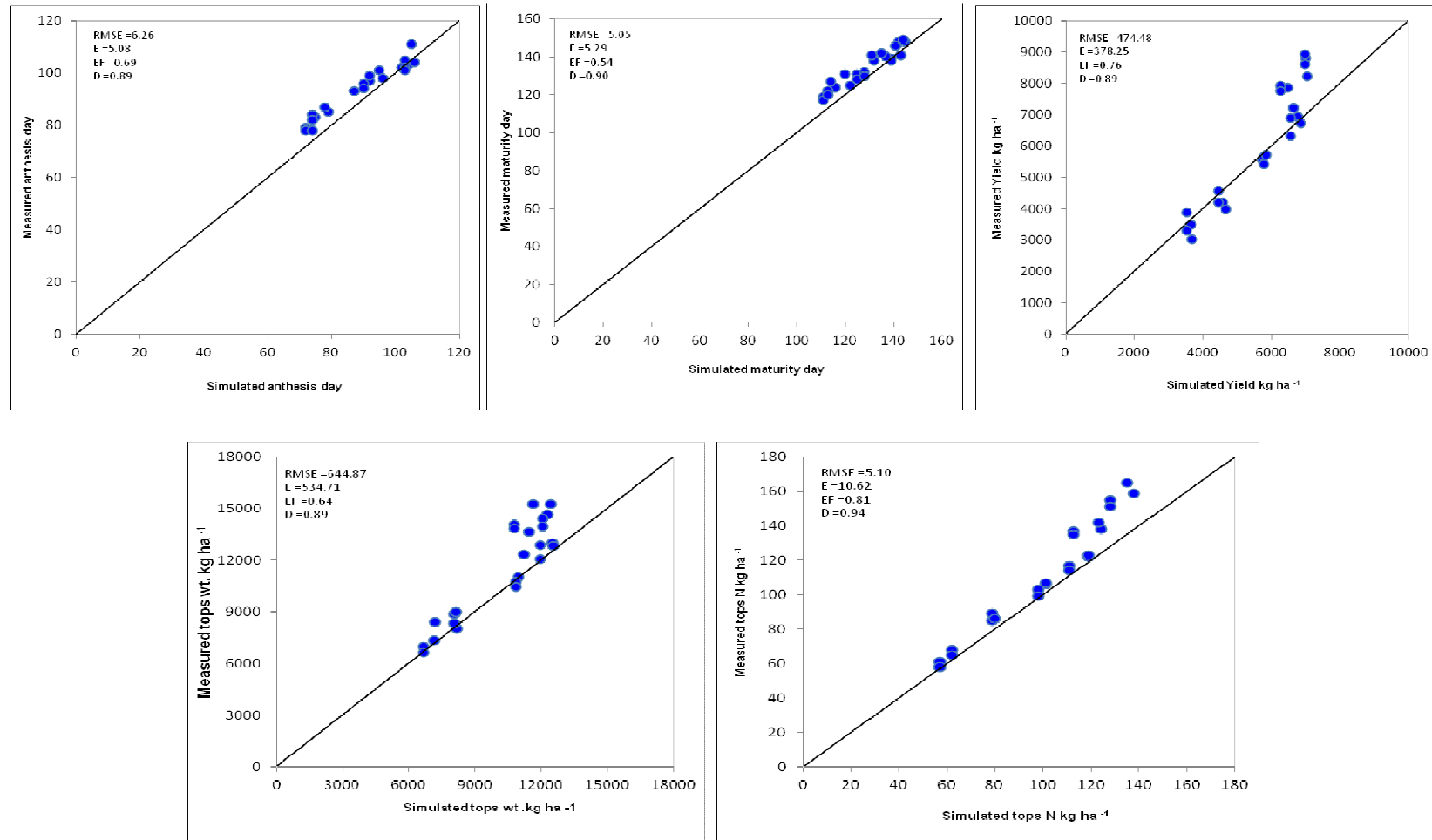


Fig. 38 : Comparison between observed and simulated days to anthesis, maturity, grain yield, tops weight at maturity and N- uptake

obtained between the actual and predicted maturity was 5.50 days with a MAE (Mean Absolute Error) of 5.04 days and D-index (Index of agreement) of 0.90 (Table 24 and Fig. 38).

Simulated data showed that 25 May recorded highest number of days to reach maturity and 25 June transplanting took least number of days to maturity.

Cultivars SKAU-341 transplanted on 25 May recorded maximum number of days to mature for both predicted and observed values whereas cultivar SKAU-382 transplanted on 25 June took least number of days to mature for both simulated and observed values.

4.6.8 Grain yield

Observed and Predicted yield have been presented in Table 24 and Fig. 38. The observed values of all treatments during both the years ranged from 3019 to 7352 kg ha⁻¹, as compared to simulated data ranging from 3216 to 7255 kg ha⁻¹. The predicted yield value varied between -8.6 to 21.7 per cent over observed values during both the years of validation. The RMSE for the grain yield was 474.48 kg ha⁻¹ with a MAE of 300.54 kg ha⁻¹ and D-index of 0.89

The grain yield was maximum for the earliest transplanting (25 May) over the year and decreased progressively with delay in transplanting. The comparison of observed and predicted grain yields both over and underestimated by the model.

Cultivar SKAU-341 recorded highest simulated yield on all transplanting dates where as cultivar SKAU-382 recorded lowest predicted yield but the observed data recorded the lowest yield for SKAU-341 and highest for Jhelum and Shalimar rice-1.

4.6.9 Tops weight at maturity

Observed tops weight at maturity ranged from 6659 to 13657 kg ha⁻¹, compared to 6483 to 13281 kg ha⁻¹ for simulated yield under different treatments

Table 25: Validation results of rice cultivars for tops N (kg ha⁻¹) and tops weight at maturity (kg ha⁻¹) under different transplanting dates at Badgam

Treatment	Tops N				Tops weight at maturity			
	Obs	Sim	Devi	% Devi	Obs	Sim	Devi	% Devi
25 th May SR-1	128	121	7	-5.47	13657	12985	672	-4.92
25 th May Jhelum	120	115	5	-4.17	13525	12638	887	-6.56
25 th May SKAU-382	113	115	-2	1.77	13289	12638	651	-4.90
25 th May SKAU-341	132	130	2	-1.52	13611	13281	330	-2.47
10 th June SR-1	109	102	7	-6.42	12134	11763	371	-3.06
10 th June Jhelum	106	100	6	-5.66	11752	10452	1300	11.06
10 th June SKAU-382	101	100	1	-0.99	10865	10452	413	-3.80
10 th June SKAU-341	111	101	10	-9.01	12757	12315	442	-3.46
25 th June SR-1	69	64	5	-7.25	7520	7246	274	-3.64
25 th June Jhelum	59	55	4	-6.78	6991	6574	417	-5.96
25 th June SKAU-382	55	55	0	0.00	6712	6574	138	-2.06
25 th June SKAU-341	70	65	5	-7.14	8574	8035	539	-6.29
25 th May SR-1	122	119	3	-2.46	13016	12499	517	-3.97
25 th May Jhelum	117	111	6	-5.13	12874	11963	911	-7.08
25 th May SKAU-382	114	111	3	-2.63	12067	11963	104	-0.86
25 th May SKAU-341	123	119	4	-3.25	12860	12540	320	-2.49
10 th June SR-1	106	101	5	-4.72	11023	10964	59	-0.54
10 th June Jhelum	103	98	5	-4.85	10752	10849	-97	0.90
10 th June SKAU-382	99	98	1	-1.01	10438	10849	-411	3.94
10 th June SKAU-341	107	101	6	-5.61	12340	11240	1100	-8.91
25 th June SR-1	68	62	6	-8.82	7329	7155	174	-2.37
25 th June Jhelum	61	57	4	-6.56	6981	6674	307	-4.40
25 th June SKAU-382	58	57	1	-1.72	6659	6674	-15	0.23
25 th June SKAU-341	65	62	3	-4.62	8379	7201	1178	-14.06
Male		4.21				484.46		
RMSE		4.80				599.92		

Obs=observed ; sim=simulated; devi=deviation; RMSE=Root mean square error; MAE=Mean Absolute Error

(Table 25 and Fig. 38). The per cent variation in simulated tops weight at anthesis over observed value ranged from -11.1 to 1.1. The model predicted top weight at maturity reasonably well with RMSE value of 644.87 kg ha⁻¹ along with MAE value of 534.04 kg ha⁻¹ and D-index value of 0.89.

For both observed and simulated data 25 May transplanting gave the maximum tops weight at maturity. While lowest tops weight at maturity was recorded on 25 June transplanting.

Cultivars Shalimar rice-1 and SKAU-341 transplanted on 25 May recorded maximum tops wt at maturity for both predicted and observed values whereas cultivar Jhelum and SKAU-382 transplanted on 25 June recorded least tops wt at maturity for both simulated and observed values.

4.6.10 N-uptake

The tops nitrogen uptake ranged from 55 to 132 kg ha⁻¹, compared to 52 to 130 kg ha⁻¹ for simulated yield under different treatments (Table 25 and Fig 38). The per cent variation in simulated N uptake over observed value ranged from -9.0 to -1.5. The model predicted N uptake reasonably well with RMSE value of 5.10 kg ha⁻¹ along with MAE value of 4.79 kg ha⁻¹ and D-index value of 0.94.

For both observed and simulated data 25 May transplanting gave the maximum nitrogen uptake and the lowest was recorded on 25 June transplanting.

Cultivars SKAU-341 transplanted on 25 May recorded maximum nitrogen uptake for both observed and simulated values. Cultivar SKAU-382 transplanted on 25 June recorded least nitrogen uptake for both observed and simulated values.

c) Anantnag station

4.6.11 Phenological observations

The simulated duration to anthesis is shown in Table 26 and Fig. 39. The per cent variation in simulated duration to anthesis over observed value ranged from -6.5 to 1.9 days. Duration to anthesis varied between sowing dates and

Table 26: Validation results of rice cultivars for, days to anthesis and maturity and yield (kg ha⁻¹) under different transplanting dates at Anantnag

Treatment	Days to anthesis				Days to maturity				Yield			
	Obs	Sim	Devi	% Devi	Obs	Sim	Devi	% Devi	Obs	Sim	Devi	%Devi
25 th May SR-1	99	102	-3	3.03	141	145	-4	2.84	8759	9011	-216	2.46
25 th May Jhelum	97	100	-3	3.09	139	141	-2	1.44	8931	9221	-290	3.25
25 th May SKAU-382	96	100	-4	4.17	138	141	-3	2.17	8612	9221	-609	7.07
25 th May SKAU-341	106	103	3	-2.83	149	145	4	-2.68	8217	9049	-832	10.13
10 th June SR-1	91	89	2	-2.20	131	128	3	-2.29	7859	8343	-484	6.16
10 th June Jhelum	90	87	3	-3.33	129	126	3	-2.33	7926	8923	-997	12.58
10 th June SKAU-382	90	87	3	-3.33	129	126	3	-2.33	7754	8923	-1169	15.08
10 th June SKAU-341	97	93	4	-4.12	139	131	8	-5.76	7210	8326	-1116	15.48
25 th June SR-1	81	79	2	-2.47	122	117	5	-4.10	4205	4384	-179	4.26
25 th June Jhelum	81	77	4	-4.94	121	116	5	-4.13	4562	4973	-411	9.01
25 th June SKAU-382	83	77	6	-7.23	123	116	7	-5.69	4208	4973	-765	18.18
25 th June SKAU-341	88	86	2	-2.27	129	125	4	-3.10	3996	4547	-551	13.79
25 th May SR-1	101	104	-3	2.97	142	145	-3	2.11	7563	7240	323	-4.27
25 th May Jhelum	98	101	-3	3.06	140	136	4	-2.86	7687	7381	306	-3.98
25 th May SKAU-382	99	101	-2	2.02	140	136	4	-2.86	7321	7381	-60	0.82
25 th May SKAU-341	107	102	5	-4.67	149	144	5	-3.36	6532	7228	-696	10.66
10 th June SR-1	91	95	-4	4.40	132	135	-3	2.27	5679	5077	602	-10.60
10 th June Jhelum	90	85	5	-5.56	132	128	4	-3.03	5832	5088	744	-12.76
10 th June SKAU-382	91	85	6	-6.59	120	128	-8	6.67	5219	5088	131	-2.51
10 th June SKAU-341	97	95	2	-2.06	138	133	5	-3.62	4924	5163	-239	4.85
25 th June SR-1	83	80	3	-3.61	123	126	-3	2.44	3106	2894	212	-6.83
25 th June Jhelum	82	77	5	-6.10	122	117	5	-4.10	3398	3414	-16	0.47
25 th June SKAU-382	83	77	6	-7.23	131	117	6	-4.88	3241	3414	-173	5.34
25 th June SKAU-341	89	82	7	-7.87	125	125	6	-4.58	2863	3058	-195	6.81
Male		3.75				4.46				47.15		
RMSE		4.02				4.73				574.21		

Obs=observed ; sim=simulated; devi=deviation; RMSE=Root mean square error; MAE=Mean Absolute Error

VALIDATION STUDIES OF ANANTNAG STATION

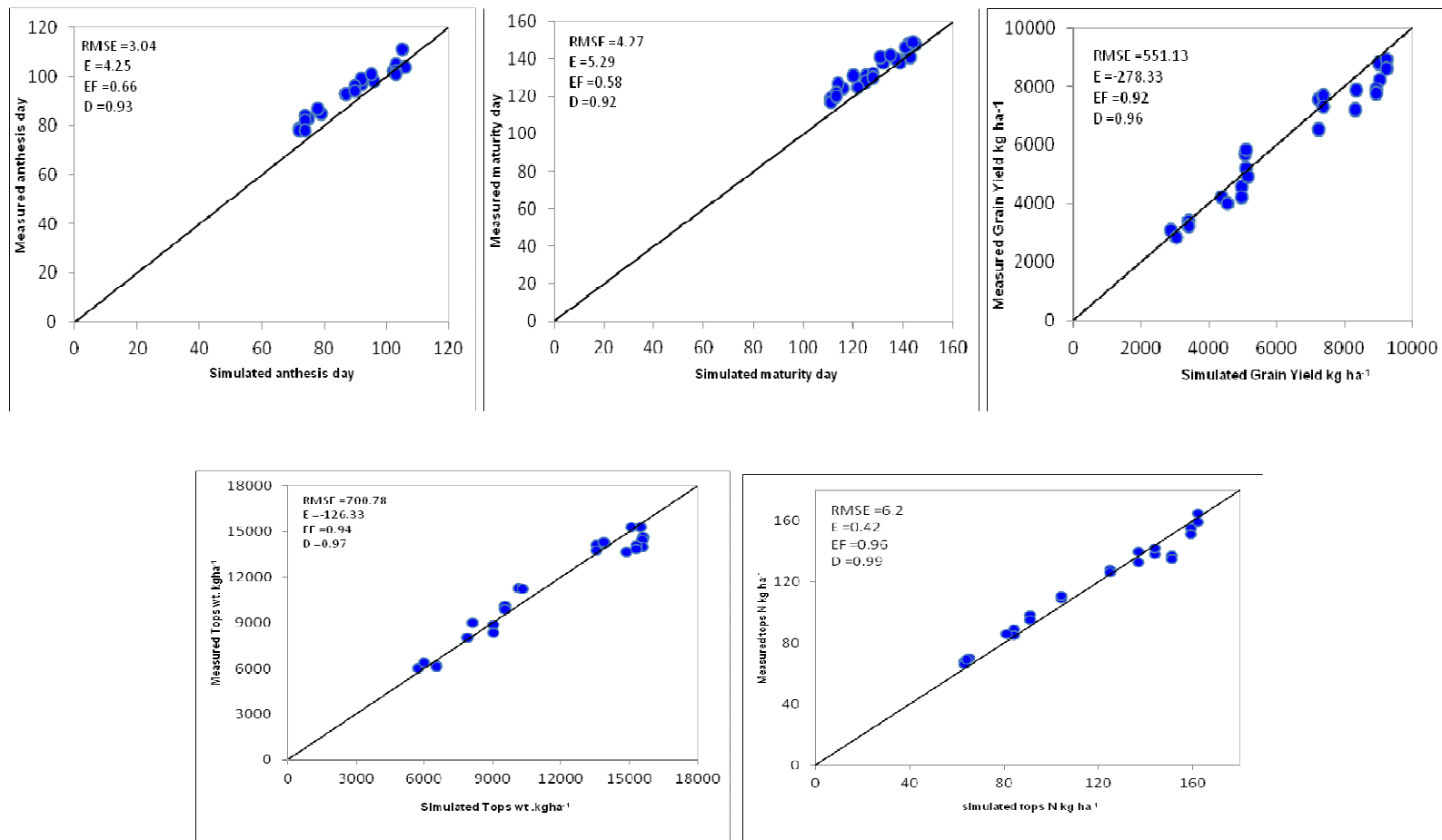


Fig. 39 : Comparison between observed and simulated days to anthesis, maturity, grain yield, tops weight at maturity and N-uptake

varieties under both simulated and observed values. The range was between 73 to 108 days and 77 to 105 days for observed and simulated data, respectively. The RMSE (Root Mean Square Error) obtained between the actual and predicted anthesis was 3.40 days with a MAE (Mean Absolute Error) of 3.0 days and D-index (Index of agreement) 0.93.

Simulated data showed that 25 May recorded highest number of days to reach anthesis and 25 June transplanting took least number of days to anthesis.

Simulated and observed data showed cultivar SKAU-382 transplanted on 25 June recorded least number of days to reach anthesis and cultivars SKAU-341 and Shalimar rice-1 transplanted on 25 May took maximum number of days to anthesis.

Duration of maturity also varied between transplanting dates and varieties under both simulated and observed values. The per cent variation in simulated duration to maturity over observed value ranged from -7.3 to 2.8 days. Duration to maturity varied between sowing dates and varieties under both simulated and observed values (Table 26 and Fig. 40). The range was between 117 to 150 days and 115 to 149 days for observed and simulated data, respectively. The RMSE (Root Mean Square Error) obtained between the actual and predicted maturity was 4.27 days with a MAE (Mean Absolute Error) of 3.88 days and D-index (Index of agreement) of 0.92.

Simulated data showed that 25 May recorded highest number of days to reach maturity and 25 June transplanting took least number of days to maturity.

Cultivars Shalimar rice-1 and SKAU-341 transplanted on 25 May recorded maximum number of days to mature for both predicted and observed values whereas cultivar Jhelum and SKAU-382 transplanted on 25 June took least number of days to mature for both simulated and observed values.

4.6.12 Grain yield

Observed and Predicted yield have been presented in Table 26 and Fig. 39.

The observed values of all treatments during both the years ranged from 3241 to 8931 kg ha⁻¹, as compared to simulated data ranging from 3058 to 9221 kg ha⁻¹. The predicted yield value varied between -12.8 to 15.5 per cent over observed values during both the years of validation. The RMSE for the grain yield was 551.13 kg ha⁻¹ with a MAE of 455.58 kg ha⁻¹ and D-index of 0.96.

The grain yield was maximum for the earliest transplanting (25 May) over the year and decreased progressively with delay in transplanting. The comparison of observed and predicted grain yields both over and underestimated by the model; however, the trend noted for the field-observed and model simulated grain yields was similar.

Cultivar SKAU-341 recorded lowest observed yield on all transplanting dates where as cultivar Jhelum recorded highest observed grain yield. The simulated results showed the same trend except 10 June transplanting 2012 where cultivar SKAU-341 recorded highest yield.

4.6.13 Tops weight at maturity

Observed tops weight at maturity ranged from 6017 to 15287 kg ha⁻¹, compared to 5732 to 15616 kg ha⁻¹ for simulated yield under different treatments (Table 27 and Fig. 39). The per cent variation in simulated tops weight at anthesis over observed value ranged from -10.2 to 9.0. The RMSE of tops weight at maturity was 700.78 kg ha⁻¹ along with MAE value of 595.63 kg ha⁻¹ and D-index value of 0.97.

For both observed and simulated data 25 May transplanting gave the maximum tops weight at maturity. While lowest tops weight at maturity was recorded on 25 June transplanting.

Cultivars SKAU-341 transplanted on all the three dates recorded maximum tops wt at maturity whereas cultivar SKAU-382 recorded least tops wt at maturity except 10 and 25 June during 2011 and 25 June during 2012. Simulated results also showed the maximum tops wt of cultivar SKAU-341

Table 27 : Validation results of rice cultivars for tops N (kg ha⁻¹) and tops weight at maturity (kg ha⁻¹) under different transplanting dates at Anantnag

Treatment	Tops N				Tops weight at maturity			
	Obs	Sim	Devi	% Devi	Obs	Sim	Devi	% Devi
25 th May SR-1	159	162	-3	1.89	14638	15616	-978	6.68
25 th May Jhelum	155	159	-4	2.58	14429	15583	-1154	8.00
25 th May SKAU-382	151	159	-8	5.30	13972	15583	-1611	11.53
25 th May SKAU-341	165	162	3	-1.82	15287	15496	-209	1.37
10 th June SR-1	138	144	-6	4.35	13651	14880	-1229	9.00
10 th June Jhelum	137	151	-14	10.22	14062	15315	-1253	8.91
10 th June SKAU-382	135	151	-16	11.85	13860	15315	-1455	10.50
10 th June SKAU-341	142	144	-2	1.41	15269	15077	192	-1.26
25 th June SR-1	86	81	5	-5.81	8017	7902	115	-1.43
25 th June Jhelum	89	84	5	-5.62	8865	9029	-164	1.85
25 th June SKAU-382	85	84	1	-1.18	8326	9029	-703	8.44
25 th June SKAU-341	86	81	5	-5.81	8991	8100	891	-9.91
25 th May SR-1	133	137	-4	3.01	14210	13901	309	-2.17
25 th May Jhelum	128	125	3	-2.34	14107	13552	555	-3.93
25 th May SKAU-382	126	125	1	-0.79	13768	13552	216	-1.57
25 th May SKAU-341	140	137	3	-2.41	14289	13880	409	-2.86
10 th June SR-1	109	104	5	-4.59	11283	10128	1155	-10.24
10 th June Jhelum	98	91	7	-7.14	10105	9524	581	-5.57
10 th June SKAU-382	95	91	4	-4.21	9865	9524	341	-3.46
10 th June SKAU-341	111	104	7	-6.31	11253	10312	941	-8.36
25 th June SR-1	70	65	5	-7.14	6017	5732	285	-4.74
25 th June Jhelum	68	63	5	-7.35	6218	6526	-308	4.95
25 th June SKAU-382	66	63	3	-4.55	6117	6526	-409	6.69
25 th June SKAU-341	69	64	5	-7.25	6410	5959	451	-7.04
Male		5.17			663.02			
RMSE		6.20			799.15			

Obs=observed ; sim=simulated; devi=deviation; RMSE=Root mean square error; MAE=Mean Absolute Error

recorded maximum tops weight except 25 June transplanting of both the years whereas SKAU-382 recorded least tops wt at maturity except 25 June transplanting of both the years.

4.6.14 N-uptake

The tops nitrogen uptake ranged from 66 to 165 kg ha⁻¹, compared to 61 to 162 kg ha⁻¹ for simulated yield under different treatments (Table 27 and Fig. 39). The per cent variation in simulated N uptake over observed value ranged from -7.6 to 10.2. The model predicted N uptake reasonably well with RMSE value of 5.81 kg ha⁻¹, MAE value of 5.0 kg ha⁻¹ and D-index value of 0.97.

For both observed and simulated data 25 May transplanting gave the maximum nitrogen uptake and the lowest was recorded on 25 June transplanting.

Cultivars SKAU-341 transplanted on 25 May recorded maximum nitrogen uptake for observed values and cultivar Shalimar rice-1 and SKAU-341 recorded maximum nitrogen uptake for simulated values. Cultivar SKAU-382 transplanted on 25 June recorded least nitrogen uptake.

4.7 Climate change

4.7.1 Simulated yield of selected varieties due to climatic change

Simulated yield of different varieties ((Shalimar rice-1, Jhelum, SKAU-341 and SKAU-382) tested at different locations indicated that there was an overall decrease in rice yield with regard to different varieties and locations (Table 28). Lowest drop in the yield with climate change was observed using weather data of Kokernag per cent decrease ranged between 11.71 to 15.52%, where at other stations i.e. Kupwara, Anantnag, Srinagar and Budgam per cent decrease ranged between 37.46 to 53.67. At Kupwara among different varieties decrease in the yield was recorded between 47.32 to 49.54 corresponding decrease at Anantnag, Srinagar and Budgam ranged between 50.91 to 53.67, 37.46 to 41.30 and 45.32 to 47.52 respectively. Data indicated that all the four cultivars did not record considerable drop in the yield at Kokernag; however at other locations

Table 28: Simulated yield (q ha⁻¹) of rice varieties as a function of climate change (temperature, precipitation and CO₂)

Variety		Locations									
		Kokernag		Kupwara		Anantnag		Srinagar		Budgam	
		Decrease (%)	Decrease (%)	Decrease (%)	Decrease (%)	Decrease (%)	Decrease (%)	Decrease (%)	Decrease (%)	Decrease (%)	Decrease (%)
Jehlum	Normal	97.81		67.81		77.96		56.81		65.69	
	Climate change	86.36	11.71	35.72	47.32	38.28	50.91	35.52	37.46	35.93	45.3
Shalimar-Rice 1	Normal	99.32		67.94		76.17		59.52		67.69	
	Climate change	84.25	15.17	34.26	49.54	35.83	52.96	35.10	41.3	35.52	47.52
SKAU-382	Normal	97.81		67.81		77.96		56.81		65.69	
	Climate change	86.36	11.71	35.72	47.32	38.28	50.93	35.52	37.46	35.93	45.3
SKAU-341	Normal	98.65		68.23		76.03		59.84		68.57	
	Climate change	87.29	15.52	35.11	48.52	35.23	53.67	35.82	41.04	36.32	47.06

% relative change in yield is computed in reference to yield from current Scenario or the current atmospheric condition (normal)

there was considerable decrease in the yield of all the varieties as a result of climate change.

4.7.2 Simulated yield of different locations due to climatic change

Simulated yield of cultivar Jhelum at different locations is presented in Table 29, as a function of various climate change parameters. It was observed that with the increase of 2°C temperature as estimated by 2040 it was expected an overall decrease of rice yield by 0.7% at all the locations, as estimated increase in minimum temperature by 2.3°C also simulated decrease by 0.55% across different locations. Precipitation with estimated decrease of 90mm of rainfall by 2040 huge decrease of yield was simulated at Kupwara, Anantnag, Srinagar and Budgam however decrease in Kukernag was not considerable. On an average decrease across the locations was 38.4%. Increase of CO₂ by 80ppm as estimated by 2040 recorded considerable increase in the yield at Kokernag, Kupwara, Srinagar and Budgam was 6.41,5.08,3.78 and 4.05 respectively, where at Anantnag the increase was only 0.5%. With regard overall change of all climatic parameters simulated the decrease of yield across the all locations is 36.67%.

The simulated periodic dry matter (Fig. 40, 42 and 44) production as influenced by climate change factors at Kupwara, Srinagar and Anantnag. periodic dry matter does not get much influenced by temperature variation and there was increase in dry matter with the increase of CO₂, but when the precipitation was decreased there was drastic reduction in dry matter production. Due to reduction in precipitation dry matter production was restricted upto 45 days after transplanting where as for normal climatic conditions or 2°C increase in maximum temperature or 2.3°C increase in minimum temperature or increase of CO₂ by 80ppm the dry matter was normal through out the growth period.

Similar trend was also observed for tiller number per square meter (Fig. 41, 43 and 45).

Table 29 : Simulated rice yield (q ha⁻¹) of cultivar Jhelum of different locations as function of various climate change parameters

Climatic parameters scenario (CO ₂ Temp and precp.)	Locations											
	Kokernag	Devi (%)	Kupwara	Devi (%)	Anantnag	Devi (%)	Srinagar	Devi (%)	Budgam	Devi (%)	Average	Devi (%)
Normal	97.81		67.81		77.96		56.80		65.69		73.21	
Maximum temperature +2 °C (C ₁)	96.09	-1.81	66.91	-1.31	78.19	+0.29	57.66	+0.25	64.82	-1.32	72.96	-0.73
Minimum temperature +2.3°C (C ₂)	97.38	-0.44	65.32	-3.73	78.11	+0.19	56.51	-0.51	66.71	-1.53	72.74	-0.55
Precipitation -90mm (C ₃)	82.16	-16.02	36.25	-46.54	38.24	-0.49	33.91	-40.32	34.93	-46.83	45.04	-38.41
CO ₂ +80ppm (C ₄)	104.45	+ 6.41	71.43	+ 5.08	78.32	+0.53	59.03	+3.78	68.46	+4.41	76.48	+4.13
ALL (C ₁ +C ₂ +C ₃ +C ₄)	86.36	-11.73	35.72	-47.32	38.28	-50.94	35.52	-37.46	35.95	-45.32	46.36	-36.67

% relative change in yield is computed in reference to yield from current Scenario or the current atmospheric condition (normal)

**Impact of climate change on Tops weight kg ha^{-1} and number of tillers m^2
Anantnag Station**

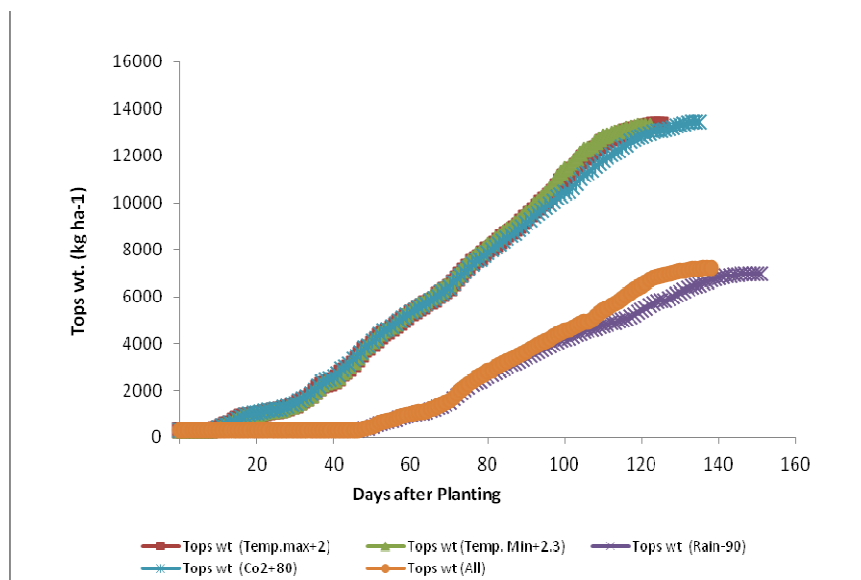


Fig. 40 : Periodic tops weight as affected by climate change

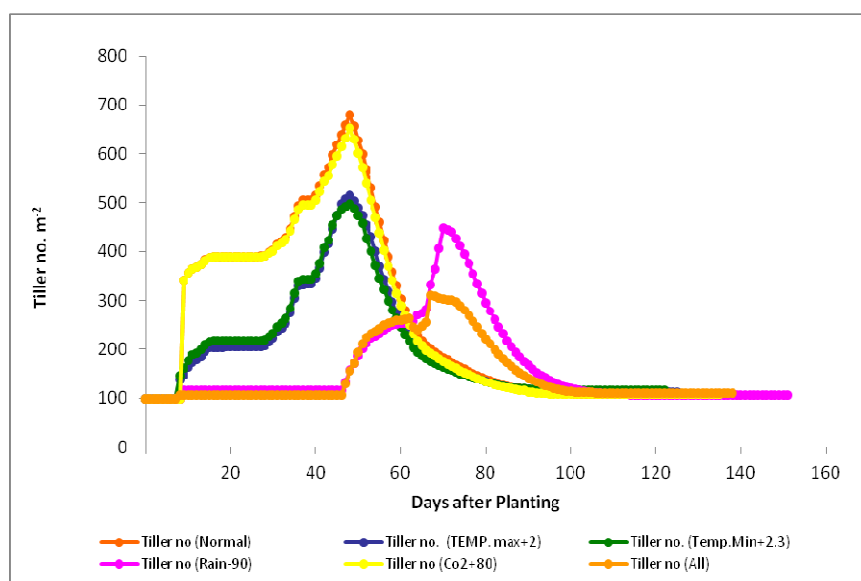


Fig. 41 : Periodic tiller/ m^2 as affected by climate change

Kupwara Station

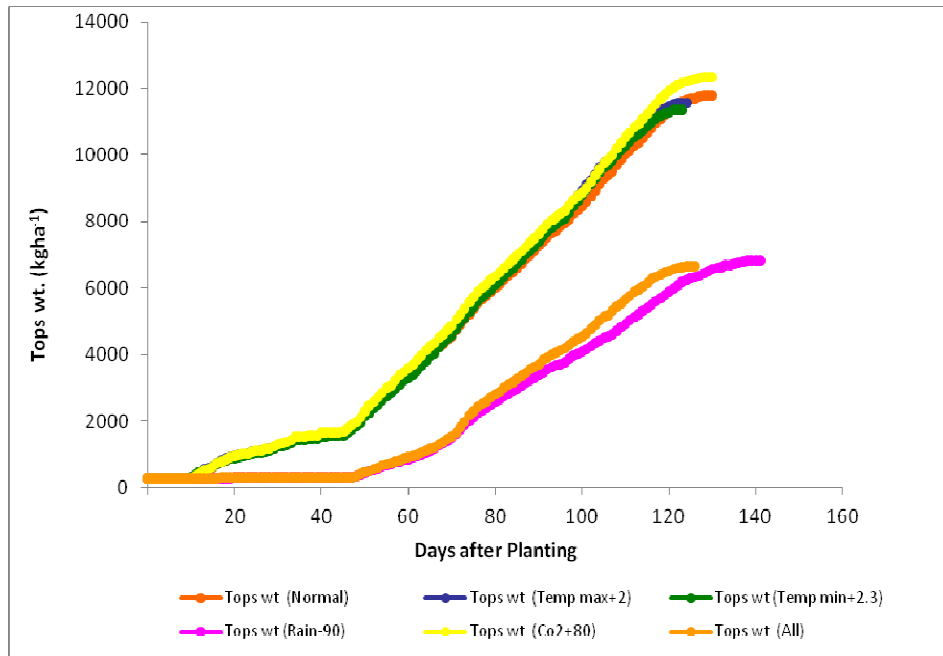


Fig. 42 : Periodic tops weight as affected by climate change

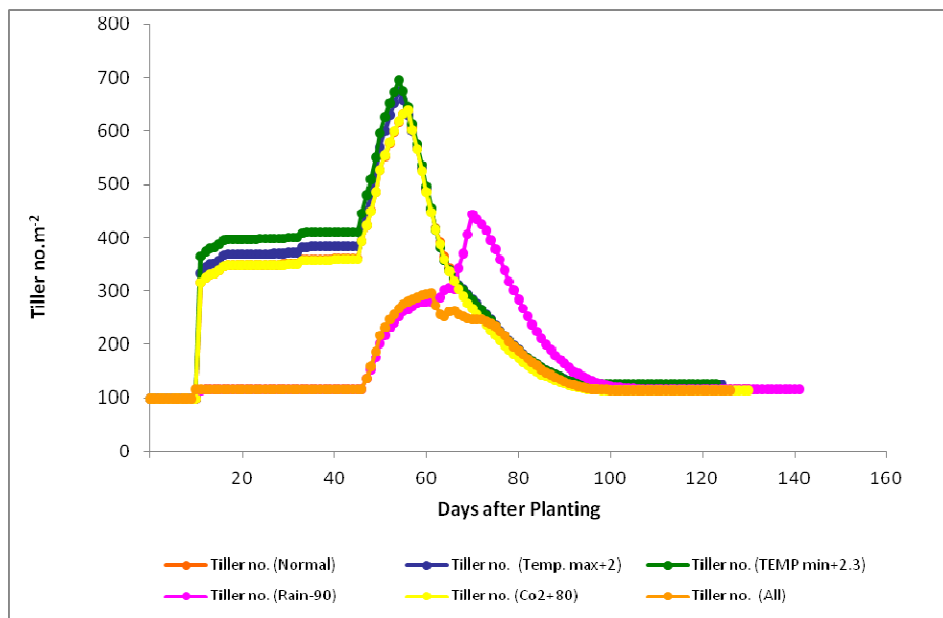


Fig. 43 : Periodic tiller/m² as affected by climate change

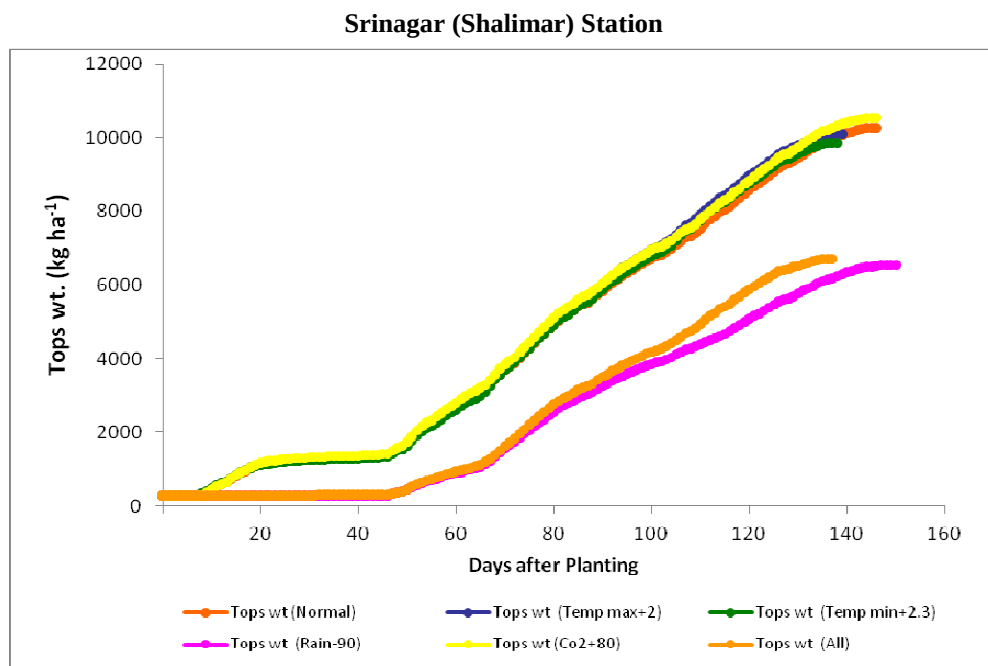


Fig. 44 : Periodic tops weight as affected by climate change

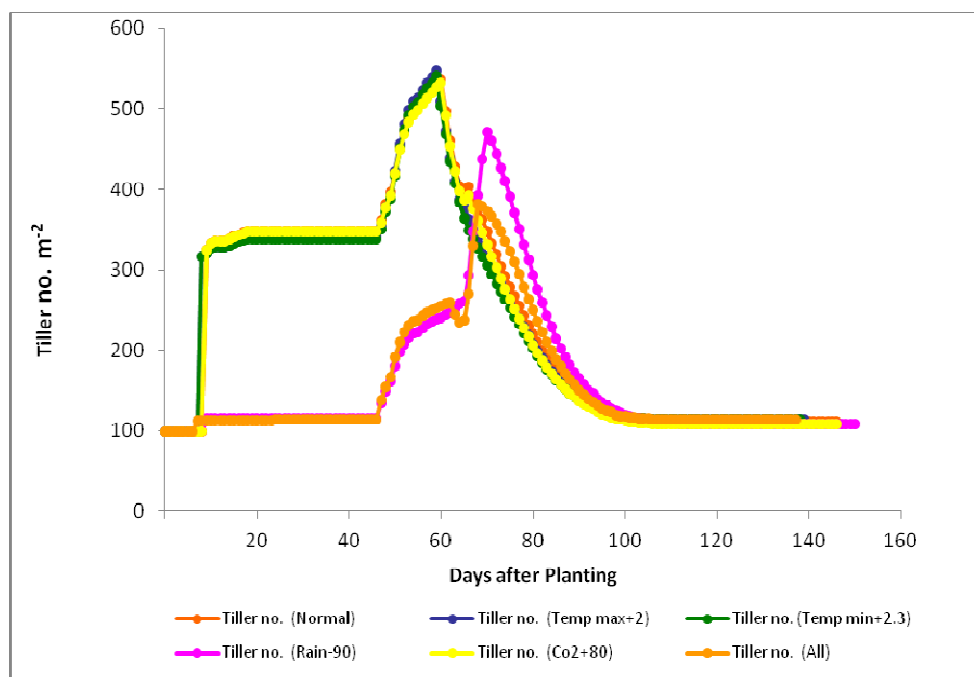


Fig. 45 : Periodic tiller/m² as affected by climate change

4.7.3 Simulated water balance as a function of climate change

Simulated water balance under variable climatic parameter change scenario is presented in Table 30. It was observed that at all the location there was not considerable change in the precipitation due to increase in the maximum temperature (C_1), minimum temperature (C_2) and CO_2 (C_4). However, under predicted treatment i.e. -90 mm precipitation (C_3), the precipitation during the growth period was predicted between 0.00 mm (Kokernag and Budgam) to 11.60 mm (Srinagar) at all the locations. Similar trend was observed by combining all the treatments i.e. C_1 , C_2 , C_3 and C_4 .

Table 30 : Simulated water balance as a function of climate change

Climatic parameters	Normal	Maximum temperature +2 °C (C ₁)	Minimum temperature +2.3°C (C ₂)	Precipitation 90 mm (C ₃)	- CO2 +80 ppm (C ₄)	ALL (C ₁ +C ₂ +C ₃ +C ₄)
Kokernag						
Effective Irrigation	162.60	167.64	166.76	423.67	162.19	395.48
Precipitation	448.45	406.19	359.62	0.00	448.45	0.00
Transpiration	325.73	286.12	279.00	303.91	317.33	273.24
Kupwara						
Effective Irrigation	1536.58	1484.36	1422.65	1838.48	1462.82	1722.81
Precipitation	427.91	411.78	391.04	7.69	427.91	7.69
Transpiration	273.47	267.81	252.50	169.39	271.98	162.56
Badgam						
Effective Irrigation	332.57	343.02	312.00	476.34	312.82	450.70
Precipitation	165.85	156.25	154.17	0.00	166.63	0.00
Transpiration	322.79	325.54	314.26	342.19	325.08	334.03
Srinagar						
Effective Irrigation	1406.97	1414.98	1410.33	1863.49	1406.20	1778.46
Precipitation	612.85	609.94	606.63	11.56	612.85	11.56
Transpiration	236.55	234.09	227.02	164.05	235.53	146.00
Anantnag						
Effective irrigation	1598.52	1496.57	1446.79	1907.76	1599.83	1823.16
Precipitation	439.64	406.09	364.81	7.30	439.64	7.30
Transpiration	291.92	282.43	280.80	186.72	278.21	165.80

Chapter – 5

DISCUSSION

The result obtained during two years of investigation “impact of climate change on different rice varieties under varied agroecological conditions of Kashmir using CERES-Rice model” are discussed in this chapter under appropriate heads.

Salient features of weather conditions during the course of investigation which explains that the precipitation received during the crop growth period (April to October) was 319.7 mm and 417.2 mm during 2011 and 2012 respectively. Wettest months during crop growth period were April (93.1 mm) and April (130.5 mm) during 2011 and 2012, respectively. The mean maximum and minimum temperature for entire crop growth period of rice crop for 2011 was 26.62 and 11.77°C respectively and corresponding values for 2012 were 27.12 and 12.67°C. For 25 May, 10 June and 25 June, transplanting the mean maximum and minimum temperature was 27.44 and 13.08, 26.29 and 12.97, 27.13 and 12.34, respectively during 2011 and corresponding values for 2012 were 27.12 and 13.31, 26.31 and 12.65, 26.95 and 11.97, respectively (Appendix-1). Sunshine hour values were comparatively higher in case of 2012 than 2011 whereas value of wind speed and relative humidity were comparatively higher in case of 2011 (Appendix-1). Comparatively higher temperature and solar radiation at different growth stages may be reason for overall higher grain yield irrespective of sowing dates and genotypes in 2012 than 2011.

5.1 Growth characters

Early transplanting (25 May) recorded significantly taller plants after 75 DAT till maturity during 2011 and 2012 (Table 7). This may be attributed to longer growth period and better weather conditions under earlier sowing date which favoured profuse vegetative growth. Similar findings were reported by Dawadi and Chaudhary (2013) and Suresh *et al.* (2001). However, upto 75 DAT

25 June recorded taller plants. As late transplanting was subjected to high temperature compared to early transplanting development phases become quicker leading to initial faster increase in height. Similar findings were also recorded by Obuchiet *al.* (2000) and Pattaret *al.* (2001).

Cultivars showed variation with respect to plant height. Cultivar SKAU 341 recorded significantly taller plants than other varieties at 60 DAT till maturity during 2011 and 2012, though Jhelum and SKAU- 382 were at par at all the recorded periodic stages. After SKAU- 341, Shalimar rice-1 significantly recorded more height than other varieties. Cultivar SKAU- 341 gained more height after panicle initiation (45DAT).variation in plant height may be due to genetic make up of rice varieties.Variation in plant height of different varieties under different agroclimatic conditions was also reported by various workers (Singh *et al.*, 2004; Lazaet *al.*, 2004 and Aboukhalifa, 2009).

Tillers number m^{-2} increased up to 45 DAT, thereafter decreased gradually up to maturity during both the years (Table 8). Results are in conformity with those of Lalithaet *al.* (2000). Transplanting on 25May and 10 June recorded less tillers during early growth period (30DAT) due to low temperature but with advancement of crop growth up to 105 DAT (maturity) 25 May recorded higher number of tillers. Also the late transplanted crop recorded less number of tiller m^{-2} because it culminate vegetative phase earlier than early planted crop. Similar results were also reported byRakesh and Sharma (2004). Transplanting dates cause significant variation in tillering of rice at maturity. Early transplanting maintained more tillers. The longer growth and congenial temperature might have resulted in better conditions for tiller production. Similar findings were reported by Dawadi and Chaudhary (2013).

Cultivar Jhelum had higher number of tillers m^{-2} during both years except at 15 and 30 DAT, where SKAU-382 produced significantly higher number of tillers. This variation in tiller production by different varieties under variable

climatic conditions was also reported by AbouKhalifa and El-Rewainy (2012); Khalifa *et al.* (2014).

LAI showed an increasing trend upto 60DAT where maximum values are recorded, there after LAI values gradually start decreasing with the advancement of rice age (Table 9). It is in congruous with the findings of Dawadi and Chaudhary (2013). It is due to more functional leaves at 60 (DAT). LAI was significantly influenced by transplanting dates and cultivars except due to cultivars at 15 DAT and 30 DAT. 25 July transplanted rice recorded higher LAI upto 45 DAT followed by 10 June and then 25 May during both the years. Similar findings were reported by Manjappa and Kumar (2002) and Singh *et al.*, 2007. At Higher maximum and minimum temperature during early growth for 25 June transplanting along with comparatively more sunshine may be the reason for higher LAI (Appendix-I). However, as growth progressed 25 May and 10 June recorded higher LAI due to its more growth period (Fig. 9). At maturity i.e. 105 DAT, LAI was again in the reverse order. At 60 DAT, 25 May transplanting was significantly superior over 10 June which in turn is significantly superior over 25 June transplanting. However, at later stages of crop i.e. 75 DAT during 2012 and 90 DAT during both the years 25 May and 10 June transplanted crop recorded at par leaf area index. At later transplanting dates higher LAI at maturity may be due to low temperature and sink limitations during both years.

Among cultivars, Jhelum and SKAU-382 were statistically at par and significantly superior over Shalimar rice1 and SKAU-341 upto 60 DAT. Higher LAI of these varieties may be because of better G x E interaction under existing agroclimatic conditions. Rest on all recorded periodic stages i.e. 60, 75, 90 and 105 DAT SKAU-341 was significantly superior over all the cultivars under study. This may be due to the reason that SKAU-341 accumulates more biomass and is 10-15 days late than other cultivars. Variation of LAI trend of different varieties at different growth stages have been also reported by Bali *et al.* (1995), Yang *et al.* (2001) and Khalifa *et al.* (2014).

Dry matter production was significantly influenced by transplanting date during both the years (Table 10 and Fig. 11). Earlier transplanting (25 May) recorded higher value of dry matter yield from 60 DAT till maturity during both years. However 25 June transplanting was significantly superior over 10 June transplanting which in turn was superior over 25 May transplanting during both the years at all the periodic stages upto 60 DAT. At maturity i.e. 105 DAT 25 May transplanting yield significantly higher dry matter followed by 10 June and then 25 June transplanting. This can be substantiated by the finding of Manjappa and Kumar (2002), Poussin (2003), Haghverdian (2010). Since this period (25 May) coincide with favorable period of crop growth reducing death of tiller and senescence of leaf thus accumulating more dry matter. Further both periods (25 May and 10 June) was also prolonged. Thus higher biomass production can attributed to higher tiller number, leaf area index and more functional leaves.

Cultivars under study responded significantly to dry matter accumulation at all the periodic stages during both the years as shown in Table-10 and illustrated in Fig. 12. At 15 DAT, all the cultivars were at par in registering dry matter accumulation during both the years. Shalimar rice-1 accumulated significantly higher dry matter over all the cultivars at 30 and 45 DAT. However, SKAU-341 provided maximum dry matter of leaf and stem from 45 DAT till maturity, but the total dry matter (including panicle weight) was significantly more in Jhelum being at par with Shalimar rice-1. This can be attributed to the genetic makeup of SKAU-341 which produces more plant height and number of leaves but the panicle weight was less. Similar findings were reported by Zhai *et al.* (2002) and Yang *et al.* (2002b).

Data presented in Table 14 and Fig. 19 revealed that leaf number per culm showed an increasing trend upto increased up to 60 DAT (anthesis) and the highest value was found at 60 DAT, thereafter the number gradually decreased in all the treatments during both the years. It is in congruous with the findings of Khanal (2005) and Streck *et al.* (2008). At 15 days after transplanting there was

no significant difference between 3 dates of transplanting during both the years. At 30DAT highest leaf number was found on 25 June transplanting followed by 10 June and then 25 May transplanting there was significant difference between all the dates of transplanting. Higher maximum and minimum temperature during early growth for 25 June transplanting along with comparatively more sunshine may be the reason for more leaf number (Appendix-1). However, as growth progressed at 45 DAT till maturity highest leaf number was recorded on 25 May transplanting followed by 10 June and then 25 June during both the years.

Among cultivars, at 15 and 30 DAT there was no significant difference. At 45 DAT Jhelum and SKAU-382 were superior to Shalimar rice-1 and SKAU-341. However SKAU-341 recorded significantly higher leaf number followed by Shalimar rice-1 from 60DAT till maturity. This might be due to prolonged growth period of SKAU-341 after panicle initiation. Variation of leaf number of different varieties at different growth stages have been also reported by Larijani (2010), Jahan and Adam (2011) and Khalifa *et al.* (2014).

Specific leaf weight was significantly affected by transplanting dates during both the years. At initial period the specific leaf weight was more 25 June transplanting than 25 May and 10 June transplanting. Among all the periods the highest specific leaf weight was recorded at 60 DAT on 25 May transplanting and lowest on 25 June transplanting. At maturity (105DAT) the 25 May transplanting recorded significantly highest specific leaf weight than 25 June but 10 June was at par with 25 May and 25 June during 2011. During 2012 the highest specific leaf weight was recorded by 25 May transplanting but there was no significant difference among transplanting dates. Similar findings were reported by Hossain and Paul (2011).

During 2011 and 2012 at 15 and 30 DAT all cultivars show no significant difference. At 60 DAT (anthesis) the cultivar SKAU-341 had highest specific leaf weight and was significantly superior than SKAU-382 but there was no significant difference among other cultivars during 2011, but during 2012 cultivar SKAU-

341 was significantly superior over other cultivars and Shalimar rice-1 was significantly superior over SKAU-382, but there was no significant difference between SKAU-382 and Jhelum. At 105 DAT (maturity) cultivar SKAU-341 recorded highest specific leaf weight and was significantly superior over Jhelum and SKAU-382, cultivar SKAU-341 and Shalimar rice-1 were at par and Shalimar rice-1 was also significantly superior over Jhelum and SKAU-382 during both the years. The results are in agreement with the findings of Xian-qing *et al.* (2003).

Relative growth rate was significantly affected by transplanting dates during both the years (Table 16 and Fig. 23). At 15-30 DAT transplanting on 25 June recorded more relative growth compared to 10 June and 25 May transplanting, 25 June was significantly superior than 25 May transplanting, where 10 June were statistically at par with 25 May and 25 June transplanting during both the years. At 60-75 DAT (flowering) 25 May transplanting was significantly superior to 25 June transplanting, 10 June being at par with 25 May and 25 June during both the years. At 90-105 DAT (maturity) 25 May transplanting had higher relative growth rate than 10 and 25 June transplanting but there was no significant difference during both years. The lowest value for early transplanting at early growth period may be attributed to low temperature at this period and the lowest value for late transplanting at later stages may be due to short growth period. Similar findings were reported by Alam *et al.* (2009) and Jahan and Adam (2011).

With regard to relative growth rate of different cultivars it varied significantly during both the years (2011 and 2012). At 15-30 DAT SR-1 significantly had higher relative growth rate than other cultivars during both the years. At 60-75 DAT (flowering) till maturity 90-105 DAT cultivar SKAU-341 significantly superior than other cultivars. At maturity SKAU-341 recorded highest value than other cultivars, but there was no significant difference among varieties at this period. At most of the growing periods SR-1, Jhelum and SKAU 382 were statistically at par during both the years. SKAU-341 had highest value

for RGR this might be due to prolonged growth period of SKAU-341 after panicle initiation stage. The results are well matched with the findings of Alam *et al.* (2009), Jahan and Adam (2011) and Azarpour *et al.* (2014).

Dead leaf weight revealed that during the period of 2011 and 2012 at 15 and 30 DAT there was no significant difference between 25 May, 10 June and 25 May transplanting (Table 17 and Fig. 25). At 45 DAT, 60 DAT and 75 DAT (anthesis) 25 June recorded significantly highest dead leaf weight followed by 10 June and then 25 May transplanting during both the years. This can be attributed to least number of days taken to various phenological stages. At maturity (105 DAT) 25 May significantly had more dead leaf weight compared to 10 and 25 June transplanting during both the years. This can be due to higher biomass production of early transplanting dates. Similar findings were reported by Sheehy and Mitchell (2013).

Among cultivars there was no significant difference at 15 and 30 DAT. At 45 DAT Jhelum and SKAU-382 were superior to Shalimar rice-1 and SKAU-341. At 75 DAT SKAU-382 significantly recorded more dead leaf weight followed by Jhelum then Shalimar rice-1 and then SKAU-341. At 105 DAT (maturity) SR-1 significantly recorded more dead leaf weight followed by Jhelum then SKAU-341 and SKAU-382. This might be due to genetic make up of cultivars. Not much research has been done on this parameter so it needs further research experiments.

5.2 Phenological stages

Days taken to various phenological stages decreased as transplanting were delayed (Fig. 27 and 28). Crop transplanted on 25 May took more days to reach various phenological stages viz. transplanting shock over, tillering, panicle initiation, anthesis 50% flowering milking and maturity compared to 10 June which in turn took more days than 25 June. Early transplanting took more days to various phenophases this is due to low temperature at initial period influenced the length of vegetative phase. The results are well matched with the findings of

Dehghan (2007), AbouKhalifa and Rewainy (2012). The late transplanting took more days to various phenological stages this is attributed to higher temperature during initial period which resulted in quicker coverage of these phases under later transplanting dates (Appendix-I). Kotera *et al.* (2004) indicated that time from emergence to heading was largely different between the winter-spring season crop grown under low temperature conditions (95-106 days) and rainy season crop grown under hot conditions (73-84 days).

It was also noted that the time between sowing to mid tillering and mid tillering to panicle initiation decreased as sowing date was delayed due to comparatively higher temperature (Appendix-I). But the number of days spent in anthesis to maturity under late transplanting crop was extended by 3 to 5 days due to low temperature (Appendix-I). It clearly showed that sowing date primarily influenced the length of vegetative phase. The results are well matched with the findings of Slaton *et al.* (2003).

Cultivars also behaved differently with regard to number of days taken to reach various phenological stages. Cultivar SKAU-341 after panicle initiation required more number of days to reach various stages, where as all other varieties almost took same days during both years. This variation might be due to genetic makeup of cultivars. Variations in crop growth period among different cultivars under different climatic condition is also reported by AbouKhalifa and El-Rewainy (2012) and Khalifa *et al.* (2014).

5.3 Yield attributing characters

Study revealed that yield attributing characters viz. Spikelets panicle⁻¹ grains panicle⁻¹ 1000-grain weight and Sterility percentage were influenced by transplanting dates during both the years (Table 19). Transplanting on 25 May being at par with 10 June recorded significantly more spikelet number than 25 June transplanting during both years. Number of grains panicle⁻¹ decreased with successive delay in transplanting date during both years. Differences between

transplanting dates with regard to 1000-grain weight varied. Heavier 1000-grain was recorded with 25 May and 10 June transplanting than 25 June during both years 2011 and 2012. This can be attributed to reduced growth phases and low temperature during reproductive phase encountered by late transplanting (Appendix-I) in temperate environments, a major limitation to rice growth is temperature around flowering time. This can be substantiated by the findings of Singh *et al.* (2005), Lack *et al.* (2012), Mukesh *et al.* (2013) and AbouKhalifa *et al.* (2014). Controlled environment studies by Heenan (1984) have shown that the most sensitive time for chilling injury is during the microspore stage of pollen development, which occurs about 10 days before heading.

Kumar (2002) concluded that under low temperature condition, a significant reduction in rates of photosynthesis (36.68%), canopy photosynthesis (44.14%), transpiration (29.30%), nitrate reductase activity (51.61%) was observed at grain filling stage. Besides, a reduction in the grain filling rate was also noted under low temperature.

Among rice cultivars Jhelum significantly recorded higher yield attributing characters like Spikelets panicle⁻¹, grains panicle⁻¹ and panicle weight at maturity during both years. However, 1000 grain weight and sterility% was highest in SKAU-341 and minimum in Shalimar rice-1 and Jhelum. Significant variation among rice cultivars with regard to yield attributes might be due to their genetic makeup. Variation in various yield attributing characters between rice varieties were also reported by Khalifa (2009), Youssef *et al.* (2011), Lack *et al.* (2012) and Mukesh *et al.* (2013)

5.4 Grain yield

The grain yield remained comparatively little higher during 2012 than 2011 irrespective of treatments. This variation in the yield might be attributed to better environmental conditions in terms of temperature and sunshine hours (Appendix-I).

The transplanting dates significantly influenced grain yield. Grain yield decreased by delaying transplanting. This is in agreement with the findings of various workers from different agro climatic conditions Singh *et al.* (2005); Vange *et al.* (2009); Youssef *et al.* (2011); Lack *et al.* (2012); Kaveh and Hamdollah (2013); Moradpour *et al.* (2013); Kumar *et al.* (2013) and Mukesh *et al.* (2013).

Rice yield is product of three components: number of panicle per unit area, number of filled spikelets panicle⁻¹ and grain weight. Highest grain yield was recorded by 25 May transplanting 74.0 and 79.0 q ha⁻¹ during 2011 and 2012 respectively over 10 June (57.3 and 57.1 q ha⁻¹) and 25 June (31.1 and 32.2 q ha⁻¹) (Table 20). As overall growth is a product of growth rate and growth duration and since growth duration is more affected by temperature under early transplanting, favourable weather conditions had beneficial influence on various growth and yield attributes and also had low floret sterility, this may have helped to increase grain yield than later transplanting.

Phases of growth and development become comparatively shorter with late transplanting. But more important is that maturity period of 25 May transplanted crop coincided with grain filling stage of 10 June and 10 June with 25 June. Floret sterility as a result of late transplanting changed balance between sink and source, resulting exceedingly high number of unfilled grains. Working under Kashmir conditions Bali *et al.* (1992) reported that crop transplanted beyond mid June was exposed to low temperature 25.6 and 12.5°C mean maximum and minimum at flowering stage during last week of August to first week of September, whereas, normal transplanted crop experience better temperature (29.3/17.1°C) at flowering stage.

Rice cultivar Jhelum with 58.3 q ha⁻¹ during 2011 and 59.0 q ha⁻¹ during 2012 was at par with Shalimar rice-1 (56.0 and 58.0 q ha⁻¹) and SKAU-382 (53.0 and 54.0 q ha⁻¹) and recorded significantly higher grain yield than cultivar SKAU-341 (49.0 and 50.3 q ha⁻¹). Higher yield recorded from Jhelum and

Shalimar rice-1 may be attributed to more grains per panicle and less spikelet sterility indicating better sink capacity than other varieties. Variety Jhelum produced higher values of grains panicle⁻¹, panicle weight at maturity. Despite the fact that of higher values for LAI and dry matter accumulation than other cultivars yield was low in SKAU-341; it may be due to limited sink size, as panicle weight at anthesis was significantly less than other varieties besides grains panicle⁻¹. Shalimar rice-1 also had good yield attributing characters i.e. test weight, dry matter accumulation, minimum sterility% but it was on number two in grain yield. This may be due to less spikelets/panicle⁻¹ and grain panicle⁻¹, which was less than cultivar Jhelum. The new released variety SKAU-382 also had good yield attributing characters but is susceptible to Helminthosporium disease which reduces the yield. Variation in grain yield between different rice varieties under different agro-climatic conditions was also reported by Messina *et al.* (2009); Youssef *et al.* (2011); Lack *et al.* (2012); Limochi and Eskandari (2013) and Mukesh *et al.* (2013).

Transplanting on 25 May (early) being at par with 10 June recorded significantly higher straw and biological yield during both the years (Table -). Higher straw and biological yield at 25 May and 10 June can be attributed to higher growth attributes like dry matter accumulation (q ha⁻¹), LAI and longer growth duration. Similar findings were reported by Ahn *et al.* (2000); Siadat *et al.* (2004) and Singh *et al.* (2007).

Cultivar SKAU-341 recorded significantly highest straw and biological yield during 2011 and 2012, followed by Shalimar rice-1, Jhelum and SKAU-341. It may be attributed to higher dry matter accumulation. Variability among different rice varieties for straw was also noticed by Hari Om *et al.* (1997); Singh *et al.* (2000) and Suresh *et al.* (2001). Variability among different rice varieties for biological yield was also noticed by Laza *et al.* (2004); Singh *et al.* (2007); Lack *et al.* (2012) and Khalifa *et al.* (2014).

Late sowing (25 June) significantly reduced harvest index (Table-20). It is obvious that high floret sterility associated with 25 June transplanting decreased economical yield and harvest index. This corroborates the findings of Singh *et al.* (2000); Ahn *et al.* (2000) and Singh *et al.* (2007). Cultivar Jhelum being at par with Shalimar rice-1 and SKAU-382 significantly recorded highest harvest index than SKAU-341 during both years. Superiority of Jhelum over other varieties indicated that this variety have efficient partitioning for assimilates of photosynthesis from source to sink (panicle). Laza *et al.* (2004), Singh *et al.* (2007) and Lack *et al.* (2012) also reported varietals differences for harvest index.

5.5 Nutrient content and uptake

N content in grain and straw on early transplanting date (25 May) significantly recorded higher value followed by 10 June and 25 June (Table-21). Similar findings were reported by Janaki and Thiyagarajan (2004), Samonte *et al.* (2006), Zhang *et al.* (2009), Pandey and Aggarwal (1991), Bali and Uppal (1995) and Dong *et al.* (2002). Grain nitrogen was less than straw, which might be due to less translocations of nitrogen from vegetative parts towards generative parts of plant leaving grainless in nitrogen compared to straw (Hatwaret *al.*, 1992). Cultivar SKAU-341 recorded significantly highest grain N content followed by SKAU-382, Shalimar rice-1 and Jhelum. The difference between the cultivars Shalimar rice-1 and SKAU-382 was not significant during 2011 but there significant difference between these two cultivars during 2012. Jhelum was at par with Shalimar rice-1 during both the years but there was significant difference between Jhelum and SKAU-382 during both the years. Cultivar SKAU-341 significantly recorded highest N content in straw followed by Shalimar rice-1, Jhelum and SKAU-382 during both the years. Variation in nitrogen content between different varieties was reported by Roy *et al.* (2004).

Straw, grain and total N-uptake significantly decreased by delaying in transplanting from 25 May to 25 June. Similar findings were reported by Singh *et al.* (2007). Higher N removal with early transplanting was mainly a resultant of

higher total biomass production and grain yield which decreased with delayed transplanting.

Among varieties N-uptake in grain was recorded highest by SKAU-341. However the difference between the cultivars Shalimar rice-1, Jhelum and SKAU -382 was not significant during both the years. N uptake of straw revealed that SKAU-341 recorded significantly higher N-uptake than other cultivars. Shalimar rice-1 was at par with Jhelum during 2011, but was significantly higher than SKAU -382 during both the years.

Total N-uptake was also higher in SKAU-341 followed by Shalimar rice-1, Jhelum and SKAU -382 but the difference was not statistically significant among varieties. Investigation corroborate with those of De *et al.* (2002) and Kumar and Prasad (2004).

5.6 Validation studies

Validation of model CERES-rice V4.5 under temperate condition of Kashmir suggest that simulated phenology of rice were found to be in reasonable agreement with the observed ones which is main requirement for accurate prediction of crop yield. Duration to anthesis ranged between 81 to 107 days and 77 to 104 days for observed and simulated data, respectively for Srinagar, 70 to 110 days and 65 to 102 days for observed and simulated data, respectively for Badgam and 73 to 108 days and 77 to 105 days for observed and simulated data, respectively for Anantnag. However, corresponding figures for days to maturity was between 121 to 149 days and 114 to 145 days for observed and simulated data, respectively for Srinagar, 107 to 147 days and 105 to 141 days for observed and simulated data, respectively for Badgam and 117 to 150 days and 115 to 149 days for observed and simulated data, respectively for Anantnag. At Srinagar station there was overestimation for rice transplanted on 25 May and underestimation for 10 and 25 June however for Badgam and Anantnag station the days were under predicted for all the three dates, largest under estimation was for

the crop transplanted on 10 and 25 June, which was possibly the effect of variable weather conditions during that period and merits further investigation. The deviation between simulated and observed timing for anthesis and maturity of both rice cultivars was similar to a study by Yao *et al.* (2005) who found that the simulation deviated 10% from the observed anthesis duration. Results are also in agreement with those obtained by Singh *et al.* (2007).

The field observed and model simulated anthesis dates were in close agreement RMSE obtained was 3.7, 6.26 and 3.4 days for Srinagar, Badgam and Anantnag respectively, MAE was, 3.5, 5.08 and 3.0 Srinagar, Badgam and Anantnag respectively and D-index 0.94, 0.89 and 0.93 Srinagar, Badgam and Anantnag respectively. The maturity dates simulated by the model corresponded reasonably well with that actually observed in the field (RMSE = 4.76, 5.50 and 3.40 days for Srinagar, Badgam and Anantnag respectively; MAE = 4.42, 5.04 and 3.0 days for Srinagar, Badgam and Anantnag respectively and D-index = 0.91, 0.90 and 0.93 for Srinagar, Badgam and Anantnag respectively).

Observed grain yield values of all treatment combinations (varieties x transplanting dates) ranged from 2763 to 8140 kg ha⁻¹, as compared to simulated data ranging from 2805 to 8085 kg ha⁻¹ 49.2 to 70.3 q ha⁻¹ for Srinagar, 3019 to 7352 kg ha⁻¹ as compared to simulated data ranging from 3216 to 7255 kg ha⁻¹ for Badgam and 3241 to 8931 kg ha⁻¹, as compared to simulated data ranging from 3058 to 9221 kg ha⁻¹ for Anantnag. The analysis suggests that simulated yields and observed yield are in very close collaboration. Yield was underestimated in Shalimar and Badgam stations at early transplanting but overestimated in some treatment combinations in late transplanting. At Anantnag the yield was underestimated at all transplanting dates, which merits further investigation as much attempts have not done of using model CERES-rice under temperate conditions of Kashmir. The RMSE, MAE and D-index was 338.79 kg ha⁻¹, 298.51 kg ha⁻¹ and 0.99 respectively for Srinagar, 474.48 kg ha⁻¹, 300.54 kg ha⁻¹ and 0.89 respectively for Badgam and 551.13 kg ha⁻¹, 455.58 kg ha⁻¹ and 0.96 respectively for

Anantnag. The variation between simulated and observed values for grain yield was largely due to uncontrolled factors that affected rice plants in the experimental fields such as weeds, crabs and diseases which were not accounted for by the model. Results are in agreement with those obtained by Cheyglinted *et al.* (2001), Ahmad *et al.* (2012). Ahmad *et al.* (2012) reported that the difference between simulated and observed values ranged from 2-15% for total above ground dry biomass and 2-3% for grain yield. Yao *et al.* (2005) also found that the simulation deviated from observed yield by 15%. In addition, Timsina *et al.* (2006) reported that the difference between simulated and observed values for biomass and grain yield was approximately 23%.

It can be brought into notice that there was close association between observed and predicted total dry matter, but not as good as for grain yields (RMSE = 873.94 kg ha⁻¹ along with MAE value of 642.88 kg ha⁻¹ and D-index value of 0.98 for Srinagar, RMSE = 644.87 kg ha⁻¹ MAE value of 534.04 kg ha⁻¹ and D-index value of 0.89 for Badgam and RMSE 700.78 kg ha⁻¹, MAE value of 595.63 kg ha⁻¹ and D-index value of 0.97 for Anantnag. Simulated and measured values of nitrogen uptake matched well at all the stations. Results are in agreement with Singh *et al.* (2007).

The results obtained with the model for four cultivars of rice crop (Shalimar rice-1, Jhelum, SKAU-341 and SKAU-382) reveal satisfactory prediction of phenology, grain yield, biomass and N-uptake of the crop. All the four cultivars showed good results but the results obtained from the cultivar SKAU-341 were not that much accurate. Vilayvong *et al.* (2012) tested the CERES-rice model performance in KhonKaen province, Thailand and found similar kind of results for biomass dynamics, crop phenology and grain yield.

The newly developed genetic coefficients were enlisted in Table 4.1. These coefficients were used for evaluating different sowing dates, and cultivars. The results obtained indicate that the coefficients can be satisfactorily utilized for

validation of growth and yield performance of the crop under a variety of growth management scenarios on independent data set.

5.7 Simulated yield of rice varieties due to climate change

Simulation studies of CERES-rice model for climate change revealed that yield of different varieties (Shalimar rice-1, Jhelum, SKAU-341 and SKAU-382) tested at different locations indicated that there was an overall decrease in rice yield with regard to different varieties and locations. Lowest drop in the yield with climate change was observed using weather data of Kokernag per cent decrease ranged between 11.71 to 15.52, where at other stations i.e. Kupwara, Anantnag, Srinagar and Budgam per cent decrease ranged between 37.46 to 53.67. At Kupwara among different varieties decrease in the yield was recorded between 47.32 to 49.54 corresponding decrease at Anantnag, Srinagar and Budgam ranged between 50.91 to 53.67, 37.46 to 41.30 and 45.32 to 47.52 respectively. Data indicated that all the four cultivars did not record considerable yield drop at Kokernag, while at other locations there was considerable decrease in the yield of all the varieties as a result of climate change. This might be attributed to altitude difference between the locations, Kokernag is high altitude area compared to other locations so the temperature is low compared to other locations, as at higher altitudes evapotranspiration demand is less and irrigation sources are snow melt streams, whereas at lower belts water deficit is observed to decrease the water flow in the streams. OTENG-DARKO *et al.* (2012) evaluated the CERES-Rice (Ver. 4.0) model for use in simulating rice yields under different climate change scenarios. The model was found to be sensitive to climatic parameters (temperature, CO₂ concentration, solar radiation and rainfall) and had various effects on rice.

The cultivar SKAU-341 and Shalimar rice-1 were found more sensitive to climate change as compared to Jhelum and SKAU-382. This is because of the reason that SKAU-341 and Shalimar rice-1 are long duration cultivars compared

to Jhelum and SKAU-382. Similar results are revealed by Rimi *et al.* (2009) and El-Marsafawy *et al.* (2012).

5.8 Simulated yield of different locations due to climatic change

It was observed that with the increase of 2°C temperature as estimated by 2040 it was expected an overall decrease of rice yield by 0.7% at all the locations, as estimated increase in minimum temperature by 2.3°C also simulated decrease by 0.55% across different locations. As higher temperatures increases rice plant respiration rate and reduce net photosynthesis hence eventually reducing yield but under existing temperate conditions, there is not declinable effect of high temperature on rice crop. Increase of CO₂ by 80ppm as estimated by 2040 recorded considerable increase in the yield at Kokernag, Kupwara, Srinagar, Budgam and Anantnag by 6.4, 5.08, 3.78, 4.05 and 0.5% respectively. This is attributed that increased atmospheric CO₂ concentrations may enhance plant growth through the fertilization effect since CO₂ is an essential component of photosynthesis. Similar results were also revealed by Wassmann *et al.* (2009). Precipitation with estimated decrease of 90mm of rainfall by 2040 results an average decrease across the locations by 38.4%. This could be because of the reason that decrease in precipitation causes drastic decrease in yield both in rainfed and irrigated conditions, as in temperate conditions of Kashmir the water for irrigation comes from the precipitation and through simulated water balance (Table 30) the precipitation during the crop growth period was drastically reduced. Among the cultivars huge decrease in yield was simulated at Kupwara, Budgam, Srinagar and Anantnag, however decrease in yield at Kokernag was not considerable. Similar results are also reported by (Watanabe and Kume, 2009) and El-Marsafawy *et al.* (2012).

Chapter – 6

SUMMARY AND CONCLUSION

The present investigation was carried out to in *kharif* season of 2011 and 2012 at Research Farm of Shalimar Campus of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir to find out appropriate dates of planting, of different rice cultivars for maximum grain yield, evaluation of CERES-rice model at different locations and impact of climate change on rice production at multi-locations. Three dates of planting (25 May, 10 June and 25 June), and four plant cultivars (Shalimar rice-1, Jhelum, SKAU-382 and SKAU-341) were tested in four replicated split plot design assigning dates of planting in main plots and cultivars in sub plots. The soil of experimental field was silty clay loam in texture.

Crop yields are dependent on soil properties agronomical practices, genetic potential of cultivar and prevailing weather conditions. Among these factors, genetic potential of cultivar remain constant, agronomical practices change slowly, and soil properties can vary to a small extent across the years, while weather may vary quite significantly. Thus, year-to-year variation in agricultural output is regulated by weather to a large extent.

Cop simulation models (CSM) have usefulness of simulating the effect of various inputs influencing the crop output. In present study the CERES model was calibrated and validated and have attempted to simulate the impact of climate change on rice in the temperate conditions of Kashmir.

GENCALC software developed by Hunt *et al.* (1983) was used to develop genetic coefficients of rice cultivars (Shalimar rice-1, Jhelum, SKAU-382 and SKAU-341). GENCALC software requires the initial values of all genetic coefficients to start with. Then software start simulating treatment and find the best match based on least square error method. Phenological coefficients, which determine the development of crops are estimated first, followed by the growth

coefficients. Genetic coefficients of all cultivars were calibrated using data set of first year from field experiment.

Validation of the model was carried out at three locations (Srinagar, Badgam and Anantnag) by using treatment combinations of sowing dates and cultivars of field observed data of 2011 and 2012. Model was tested by judging performance of crop in terms of phenology, grain yield, top weight (Dry biomass yield) and tops N.

Climate change impact was carried out by simulation study using CERES-rice model embedded in DSSAT (V 4.5) (Jones *et al.*, 2003, 2004) to evaluate the potential consequences of climate change on the rice in terms of yield in different locations of Kashmir valley. Base line data for climate change scenario were obtained from the thesis (Ph.D. Environmental Science) of SKUAST-Kashmir in which the climatic scenario for 2011-2090 under A1B was extracted from a PRECIS run obtained from IITM (Indian Institute of Tropical Meteorology) which showed that in the year 2040 the maximum temperature will increase by 2°C, minimum temperature increases by 2.3°C, CO₂ concentration will increase by 80 ppm and the projected precipitation is likely to decrease by 90mm.

The observations on important growth characters, yield attributes and yield were recorded in both the years and thus the data collected so far, averaged and tabulated for statistical analysis for individual years. The important findings of present investigation are summarized below and conclusions drawn from these observations are incorporated herein.

Transplanting date

1. The plant height recorded at 75 DAT till harvest stage was significantly higher in 25 May transplanting than 10 and 25 June transplanting.
2. The crop planted on 25 May and 10 June recorded less tillers during early growth period (30DAT) due to low temperature but of tillers with

advancement of crop growth up to 105 DAT (maturity) 25 May recorded higher number of tiller m^{-2} followed by 10 June and 25 June.

3. Transplanting Maximum LAI was recorded at 60 DAT (anthesis stage) of all transplanting dates and it was significantly more in 25 May at this period.
4. The dry weight per hill recorded at 60 DAT till harvest stage of crop was significantly more in 25 May than 10 and 25 June transplanting and was adversely affected by late transplanting (25 June).
5. The crop transplanted on 25 May had given significantly more number of functioning leaves from 45 DAT upto harvesting than the crop transplanted on 10 and 25 June.
6. Specific leaf weight was significantly affected by transplanting dates. Among all the periods the highest specific leaf weight was recorded at 60 DAT on 25 May transplanting and lowest on 25 June transplanting.
7. At initial period (15-30 DAT) 25 June recorded more relative growth compared to 10 June and 25 May transplanting. At maturity (90 -105 DAT) 25 May transplanting had higher relative growth rate than 10 and 25 June transplanting but there was no significant difference during both years.
8. At 60 DAT (anthesis) 25 June recorded significantly highest dead leaf weight followed by 10 June and then 25 May transplanting. At maturity (105 DAT) 25 May significantly had more dead leaf weight compared to 10 and 25 June transplanting.
9. Days taken to phenological stages were curtailed with 25 June transplanting compared to 10 June and 25 May.

10. Yield attributes like Spikelets panicle⁻¹ grains panicle⁻¹ and 1000-grain weight decreased with delay in transplanting and Sterility percentage increased with delay in transplanting.
11. Yield index was adversely affected by delay in transplanting as highest yield of 74.0 and 79.0 q ha⁻¹ was realized by 25 May transplanting during 2011 and 2012, respectively followed by 10 June (57.3 and 57.1 q ha⁻¹) and least by 25 June (31.1 and 32.2 q ha⁻¹). The reduction in grain yield by transplanting on 25 June was 58.0 and 45.7 per cent than 25 May and 10 June respectively, during 2011. However, during 2012, decrease in grain yield on 25 June transplanting was 59.2 and 43.6 per cent than 25 May and 10 June respectively.
12. Nitrogen content of grain and straw decreased by late transplanting (25 June), and it was maximum with early transplanting (25 May). Nitrogen uptake (grain and total) of plant decreased by delay in transplanting.

Cultivars

1. The cultivar SKAU-341 recorded significantly highest plant height after panicle initiation during 2011 and 2012.
2. Jhelum recorded significantly higher number of tillers m⁻² at all periodic stages (except at 15 DAT during both the years).
3. LAI among cultivars, Jhelum and SKAU-382 were statistically at par and significantly superior over Shalimar rice1 and SKAU-341 upto 60 DAT. Rest on all recorded periodic stages SKAU-341 was significantly superior over all the cultivars under study.
4. SKAU-341 provided maximum dry matter of leaf and stem from 45 DAT till maturity, but the total dry matter (including panicle weight) was significantly more in Jhelum being at par with Shalimar rice-1.

5. SKAU-341 recorded significantly higher leaf number followed by Shalimar rice-1 from 60DAT till maturity.
6. Regarding specific leaf weight there was no significant difference among cultivars but at maturity SKAU-341 being at par with Shalimar rice-1 recorded significantly higher specific leaf weight than Jhelum and SKAU-382.
7. Relative growth rate at 60 DAT (flowering) till maturity 90 DAT cultivar SKAU-341 significantly superior then other cultivars. At maturity SKAU-341 recorded more relative growth rate but there was no significant difference among cultivars.
8. Dead leaf weight at initial stages among cultivars was statistically at par. At 45 DAT Jhelum and SKAU-382 recorded significantly more dead leaf weight than other cultivars. At maturity Shalimar rice-1 significantly recoded more daed leaf weight among cultivars.
9. Cultivar SKAU-341 followed by Shalimar rice-1 required more number of days to reach various stages.
10. Jhelum indicated superiority on the yield attributing characters viz. Spikelets panicle⁻¹, grains panicle⁻¹ and panicle weight at maturity during both years. However, 1000 grain weight and sterility% was highest in SKAU-341 and minimum in Shalimar rice-1 and Jhelum.
11. Yield index was recorded highest with Jhelum. The superiority of variety Jhelum over Shalimar rice-1, SKAU-382 and SKAU-341 was 3.9, 9.1 and 15.9 per cent, respectively during 2011 and corresponding values for year 2012 were 1.7, 8.5 and 14.7 per cent, respectively.

Validation studies

1. Model CERES-rice was validated at three locations for four rice cultivars transplanted on 25 May, 10 and 25 June in terms of phenology, grain yield,

top weight at maturity and N-uptake.

2. Simulated phenology in terms of days to anthesis, days to maturity, grain yield and top weight at maturity for different cultivars under varied transplanting dates at different locations matched well with observed values.
3. The RMSE obtained between observed and simulated anthesis was 3.7, 6.26 and 3.4 days for Srinagar, Badgam and Anantnag respectively, MAE was, 3.5, 5.08 and 3.0 Srinagar, Badgam and Anantnag respectively and D-index 0.94, 0.89 and 0.93 Srinagar, Badgam and Anantnag respectively. The maturity dates simulated by the model actually observed in the field were having RMSE = 4.76, 5.50 and 3.40 days for Srinagar Badgam and Anantnag respectively; MAE= 4.42, 5.04 and 3.0 days for Srinagar Badgam and Anantnag respectively and D-index = 0.91, 0.90 and 0.93 for Srinagar, Badgam and Anantnag respectively. The RMSE, MAE and D-index for grain yield was 338.79 kg ha⁻¹, 298.51kg ha⁻¹ and 0.99 respectively for Srinagar, 474.48 kg ha⁻¹, 300.54 kg ha⁻¹ and 0.89 respectively for Badgam and 551.13 kg ha⁻¹, 455.58 kg ha⁻¹ and 0.96 respectively for Anantnag.

Climate change

Climate change scenario revealed that elevation in temperature decreased yield because days to maturity were decreased. Elevated CO₂ levels increased simulated grain yield of rice with no change in maturity days, but decrease in precipitation decreases the yield drastically at all locations. Lowest drop in the yield with climate change was observed using weather data of Kokernag where per cent decrease ranged between 11.71 to 15.52%, at other stations i.e. Kupwara, Anantnag, Srinagar and Budgam per cent decrease ranged between 37.46 to 53.67. The cultivar SKAU-341 and Shalimar rice-1 were found more sensitive to climate change as compared to Jhelum and SKAU -382. This is because of the reason that SKAU-341 and Shalimar rice-1 are long duration cultivars compared to Jhelum and SKAU-382.

CONCLUSION

On the basis of experimental findings and discussion of present investigation following conclusions may be drawn.

- 1) Among transplanting dates 25 May transplanting of rice is most suitable in terms of yield under temperate Kashmir.
- 2) Cultivar Jhelum out yield all other rice varieties and can be recommended for getting higher productivity in the of Valley.
- 3) Results from these studies suggest that rice yield potential is affected more by planting date than by cultivar selection when pests are controlled and cultural practices are implemented to optimize grain yield.
- 4) Crop growth models are very good tools for analyzing the earth-plant-atmospheric system and their interactions. The crop models can provide a frame work for interpreting the output from field experiments and they can be used to explore ways of improving management
- 5) A rice yield of various locations simulated by the crop model agrees well with the actual yield record. Thus study demonstrates that CERES-rice can be utilized to predict development (phenological stages), growth, yield and yield attributes at different locations of Kashmir.
- 6) The results showed that CERES- rice model could simulate the yield with acceptable accuracy both for baseline and under futuristic climate scenarios.
- 7) The potential impact of climate change on rice varieties at various locations was evaluated by simulating under different climatic scenarios in the temperate conditions of Kashmir. Under climate

change scenarios, yield of rice varieties decreased in comparison to current climate conditions at all areas under study. According to the present simulation study, the impact of climate change on rice yields would be severe in comparison with current climate conditions.

- 8) Future climate adaptations to climate change could defeat adverse impact of climate change through the concerted efforts of agricultural research and policies aiming to improve are more irrigation, short-duration rice varieties, supplementary irrigation, changing planting date and accompanying management strategies.

Suggestions for future work

1. Models have been calibrated and validated on one year data set, which needs to be increased for at least three years.
2. It would be a wise step if the performance of models could be evaluated on other agroclimatic zones of Kashmir.
3. The models have been validated and calibrated only for four rice cultivars. It is suggested to include other rice cultivars.
4. The ability of model to forecast the yield, well in advance needs to be evaluated.
5. Further investigation should be conducted for the particular site regarding the response of rice to climate change.

LITERATURE CITED

- Abbaspour, K.C., Hall, J.W. and Moon, D.E. 1992. A yield model for use in determining crop insurance premiums. *Agric. For. Met.* **60**: 33-51.
- Abo-Youssef, M.I., Sorour, S.G., Abdelkrem, M.Z. and Tawfik, M.A. 2011. The effect of sowing dates on the productivity of some rice varieties. *Journal of Agricultural Research Kafer El-Sheikh University* **37**(2) : 20-31.
- Adams, R.M., Rosenzweig, C., Peart, R.M., Ritchie, J.R., McCarl, B.A., Glycer, J.D., Curry, R.B., Jones, J.W., Boote, K.J. and Allen, L.H. 1990. Global climate change and US agriculture. *Nature* **345**:219-224.
- Aggarwal, P.K. and Karla N. 1994. Analyzing the limitations set by climatic factors, genotype and water and nitrogen availability on productivity of wheat 11. Climatically potential yields and management strategies. *Field crops Research* **38** : 93-103
- Aggarwal, P.K. 1988. Wheat production in South-east Asia-potential and constraints. *Outlook on Agriculture* **17**:49:53.
- Aggarwal, P.K. 1993. Agro-ecological zoning using crop growth simulation models : characterization of wheat environments of India. **In** : *Systems Approaches for Agricultural Development* (Eds. Penning de Vries, F.W.T., Teng, P. and Metselaar, K.) Vol. 2, Kluwer Academic publishers, Dordrecht, The Netherlands, pp 97-109.
- Aggarwal, P.K. and Sinha, S.K. 1993. Effect of probable increase in carbon dioxide and temperature on productivity of wheat in India. *Journal of Agricultural Meteorology* **48**(5):811-814.

- Aggarwal, P.K., Kropff, M.J., Cassman, K.G. and Bergeten, H.F.M. 1997. Simulating genotypic strategies for increasing rice yield potential in irrigated, tropical environments. *Field Crops Research* **51**(1-2) : 5-17.
- Ahmad, S., Ahmad, A., Tojo, Soler, C.M., Ali, H., Zia-Ul-Haq, M., Anothai, J., Hussain, A., Hoogenboom, G. and Hasanuzzaman, M. 2012. Application of the CSM-CERES-Rice model for evaluation of plant density and nitrogen management of fine transplanted rice for an irrigated semiarid environment. *Precision Agriculture* **13**:200-218.
- Ahmad, Z., Alim, S., Dil, R. and Tahir, M. 1996. Rice Genotypes responses to environment stresses in term of yield and yield components in sub mountainous region of swat. *Sarhad Journal of Agriculture* **12** : 619- 624.
- Ahn, D., Choi, J., Choi, C., Lee, S., Choi, B. and Lee, S. 2000. Effect of seeding dates for direct seeding on dry paddy on growth and yield of rice varieties in Youngman regions. *Korean Journal of Crop Science* **45**(3): 185-189.
- Ahn, D.J., Choi, J.S., Choi, C.D., Lee, S.P., Choi, B.S. and Lee, S.E. 2000. Effect seeding dates for direct seeding on dry paddy on growth and yield of rice varieties in Youngman region Korean. *Journal of Crop Science* **45**(3) : 185-189.
- AICRIP, 1991. *Annual Progress Report*, 1990-91. All India Coordinated Rice Improvement Programme, Agronomy Chapter, pp. 171-180
- *Akita, S., Ishikawa, T., Li, Q. and Lee, B.W. 1992. Physiological significance of higher accumulation of non-structural carbohydrate before heading in semi-dwarf indica rice(*Oryza sativa*L.. *Japanese Journal of Crop Science* **61**: 84-85 [c.f. CAB Abstracts CD-ROM, 1992].

- Akram, H.M., Ali, A., Nadeem, M.A. and Iqbal, M.S. 2007. Yield and yield components of rice varieties as affected by transplanting dates. *Journal of Agricultural Research* **45**(2) : 105-111.
- Alam, M.M., Hasanuzzaman, M. and Nahar, K. 2009. Growth pattern of three high yielding rice varieties under different phosphorus levels. *Advances in Biological Research* **3**(3-4): 110-116.
- Ali Zadeh, M.A. and Isvand, H.R. 2006. Rice in Egypt. Rice and pulse office. Agronomy Deputy. Ministry of Jihad-e-Agriculture Publications, pp. 541.
- Almaraz, J.J., Mabood, F., Zhou, X., Gregorich, E.G. and Smith, D.L. 2008. 'Climate change, weather variability and corn yield at a higher latitude locale: Southwestern Quebec. *Climatic Change* **88**(2) : 187-197.
- Amien, I., Redjekiningrum, P., Kartiwa, B. and Estiningtyas W. 1999. Simulated rice yields as affected by interannual climate variability and possible climate change in Java. *Climate Research* **12** : 145-152.
- Amien, I., Rejekiningrum, P., Pramudia, A. and Susanti, E. 1996. Effects of interannual climate variability and climate change on rice yield in Java, Indonesia. *Water, Air and Soil Pollution* **92**: 29-39.
- Amir, J. and Sinclair, T.R. 1990. A model of temperature and solar radiation. Effects on spring wheat growth and yield. *Field Crops Research* **28**: 47-58.
- Amthor, J. S. 2000. The McCree-de Wit-Penning de Vries-Thornley Respiration Paradigms: 30 Years Later. *Annals of Botany* (London) **86** : 1-20.
- Angus, J.F. 1989. A simulation model for multiple crops in a rainfed rice-based cropping system. Technical memorandum, Division of Water Resources, Institute of National Resources and Environment, *CSRO* **89**(5): 195-208.

- Angus, J.F., Stapper, M. and Donnelly, J.R. 1993. Simulation models for strategic and tactical management of crops and pastures. *Journal of Agricultural Meteorology* **48**: 775-778.
- Anonymous, 2004. Digest of statistics 2004-05. Directorate of Economics and Statistics, Planning and Development Department, Jammu and Kashmir.
- Anonymous, 2009. Digest of Statistics 2007-08, Directorate of Economics and Statistics, Government of Jammu and Kashmir.
- Aslam, M., Shah, S.H. and Nazir, M.S. 2001. Agronomic traits or direct seeded fine rice as affected by seeding density and planting time. *International Journal of Agriculture and Biology* **31**(1): 35-38.
- Azarpour, E., Moraditochae, M. and Bozorgi, H.R. 2014. Effect of nitrogen fertilizer management on growth analysis of rice cultivars. *International Journal of Biosciences* **4**(5): 35-47.
- Babapour, J. 1998. The study of bush density with different amounts of Azzot fertilizer in Tarom. Rice yield. A researcher report, rice Research institute of IRAN located in Mazandaran.
- Balaswamy, K. and Kulkarni, N. 2001. Influence of time of transplanting on the performance of certain scented rice varieties in Andhra Pradesh. *Journal of Research ANGRAU* **29**(2-3) : 98-101.
- Bali, A.S. and Uppal, H.S. 1995. Effect of date of transplanting and water management practices on yield of Basmati rice (*Oryza sativa*). *Indian Journal of Agronomy* **40**(2) : 186-192.
- Bali, A.S., Singh, K.N., Balli, A.S., Ganai, B.A. and Hasan, B. 1995. Effect of transplanting dates, number and age of seedling on rice. *Indian Journal of Agronomy* **40**(3) : 504-507.

- Bali, Amarjit, S., Kanth, R.H., Singh, K.N., Bali, A.S. and Shah, M.H. 2000. Behaviour of rice under different transplanting and irrigation schedules in Kashmir Valley. *SKUAST Journal of Research* 2 : 37-42.
- Bali, Amarjit. S., Sidique, M., Ganai, B.A., Khan, H.U., Singh, K.N. and Bali, A.S. 1995. Response of rice (*Oryza sativa*) genotypes to nitrogen level under transplanted condition in Kashmir Valley. *Indian Journal of Agronomy* 40(1) : 35-37.
- Baloch, M.S., Awan, I.U. and Hassan, G. 2006. Growth and yield of rice as affected by transplanting dates and seedlings per hill under high temperature of Dera Ismail Khan, Pakistan. *Journal of Zhejiang Univeristy of Science* 7(7): 572-579.
- Basak, J.K., Ali, M.A., Islam, M.N. and Rashid, M.A. 2010. Assessment of the effect of climate change on boro rice production in Bangladesh using DSSAT model. *Journal of Civil Engineering (IEB)* 38(2) : 95-108.
- Basal, H., Unay, A., Canavar, O. and Yavas, I. 2009. Combining ability for fiber quality parameters and within-boll yield components in intraspecific and interspecific cotton populations. *Spanish Journal of Agricultural Research* 7(2): 364-374.
- Batchelor, W.D. 2003. New features in the DSSAT 4.0 release of the CERES-Maize, Millet and sorghum models. Unpublished report, Iowa State Univesity, Ames, USA.
- Behera, U.K., Singh, Y.V. and Jha, K.P. 1997. Comprehensive investigation on verietal evaluation, time of sowing and wetting and nitrogen requirement of upland rice in the drought prone Kalahandi district of Orissa. *Oryza* 34 : 131-139.

- Behnassi, M. and Yaya, S. 2011. Food Crisis Mitigation: The Need for an Enhanced Global Food Governance. **In** : *Global Food Insecurity* (Eds. M. Behnassi, S. Draggan and S. Yaya). Springer Verlag, Dordrecht/New York/Heidelberg/London, pp. 93-125.
- Berge, H.F.M., Thiyagarajan, T.M., Slu, Q., Wopereis, M.C.S., Drenth, H. and Jansen, M.J.W. 1997a. Numerical optimization of nitrogen application to rice. Part 1. Description of MANAGE-N. *Field Crops Research* **51**(1-2) : 29-42.
- Berge, H.F.M., Shi, Q., Zheng, Z., Rao, K.S., Rithoven, J.J.M., Zhong, X. 1997b. Numerical optimization of nitrogen application to rice. Part II. Field evaluations. *Field Crops Research* **51**(1-2) : 43-54.
- Bhowmick, N and Nayak, R.L. 2000. Response of hybrid rice(*Oryza sativa*) varieties to nitrogen, phosphorus and potassium fertilizer during dry(boro) season in West Bengal. *Indian Journal of Agronomy* **45**(2) : 323-326.
- Biradarpatil, N.K. and Shekhargouda, M. 2001. Effect of sowing date on flowering behaviour in the parental lines of Karnataka Rice Hybrid-2. *Seed Research* **29**(2) : 243-244.
- Black, C.A. 1965. Methods of Soil Analysis, part 1, Agronomy 9. *American Society of Agronomy, Madison, USA*, pp. 374-390.
- Boote, K.J., Jones, J.W. and Pickering, N.B. 1996. Potential uses and limitations of crop models. *Agronomy Journal* **88** : 704-716.
- Bouman, B.A.M., Vries, F.W.T.P., Riethoven, J.J.M., Kropff, M.J., Wopereis, M.C.S., Devries, F.W.T.P., Sehgal, J., Blum, W.E. and Gajbhiye, K.S. 1998. Application of simulation and systems analysis in rice-cropping optimization. *Red and Lateritic Soils* **1** : 163-176.

- Butler, T.J., Gerald, W.E., Hussey, M.A. and Lavery, J.R. 2002. Rate of leaf Appearance in crimson clover. *Crop Science* **42** : 237-241.
- Chaudhary, J.K. 1999. Weed competitiveness of new transplanted rice(*Oryza sativa*) varieties. *Indian Journal of Agronomy* **44**(2): 331-334.
- Chaudhary, J.L., Sastri, A.S.R.A.S. and Sahu, R.K. 1996. Analysis of growth duration and heat units of different rice genotypes. *International Rice Research Notes* **21**(2-3): 65.
- Cheng, W., Hidemitsu, S., Kazuyuki, Y. and Toshihiro, H. 2009. Interactions of elevated CO₂ and night temperature on rice growth and yield. *Agricultural and Forest Meteorology* **149** : 51-58.
- Cheng, W.G., Inubushi, K., Yagi, K., Sakai, H. and Kobayashi, K. 2001 Effects of elevated carbon dioxide concentration on biological nitrogen fixation, nitrogen mineralization and carbon decomposition in submerged rice soil. *Biol. Fertil. Soils* **34** : 7-13.
- Cheyglinted, S., Ranamukhaarachchi, S.L. and Singh, G. 2001. Assessment of the CERES-Rice model for rice production in the Central Plain of Thailand. *Journal of Agricultural Science* **137**:289-298.
- Chmielewski, F.M., Muller, A. and Bruns, E. 2004. Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961-2000. *Agric. For. Meteorol.* **121** : 69-78.
- Cho, Y. and Kobata, T. 2002. N top dressing and rice straw application for low input cultivation of transplanted rice in Japan. *Korean Journal of Crop Science* **47**(4): 273-278.
- Chopra, N.K. and Chopra, N. 2004. Influence of transplanting dates on heat-unit requirement of different phenological states and subsequently yield and

- quality of scented rice(*Oryza sativa*) seed. *Indian Journal of Agricultural Sciences* **74**(8): 415-419.
- CRRI, 1997. Effect of date of planting on selected hybrid rice. *Annual Report* 1996-97. Central Rice Research Institute, Cuttack, pp. 126-127.
- Dawadi, K.P. and Chaudhary, N.K. 2013. Effect of sowing dates and varieties on yield and yield attributes of direct seeded rice in Chitwan, Nepal. *International Journal of Agricultural Science Research* **2**(4) : 095-102.
- De Datta, S.K. 1981. Principles and Practices of rice production. John Wiley and Sons, New York. pp. 9-40.
- De, D.K., Pal, S.K., Ghosh, M., Pal, A.K. and Basak, S. 2002. Evaluation of aromatic rice cultivars in foot hills zone of West Bengal. *Indian Journal of Agricultural Sciences* **72**(7): 379-382.
- Dehghan, A. 2007. The effect of delayed planting date on grain yield and yield components of three Sorghum in Khouzestan. *The Scientific Journal of Agriculture* **30**(4): 123-132.
- Deressa, T.T. and Hassan, R.M. 2009. Economic impact of climate change on crop production in Ethiopia : Evidence from cross-section measures. *Journal of African Economies* **18**(4) : 529-54.
- Devi, J. and Borua, P.K. 2002. Morphological and quality traits in eight indigenous rice (*Oryza sativa* L.) varieties of Assam. *Plant Archives* **2**(1): 111-113.
- Dey, P.C. and Chandra, K. 1994. Effect of water logging on nitrogen, carbohydrate, photosynthetic reserves and grain yield in rice. *Indian Journal of Plant Physiology* **37**(1): 50-52.

- Dhiman, S.D., Om, H., Singh, B. and Bikram, Singh 1995. Yield stabilization of scented dwarf rice under late planting through spacing and seedling age. *Haryana Agricultural University Journal of Research* **25**(3) : 95-99.
- Dhiman, S.D., Nandal, D.P. and Hari Om. 1997. Performance of scented, dwarf rice(*Oryza sativa*) varieties under different time of transplanting. *Indian Journal of Agronomy* **42**(2): 253-255.
- Dingkuhn, M. 1995. Climate determinants of irrigated rice performance in the Sahd-III. Characterizing environments by simulating crop phenology. *Agricultural Systems* **48**(4): 435-456.
- Dingkuhn, M. and Asch, F. 1999. Phenological responses of *Oryza sativa*, *O. glaberrima* and inter-specific rice cultivars on a toposquence in West Africa. *Euphytica* **110** : 109-126.
- Dingkuhn, M. and Sow, A. 1997. Potential yield of irrigated rice in African arid environments. *In* : Application of systems approaches at the field level (Eds. M.J. Kropff, P.S. Teng, P.K. Aggarwal, J.Bouma, B.A.M. Bouman., J.W. Jones and H.H. Van Laar), Kluwer Academic, Dordrecht, The Netherlands, pp. 79-99.
- *Dingkuhn, M., and Asch, F. 1999. Phenological responses of *Oryza sativa*, *O. glaberrima* and inter-specific rice cultivars on a Toposequence in West Africa. *Euphytica* **110**: 109-126 [c.f. CAB Abstracts CD-ROM, 1998/08-2000/07].
- Dingkuhn, M., Luquet, D., Kim, H., Tambour, L. and Clement-Vidal, A. 2006. Eco-Meristem, a model of morphogenesis and competition among sinks in rice. 2. Simulating genotype responses to phosphorus deficiency. *Functional Plant Biology* **33** : 325-337.

- Dixit, A. J., Thorat, S.T., Gaikwad, V.V. and Jadhav, M.G. 2004. Yield attributes and yield of parental lines of sahyadri hybrid rice as influenced by sowing dates. *Journal of Agrometeorology* **6** : 95-97.
- Dixit, A.J., Gaikwad, V.V., Jadhav, M.G. and Thorat, S.T. 2004. Effect of sowing times on the phenology and growth of hybrid rice parents. *Journal of Agrometeorology* **6**(special issue): 72-76.
- *Dong, M., Zhang, H., Dai, Q., Huo, Z. and Meng, L. 2002. Research on the nitrogen absorption and utilization of different rice varieties. *Journal of Yangzhou University, Agricultural and Life Science* **23**(4): 43-46 [c.f. CAB Abstracts CD-ROM, 2002/08-2003/04].
- Dongarwar, U.R., Shinde, V.S. and Mondhe, C.B. 2005. Performance of scented rice varieties under different transplanting date in eastern vidarbha zone. *PKV Research Journal* **29**(2) : 239-241.
- Drenth, H., Bergeten, H.F.M. and Riethoven, J.J.M. 1994. 'ORYZA Simulation Modules for Potential and Nitrogen Limited Rice Production. SARP Research Proceedings, IRRI, LOS Banos, Philippines.
- DRR, 1991. *Annual Progress Report*, 1990-91. Directorate of Rice Research, Rajendranagar, Hyderabad, pp. 34-39.
- DRR, 1995. Agronomic package of practices for hybrid rice. *Progress Report, Kharif*. Directorate of Rice Research, Rajendra Nagar, Hyderabad, pp. 72-74.
- Du, H. and Cao, W. 1999. Modeling suitable genotypes and plant growth characters for high yield rice. *Acta Agriculturae Shinghai* **15**(2) : 51-55.
- El-Khoby, W.M. 2004. Study the effect of some cultural practices on rice crop. Ph.D. thesis, Faculty of Agricultural Kafr El-sheikh, Tanta. University.

- El-Marsafawy, Samia M., Hassanein, M.K. and Abdel-Latif, K.M. 2012. Impact of Climate Change on the Behaviour of Some Rice varieties in Egypt. *Researcher* **4**(6) : 23-30.
- Erda, L., Wei, X., Hui, J., Yinlong, X., Yue, L., Liping, B. and Liyong, X. 2005. Climate change impacts on yield formation of CO₂-enriched inter-subspecific hybrid rice cultivar Liangyoupei jiu under fully open-air field condition in a warm sub-tropical climate crop yield and quality with CO₂ fertilization in China. *Philosophical Transactions of the Royal Society*, **360** : 2149-2154.
- Fageria, N.K., Baligar, V.C. and Jones, C.A. 1997 Growth and Mineral Nutrition of Field Crops, 2nd Ed, Marcel Dekker: New York.
- FAO, 2006. *Livelihood adaptation to climate variability and change in drought-prone areas of Bangladesh*, Food and Agriculture Organisation, Rome.
- FAOSTAT, 2003. Statistical Databases. Food and Agriculture Organization (FAO) of the United Nations, Rome. <http://www.Fao.org>.
- Farrell, T.C., Fox, K., Williams, R.L., Fukai, S. and Lewin, L.G. 2003. Avoiding low temperature damage in Australia's rice industry with photoperiod sensitive cultivars. Proceedings of the 11th Australian Agronomy Conference. Geelong, 2-6 February 2002, Deakin University, Australia, pp. 35.
- Ferrero, A. and Nguyen, V.N. 2004. The sustainable development of rice-based production systems in Europe. *IRC Newsletter* **54**:115-124.
- Food and Agriculture Organization, 2010. Food and Agriculture Organization Statistics Division, 11 June 2012. Available. at: <http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor>

- Fraser, E. 2008. "Crop yield and climate change", Retrieved on 14 September 2009.
- Ganajaxi., Mohankumar, H.D., Hegde, Y. and Angadi, V.V. 2001. Effect of planting dates and N levels on the grain yield of aeromatic rice genotypes under rainfed conditions. *Karnataka Journal of Agricultural Sciences* **14**(3) : 758-759.
- Gangwar, B. and Ahamed, R. 1990. Effect of planting time on growth, yield and incidence of insect pests in rice. *Oryza* **27** : 497-500.
- Gangwar, K.S. and Sharma, S.K. 1998. Effect of planting dates on productivity and profitability of scented rice (*Oryza sativa*) and wheat(*Triticum aestivum*) varieties in rice-wheat system. *Indian Journal of Agronomy* **43**(1) : 1-6.
- Gao, L.Z., Jin, Z.Q., Huang, Y. and Zhang, L.Z. 1992. Rice model- a computer model to simulate rice development. *Agricultural and Forest Meteorology* **60** : 1-16.
- *Gao, Y., Wang, F. and Yao, K. 1998. Numerical simulation of dry matter for rice and its regionalization. *Journal of Nanjing Institute of Meteorology* **21**(4) : 638-646. [c.f. CAB Abstracts CD-ROM, 1996-1998/07].
- Geetha, S.A. and Thiyagarajan, T.M. 2003. Partitioning and remobilization of nitrogen in rice genotypes. *Crop Research* **25**(3) : 406-409.
- Gen-Yun, C., Zhen-Hua, Y., Yi, L., Dao, Y., Zhang, Y., Chen, H.Z., Juan, C., Jian-Guo, Z. and Da-Quan, X. 2005. Photosynthetic acclimation in rice leaves to free-air CO₂ enrichment related to both Ribulose-1, 5-bisphosphate Carboxylation Limitation and Ribulose-1, 5-bisphosphate Regeneration Limitation. *Plant and Cell Physiology* **46**: 1036-1045.

- George, S.P., Devadas, V.S., George, S. and Pillai, G.R. 1993. Performance evaluation of certain rice cultivars. *Journal of Tropical Agriculture* **31**(2) : 188-192.
- Ghosh, D.C. and Singh, B.P. 1994. Effect of cultural practices on leaf area index, light interception rate and grain yield of wetland rice. *Indian Journal of Agricultural Research* **28**(4): 275-279.
- Ghosh, M. 2001. Performance of hybrid and high yielding rice varieties in Terai region of West Bengal. *Journal of Interacademia* **5**(4) : 578-581. [c.f. CAB Abstracts CD-ROM, 2000/08-2002/07].
- Ghosh, M., Mandal, B.K., Mandal, B.B., Lodh, S.B. and Dash, A.K. 2004. The effect of planting date and nitrogen management on yield and quality of aromatic rice(*Oryza sativa*). *Journal of Agricultural Science* **142**(2) : 183-191.
- Godwin, D and Jones, C.A. 1991. Nitrogen dynamics in soil-crop systems. In: Hanks, R.J and Ritchie, J.T.(Eds.) "Modelling plant and soil systems" Agronomy Monograph 31, American Society of Agronomy, Madison, Wisconsin, USA, pp. 287-321.
- Godwin, D. and Singh, U. 1998. Nitrogen balance and crop response to nitrogen in upland and lowland cropping systems. **In** : *Understanding options for agricultural production* (Eds. Tsuji, G.Y., Hoogenboon, G., Thornton, P.K.). Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 55-78.
- Gohain, T. and Saikia, L. 1996. Effect of date of transplanting on growth and yield of rainfed lowland rice (*Oryza sativa*). *Indian Journal of Agronomy* **41**(3) : 488-490.

- Gomez, K. A. and Gomez, A. L. 1984. Statistical procedures for agricultural research. An International Rice Research Institute Book. Willey, Interscience Publication, New York, pp. 1-450.
- Gopain, T. and Saikia, L. 1996. Effect of date of transplanting on growth and yield of rainfed low land rice. *Indian Journal of Agronomy* **41**(3) : 488-490.
- Gorth, D.E. and Lee, F.N. 2003. Rice disease. **In:** *Rice: Origin, History, Technology and Production* [Eds. C.W. Smith and R.H. Dilday]. John Wiley and Sons, Hoboken, New Jersey, pp. 413-416.
- Govt. of Pakistan, 2008. Economic survey of Pakistan 2007-08. Pakistan Food Agriculture and Livestock Division of Economic wing, pp. 17-23.
- *Gravois, K.A. and Helms, R.S. 1998. Seeding date effects on rough rice yield and head rice and selection for stability. *Euphytica* **102** : 151-159. [c.f. CAB Abstracts CD-ROM, 1998/08-2000/07].
- Gravois, K.A. and Helms, R.S. 1998. Seeding date effects on rough rice yield and head rice and selection for stability. *Euphytica* **102** : 151-159.
- Gregory, P.J., Ingram, J.S. and Brklacich, M. 2005. Climate change and food security. *Philosophical Transactions of the Royal Society* **360**(1463) : 2139-2148.
- *Guilani, A., Fathi, G. and Siadat, S.A. 2002. Effect of planting date on yield and yield components of seven high quality rice cultivars in Khuzestan. *Journal of Science and Technology of Agriculture and Natural Resources* **61**(1) : 163-176. [c.f. CAB Abstracts CD-ROM, 2002/08-2003/10].
- Habibullah, N.H., Shah, N.A. and Iqbal, F. 2007. Response of rice varieties to various transplanting dates. *Pakistan Journal of Plant Science* **13**(1):1-4.

- Haghverdian, M. 2010. The study of the effects of planting date on agronomy characteristics of different varieties in rice direct cultivation M.A thesis, agronomy field, Islamic Azad University, Chaloos Branch, pp. 100.
- Halder, K.P., Sattar, S.M.A., Islam, M.S. and Chawdhury, M.J.U. 2004. Effect of planting dates on phenological events of transplanted aman rice. *Journal of Agronomy* **3**(2) : 90-93.
- Haque, M.Z. 1986. Effect of nitrogen, phosphorus and potassium on spikelet sterility induced by high temperature at heading stage of rice. *Bangladesh Journal of Agriculture* **11** : 25-32.
- Hari Om., Katyal, S.K. and Dhiman, S.D. 1997. Effect of time of transplanting and rice(*Oryza sativa*) hybrids on growth and yield. *Indian Journal of Agronomy* **42**(2) : 261-264.
- Hari Om., Katyal, S.K., Dhiman, S.D. and Sheoran, O.P. 1999. Physiological parameters and grain yield as influenced by time of transplanting and rice (*Oryza sativa*) hybrids. *Indian Journal of Agronomy* **44**(4) : 696-700.
- Hari Om., Katyal, S.K., Dhiman, S.D. and Om, H. 1999. *Indian Journal of Agricultural Sciences* **70**(3) : 140-142.
- *Hasegawa, T. and Horie, T. 1996. Rice leaf photosynthesis as a function of nitrogen content and crop developmental stage. *Japanese Journal Crop Science* **65**(3) : 553-554 [c.f. CAB Abstracts CD-ROM, 1996-1998/07].
- Hassan, G., Khan, N.U. and Khan, Q.N. 2003. Effect of transplanting date on the yield and yield components of different rice cultivars under high temperature of D.I. Khan. *Sci. Khy.* **16**(2): 129-137.
- Hayat, K., Awan, I.U. and Hassan, G. 2003. Impact of seeding dates and varieties on weed infestation yield and yield components of rice under direct wet

- seeded culture. *Pakistan Journal of Weed Science and Research* **91**(2): 59-65.
- Hayat, K., Awan, I.U. and Hassan, G. 2003. Impact of seeding dates and varieties on weed infestation yield and yield components of rice under direct wet seeded culture. *Pakistan Journal of Weed Science Research* **91**(2): 59-65.
- Heenan, D.P. 1984. Low temperature induced floret sterility in the rice cultivars calrose and Inga as influenced by nitrogen supply. *Australian Journal of Experimental Agriculture and Animal Husbandry* **24** : 255-259.
- *Hiraoka, K., Takebe, M. and Yoneyama, T. 1992. Physiological characteristics of high yielding rice varieties (iv) : High productivity of Kanto 146(Takanari) with special reference to nutrient petitioning and sink(Panicle) structure. *Japanese Journal of Soil Science and Plant Nutrition* **63** : 517-523 [c.f. CAB Abstracts CD-ROM, 1992].
- Hodges, T., Botner, D., Sakamoto, C. and HaysHaug, J. 1987. Using the CERES-Maize model to estimate production for the U.S. Corn-belt. *Agric. For. Meteorol.* **40**:293-203.
- Hoogenboom, G., Jones, J.W., Wilkens, P.W., Porter, C.H., Batchelor, W.D. and Hunt, L.A. 2010. Decision Support System for Agrotechnology Transfer (DSSAT) version 4.5. Honolulu University of Hawaii. CD-ROM.
- Horie, T., Shiraiwa, T., Homma, K., Katsura, K., Maeda, S. and Yoshida, H. 2005. Can the yield of lowland rice resume the increase that were obtained in 1980? *Plant Production Science* **8**(3) : 259-274.
- Hossain, M.A., Sarkar, M.A.R. and Paul, S.K. 2011. Growth Analysis of Late Transplant Aman Rice (cv. BR23) Raised from Tiller Seedlings. *Libyan Agriculture Research Center Journal International* **2**(6): 265-273.

- Huang, Y., Gao, L., Jin, Z. and Chen, H. 1998. Simulating the optimal growing season of rice in the Yangtze River Valley and its adjacent area, China. *Agricultural and Forest Meteorology* **91**(3-4) : 251-262.
- Hundal, S.S. and Kaur, P. 1999. Evaluation of agronomic practices for rice using computer simulation model, CERES-Rice. *Oryza* **36**(1) : 63-65.
- Hunsaker, D.J., Kimball, B.A., Pinter, P.J., Jr., Wall, G.W., LaMorte, R.L., Adamsen, F.J., Leavitt, S.W., Thompson, T.L., Matthias, A.D. and Brooks, T.J. 2000. CO₂ enrichment and soil nitrogen effects on wheat evapotranspiration and water use efficiency. *Agricultural and Forest Meteorology* **104**:85-105.
- Hunt, L.A., and Boote, K.J. 1994. Data for model operation, calibration and validation. **In** : *IBSNAT a system approach to research and decision making* (Eds. Tsuji, G.Y., Hoogenboom, G., Thornton, P.K.). University of Hawaii, Honolulu, Hawaii, USA, pp. 9-40.
- Hwang, C.D., Shin, D.K., Lee, K.Y., Park, S.T. and Kim, S.C. 998. The critical seeding date of corrugated furrow seeding rice in eastern coastal area. *RDA Journal of Crop Science* **40** : 62-69.
- IPCC, 2001. Climate change 2001: Impacts, adaptation and vulnerability. Intergovernmental Panel on Climate Change. New York, USA.
- IPCC, 2007. Climate Change 2007. Impacts, adaptation and vulnerability: contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.
- IPCC, 2007. Climate Change 2007. The physical science basis. **In** : *Contribution of Working Group I to the Fourth Annual Assessment Report of the*

Intergovernmental Panel on Climate Change (Eds. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, H.L. Miller), Cambridge University Press, Cambridge, UK, pp 996.

Iqbal, S., Ahmad, A., Hussain, A., Ali, A.M., Khalig, T. and Wajid, S.A. 2008. Influence of transplanting date and nitrogen management on productivity of paddy cultivars under variable environments. *International Journal of Agricultural Biology* **10**(3): 288- 292.

IRRISTAT, 2004. Rice statistics. International Rice Research Institute(IRRI), Phillipines. <http://www.irri.org/science/rice> stat

Jackson, M.L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Private Limited, New Delhi, p.498.

Jaffuel, S. and Dauzat, J. 2005. Synchronism of leaf and tiller emergence Relative to position and to main stem development stage in a rice cultivar. *Annals of Botany* **95**: 401-412.

Jalali, J. 2007. The study of planting date on agronomy characteristics and physiological indexes of rice different varieties, in direct planting system. M.A thesis, agronomy field. Islamic Azad University, Research and Science Branch, 111 pp.

Jamieson, P.D. and Munro, C.A. 1999. A simple method for the phenological evaluation of new cereal cultivars. *Agronomy New Zealand* **29** : 63-68.

*Janaki, P. and Thiyagarajan, T.M. 2004. Effect of SPAD techniques and planting density on 'y' leaf nitrogen concentration in transplanted rice. *Acta Agronomica Hungarica* **52**(1) : 95-104. [c.f. CAB Abstracts CD-ROM, 2003/11-2004/07].

- Jand, V., Bains, G.S., Mavi, H.S. and Mathauda, S.S. 1994. Validation of CERES rice model under Punjab conditions. *Indian Journal of Plant Physiology* **37** 1) : 46-49.
- Jiang, L., Dai, T., Jiang, D., Cao, W., Gan, X. and Wei, S. 2004. Characterizing physiological N-use efficiency as influenced by nitrogen management in three cultivars. *Field Crops Research* **88**(2/3) : 239-250.
- Jones, J.W. 1993. 'Decision support systems for agricultural development. **In:** *Systems Approaches for Agricultural Development* (Eds. Penning de Vries, F.W.T., Teng, P.S., Metselaar, K.), Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 459-472.
- Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Junt, L.A., Wilkens, P.W., Singh, U., Gijsman, A.J. and Ritchie, J.T. 2003. The DSSAT cropping system model. *European Journal of Agronomy* **18** : 235-265.
- Jones, J.W., Tsuji, G.Y., Hoogenboom, G., Hunt, L.A., Thornton, P.K., Wilkens, P.W., Imamura, D.T., Bowen, W.T., Singh, U. 1998. Decision support system for Agrotechnology transfer, DSSAT v 3. **In** : *Understanding options for Agricultural Production* (Eds. Tsuji, G.Y., Hoogenboom, G., Thornton, P.K.). Kluwer Academic Publishers, Dordrecht, the Netherlands, pp. 157-177.
- *Juliano, B.O. 1992. Rice starch properties and grain quality. *Journal of Denpun Kagaku* **39**(1) : 11-21. [c.f. CAB Abstracts CD-ROM, 1992].
- Juliano, B.O. 1993. Rice in human nutrition (FAO Food and Nutrition Series No. 26) Int. Rice Res. Inst. Manila, Philippines, pp. 40-41.
- Kalra, N. and Agarwal, P.K. 1996. Evaluation the growth response for wheat

under varying inputs and changing climate options using Wheat growth Simulator -WTGROW. **In** : *Climate Variability and Agriculture* (Eds. Abrol, Y.P., Sulochna, G., Govind B. Pant), Narosa Publishing House, London, U.K., pp 320-338.

Kalra, N. and Aggarwal, P.K. 1995. Evaluating water production functions for yield assessment of wheat using crop simulation models. **In** : *Proceedings Nitrogen economy of irrigated rice: Field and Simulation studies, SARP Research* (Eds. Ten Berge, H.F.M., Wopereis, M.C.S. and Shin, J.C.). AB-DLO, Wageningen, pp 254-256.

Kanemoto, K., Yumiko, Y., Tomoko, O., Naomi, I., Nguyen, T.N., Ryuichi, S., Pravati, K.S., Syunsuke, K., Reda E.M., Junki, I. Hany El-Shemy and Kounosuke, F. 2009. Photosynthetic acclimation to elevated CO₂ is dependent on N partitioning and transpiration in soybean. *Plant Science* **177**: 398-403.

Karim, Z., Ahmed, M., Hussain, S.G. and Rashid, K. B. 1994. Impact of climate change on the production of modern rice in Bangladesh. **In**: *Implications of climate change for international agriculture: Crop modelling study* (Eds. C. Rosenzweig and A. Iglesias, A.). US Environmental Protection Agency, EPA 230-B-94-003, Washington, USA.

Kaya, C., Kirnak, H. and Higgs, D. 2001. Effects of supplementary potassium and phosphorus on physiological development and mineral nutrition of cucumber and pepper cultivars grown at high salinity (NaCl). *Journal of Plant Nutrition* **24**:1457-1471.

Keating, B.A., Robertson, M.J., Muchow, R.C. and Huth, N.I. 1999. Modeling sugarcane, production system I: Development and performance sugarcane module. *Field Crop Research* **61**:253-271.

- Keisling, T.C., Wells, B.R. and Davis, G.L. 1984. Rice management decision aids based upon thermal time base 50°F. Technical Bulletin 1. University of Arkansas, Little Rock, A.R.
- Kerdsuk, V. 2002. Application of Crop Modeling and GIS for Agroclimatic of KDML105 in Tung Samrit, Nakhon Rachasima, Thailand. Suranaree University of Technology, Thailand.
- Khalif, A.B. Abd-El-Wahab, A.E., El-Ekhtyar, A.M. and Zaed, B.A. 2007. Response of some hybrid rice varieties to irrigation intervals under different dates of sowing. *African Crop Science Conference Proceedings* **8** : 67-74.
- Khalifa, A., Ali, A.A. and El-Rewainy, I.M. 2012. Study some physiological characters, yield and yield component for five new rice varieties under different sowing dates. *Advances in Applied Science Research* **3**(1) : 440-445.
- Khalifa, A., Ali, A., ELkhoby, W. and Okasha, E.M. 2014. Effect of sowing dates and seed rates on some rice cultivars. *African Journal of Agricultural Research* **9**(2) : 196-201.
- Khalifa, A.A. 2005. Physiological behaviour of some rice cultivars under different sowing dates and seedling age. The 11th Conference of Agronomy, Agron Dept., Assiut. Univ., Nov 15-16, pp. 285-295.
- Khalifa, A.A.B.A. 2009. Physiological evaluation of some hybrid rice varieties under different sowing dates. *Australian Journal of Crop Science Southern Cross Journals* **3**(3):178-183.
- Khanal, R.R. 2005. Phyllochron and leaf development in field grown rice genotypes under varying thermal environments of a high altitude cropping

system. Thesis in partial fulfilment of the requirements for the academic degree of Master of Science. Universität zu Bonn.

Kim, H.Y., Lieffering, M., Miura, S., Kobayashi, K. and Okada, M. 2001. Growth and nitrogen uptake of CO₂-enriched rice under field conditions. *New Phytology* **150** : 223-229.

Kotera, A., Nawata, E., Chuong, P.V., Giao, N.N. and Sakuratani, T. 2004. A model for phenological development of Vietnamese rice influenced by transplanting shock. *Plant Production Science* **7**(1) : 62-69.

Kropff, M.J., Cassman, K.G., Peng, S. and Laar, H.H. 2003. Yields at IRRI research farm are still close to the climatic potential level. *International Rice Research Notes* **28**(2) : 19-21.

Kumar, M., Das, A., Ramkrushna, G.I., Munda, G.C., Naropongla and Buragohain, J. 2013. Effect of nutrient sources and transplanting date on aromatic rice (*Oryza sativa* L.) under mid hills of north eastern India. *Indian Journal of Agronomy* **58**(3): 322-326.

Kumar, M.R., Subbaiah, S.V. and Pillai, G.K. 1998. Response of rice hybrids to different dates of planting in vertisols of Andhra Pradesh, *Oryza* **35**(3) : 285-287.

Kumar, N. and Prasad, R. 2004. Nitrogen uptake and apparent N recovery by a high yielding variety and hybrid of rice as influenced by levels and source of nitrogen. *Fertilizer News* **49**(5) : 65-67.

Kumar, N., Tripathi, P. and Pal, R.K. 2010. Simulation modeling of growth parameters for rice genotypes at different nitrogen level and different dates of transplanting using CERES 3.5 v for eastern Uttar Pradesh. *Indian Journal of Agricultural Research* **44**(1) : 20-25.

- Kumar, P. 2002. Photosynthetic and yield performance of rice(*Oryza sativa*) genotypes under low temperature condition in hills. *Indian Journal of Agricultural Sciences* **72**(7) : 383-388.
- Kumar, R. and Sharma, H.L. 2004. Simulation and validation of CERES-rice (DSSAT) model in north-western Himalayas. *Indian Journal of Agricultural Sciences* **74**(3) : 133-137.
- Laborte A., A. Nelson, K. Jagadish, J. Aunario, A.Sparks, C. Ye and Ed Redoña 2012. Rice feelsthe heat. *Rice Today*. July-September: 30-31.
- Lack, Shahram., Marani, Nasim Mahdian and Mombeni, Mehran. 2012. The Effects of Planting Date on Grain Yield and Yield Components of Rice Cultivars. *Advances in Environmental Biology* **6**(1): 406-413
- Lalitha, K., Raji Reddy, D. and Narasimha Rao, S.B.S. 2000. Influence of temperature on duration of tilling in lowland rice varieties. *Journal of Agrometeorology* **2**(1) : 65-67.
- Lansigan, F.P., Pandey, S. and Bouman, B.A.M. 1997. Combining crop modeling with economic risk-analysis for the evaluation of crop management strategies. *Field Crops Research* **51**(1-(2) : 133-145.
- Lansigan, F., De los Santos, W. and Coladilla, J. 2000. Agronomic impacts of climate variability on rice production in the Philippines. *Agriculture, Ecosystems and Environment* **82**(1-3) : 129-137.
- Lansigan, F.P., de-los Santos, W.L., Santos, R.E.V. and Fabellar, M.T. 2002. Generation of crop coefficient for selected local corn varieties for simulation modeling.

- Larijani, B.A. 2010. Effect of seedling age on main stem leaf appearance rate and total leaf number in transplanted rice. *International Journal of Agriculture and Crop Science* 2(1) : 26-29.
- Laza, R.C., Peng, S., Sanico, A.L., Visperas, R.M. and Akita, S. 2001. Higher leaf area growth rate contributes to greater vegetative growth of F₁ rice hybrids in the Tropics. *Plant Production Science* 4(3) : 184-188.
- Laza, R.C., Peng, S., Akita, S. and Saka, H. 2003. Contribution of biomass partitioning and translocation to grain yield under sub-optimum growing conditions in irrigated rice. *Plant Production Science* 6(1) : 28-35.
- Laza, R.C., Peng, S., Akita, S. and Saka, H. 2004. Effect of panicle size on grain yield of IRRI-released indica rice cultivars in the wet season. *Plant Production Science* 73(3) : 271-276.
- Lee, C.K., Lee, B.W., Shin, J.C. and Yoon, Y.H. 2001. Heading date and final leaf number as affected by sowing date and prediction of heading date based on leaf appearance model in rice. *Korean Journal of Crop Science* 46(3) : 195-201.
- Lee, D.J., Shim, I.S., Seo, J.H., Cho, K.J. and Chae, J.C. 1994. Growth and grain yield of infant seeding in rice as affected by different planting date in Southern alpine area. *RDA Journal of Agricultural Science, Rice* 36(1) : 1-7.
- Lee, M.H., Lee, D.J., Park, S.K., Rho, Y.D., Lee, J.H. and Park, R.K. 1987. Varietal difference of low temperature damage at reproductive, heading and ripening stage of rice plant. Research Report of Crop Experiment Station-Phytotron Experiment 11. pp. 38-59.

- Li, X., Takahashi, T., Suzuki, N. and Kaiser, H.M. 2011. The impact of climate change on maize yields in the United States and China. *Agricultural Systems* **104**(4) : 348-53.
- *Li, Z., Sarkar, R.S., Nayak, S.K. and Ravi, I. 1997. Physiological effect of nitrogen application on aromatic rice. *Journal of South China Agricultural Univeristy* **18**(3) : 13-17 [c.f. CAB Abstracts CD-ROM, 1996-1998/07].
- Limochi, K. and Eskandari, H. 2013. Effect of Planting Date on the Performance of Flag Leaf Stomata and Grain Yield of Rice Cultivars. *International Journal of Agronomy and Plant Production* **4**(4) : 769-773.
- Linscombe, S.D., Jordan, D.L., Burns, A.B. and Viator, R.P. 2004. Rice response to planting date differs at two locations in Louisiana. *Online Crop Management*.
- Liu, S., Mo, X., Lin, Z., Xu, Y., Ji, J., Wen, G. and Richey, J. 2010. Crop yield responses to climate change in the Huang-Huai-Hai Plain of China. *Agricultural Water Management* **97**(8): 1195-209.
- Long, S.P., Ainsworth, E.A., Rogers, A. and Ort, D.R., 2004. Rising atmospheric carbon dioxide: plants FACE the future. *Annual Review of Plant Biology* **55**: 591-628.
- Maclean, J.L. and Dawe, D.C. 2002. Rice almanac: Source book for the most important economic activity on earth, CABI Publishing, UK.
- Mahal, S.S., Uppal, H.S. and Mankotia, B.S. 1999. Influence of planting date and irrigation management in scented rice varieties in Trans Gangatic Plain region. *Environmental and Ecology* **17**(3) : 557-559.

- Mahmood, R. 1997. Impacts of air temperature variations on the boro rice phenology in Bangladesh : implications for irrigation requirements. *Agricultural and Forest Meteorology* **84**(3-4) : 233-247.
- Mahmood, R. 1998. Air temperature variations and rice productivity in Bangladesh: a comparative study of the performance of the yield and the CERES-Rice models. *Ecological Modelling* **106**(2) : 201-12.
- Mahmood, R., Legates, D.R. and Meo, M. 2004. The role of soil water availability in potential rainfed rice productivity in Bangladesh : applications of the CERES-Rice model. *Applied Geography* **24**(2) : 139-159.
- Mall, R.K. and Aggarwal, P.K. 2002. Climate change and rice yields in diverse agro-environments of India 1, Evaluation of impact assessment models. *Climate Change* **52** : 315-330.
- Mandal, N. and Ghosh, M. 2003. Thermal time indices and yield correlations for hybrid rice in Terai zone of West Bengal. *Journal of Agrometeorology* **5**(2) : 98-101.
- Manjappa, K. and Kumar, P. 2002. Performance of rainfed transplanted rice under different dates of planting in hilly zone of Karnataka. *Karnataka Journal of Agricultural Sciences* **15**(1) : 136-138.
- Mann, T.R. 1999. Crop scientists see a new revolution. *Science* **283** : 310-316.
- Matsubayashi, M., Ito, R., Nomota, T., Takase, T. and Yamada, N. 1963. Theory and practice of growing rice, Fuji Publishing Co., Tokyo, Japan. p. 177.
- Matsui, T. and Omasa, K.T. 2000. High temperature at flowering inhibits swelling of pollen grains, a driving force for anther dehiscence in rice (*Oryza sativa* L.) *Plant Production Science* **3** : 430-434.

- Matthews R.B. and Stephens,W. 2002. Crop -Soil Simulation Models: Application in Developing Countries. CABI Publishing, CAB International, Wallingford, Oxon, United Kingdom pp 80-90.
- Matthews, R., Stephens, W., Hess, T., Middleton, T. and Graves, A. 2002. Application of crop/soil simulation models in tropical agricultural system. *Advances in Agronomy* **76** : 31-124.
- Mavi, H.S. 1994. Introduction to Agrometeorology. Oxford and IBH Publishing Co. pp. 122-148.
- Mckenzie, K.S., Bollich, C.N., Rutger, J.N. and Moldenhauer, K.A.K. 1986. Rice breeding in the United States. *In*: W.R. Fehr(ed.) Handbook of Plant Breeding, vol.2 MacMillan Publ. Co., New York. pp. 487-532.
- Mckenzie, K.S., Linscombe, S.D., Jodari, F.L., Oard, J.H. and White, L.M. 1999. Rice varieties in Louisiana rice production handbook. Publication 2321. Louisiana State University Baton Rouge, LA.
- Medhi, A.K. and Baruah, K.K. 2001. Effect of low temperature on growth physiology and yield of rice. *Journal of Hill Research* **14**(1) : 51-53.
- Mendelsohn, R, 2008. The impact of climate change on agriculture in developing countries. *Journal of Natural Resources Policy Research* **1**(1) : 5-19.
- *Meng, L., Cao, W., Zhou, Z. and Liu, X. 2003. A process-based model for simulating phasic development and phenology in rice. *Scientia Agriculture Sinica* **36**(11) : 1362-1367 [c.f. CAB Abstracts CD-ROM, 2003/11-2004/07].
- Merwin, H.D. and Peech, M. 1951. Exchangeability of soil potassium in the sand, silt and clay fractions as influenced by the nature of the complimentary

exchangeable cations. *Soil Science Society of America Proceedings* **15** : 125-128.

Mesbah, M., Souroush, H.R. and Zadeh, A.H.H. 2004. A study of relationship between grain yield and yield components in rice. *Iranian Journal of Agricultural Sciences* **5**: 983-993.

Mesbah, M., Souroush, H.R. and Zadeh, A.H.H. 2004. A study of relationship between grain yield and yield components in rice. *Iranian Journal of Agricultural Sciences* **5** : 983-993.

Messina, C., Hammer, G., Dong, Z., Pondilch, D. and Cooper, M. 2009. Modelling crop improvement in a GxExM. Crop physiology: Applications for Genetic Improvement and Agronomy. Elsevier, Netherlands, pp 235-265.

*Miah, M.N.H., Yoshida, T., Yamamoto, Y. and Nitta, Y. 1996. Characteristic of dry matter production and partitioning of dry matter in high yielding semi-dwarf indica and Japonica-indica hybrid rice varieties. *Japanese Journal of Crop Science* **65** : 672-685 [c.f. CAB Abstracts CD-ROM, 1996-1998/07].

Min, J. and Zhi-qing, J. 2009. A Method for upscaling genetic parameters of CERES-rice in regional applications. *Rice Science* **16**(4): 292-300.

Moradpour, S., Koohi, R., Babaei, M. and Goldoust, K.M. 2013. Effect of planting date and planting density on rice yield and growth analysis. *International Journal of Agriculture and Crop Sciences* **5**(3) : 267-272.

*Moriwaki, T. 1999. On the ideal culm elongation in rice plants(3. *Nogyogijyutu* **54** : 133-138 [c.f. CAB Abstracts CD-ROM, 1998/08-2000/07].

- Mukesh, Singh, I., Pannu, R.K., Prasad, D. and Ram, A. 2013. Effect of different transplanting dates on yield and quality of basmati rice (*Oryza sativa*) varieties. *Indian Journal of Agronomy* **58**(3): 256-258.
- Munakata, K. 1976. Effects of temperature and light on the reproductive growth and repining of rice. **In:** *Climate and Rice*. The International Rice Research Institute, Manila, Philippines, pp. 187-210.
- Naher, Q., Hasan, M.A., Salam, M.U. and Salim, M. 1999. Yield and yield components of two modern photoinensitive rice varieties under year round transplanting. *Indian Journal of Agricultural Research* **33**(4) : 259-268.
- Nanja Reddy, Y.A., Prasad, T.G. and Udayakumar, M. 1995. Relationship between leaf area index, specific leaf weight and assimilation rate in rice genotypes. *Madras Agriculture Journal* **82**(11) : 616-617.
- Nayak, B.C., Dalei, B.B. and Chodhury, B.K. 2003. Response of hybrid rice to date of planting, spacing and seedling rate during wet season. *Indian Journal of Agronomy* **48**(3) : 172-174
- Nishiyama, I. 1976. Effects of temperature on the vegetative growth of rice plants. *In:* *Climate and Rice*. The International Rice Research Institute, Manila, Philippines, pp. 159-185.
- Noorbakhshian, S.J. 2003. Effect of seed rate, planting date in nursery and transplanting date on yield and yield components of rice. *Iranian Journal of Crop Sciences* **5**(4): 261-272.
- Noorka, I.R., Rehman, S., Haidry, J.R., Khaliq, I., Safdar, M.E., Ali, A., Muhammad, S., Sarwar, G. and Awan, T.H. 2008. Effect of transplanting

dates on paddy yield of fine grain rice genotypes. *Pakistan Journal of Botany* **40**(6): 2403-2411.

Norman, R.J., Slaton, N.A. and Moldenhaner, K.A.K. 1998. Development of the DD50 database for new rice cultivars. **In:** *B.R. Wells Rice Research Studies 1997* (Eds. R.J. Norman and T.H. Johnson). *Research Series* **460** : 144-146.

Norman, R.J., Slaton, N.A. and Moldenhaner, K.A.K. 1999. Development of the DD50 database for new rice cultivars. **In:** *B.R. Wells Rice Research Studies 1998* (Eds. R.J. Norman and T.H. Johnson). *Research Series* **468** : 250-256.

Norman, R.J., Slaton, N.A., Cox, D.C. and Boothe, D.L. 2000a. Grain yield performance of rice cultivars grown in northeast Arkansas as influenced by seeding date. *Research Series, Arkansas Agricultural Experimentation Station* **476** : 256-260.

Norman, R.J., Slaton, N.A., Cox, D.C., Wilson, C.E. and Boothe, D.L. 2001a. Grain yield performance as influenced by seeding date of rice cultivars grown in Northeast Arkansas. *Research Series, Arkansas Agricultural Experimentation Station* **485** : 185-188.

Norman, R.J., Slaton, N.A., Moldenhauer, K.A.K. and Boothe, D.L. 2001b. Influence of seeding date on the degree day 50 thermal-heat unit accumulations and grain yield of new rice cultivars. In : R.J. Norman(ed.) *B.R. Wells Rice Research Studies 2000. Research Series* **485** : 189-196.

Norman, R.J., Slaton, N.A., Moldenhauer, K.A.K. and Boothe, D.L. 2000b. Influence of seeding date on the degree day 50 thermal heat unit accumulations and grain yield of new rice cultivars. **In:** *B.R. Wells Rice*

Research Studies 1999 (Eds. R.J. Norman and C.A. Beyrouthy). *Research Series* **476**: 261-266.

Obuchi, Y., Oswa, M. and Narizuka, A. 2000. The characteristic investigation on the different transplanting dates of low amylose content paddy rice variety Sawapikari. *Bulletin of Gunma Agricultural Experiment Station* **6** : 15-20.

Ohsumi, A., Lubis, I., Horie, T. and Ohnishi, M. 2002. Identification and evaluation of major traits determining yield potential of rice under field conditions. 5. Genotypic differences in the leaf photosynthetic rate and associated plant factors. *Japanese Journal of Crop Science* **71** : 14-15.

Oldeman, L.R., Seshu, D.V. and Cady, F.B. 1987. Response of rice to weather variables. **In:** *Weather and Rice*. International Rice Research Institute, Manila, Philippines. pp 5-39.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus by extraction with sodium bicarbonate. U.S. Department of Agriculture, Circular 939.

Om, H., Katyal, S.K. and Dhiman, S.D. 1997. Effect of time of transplanting and rice hybrids on growth and yield. *Indian Journal of Agronomy* **42**(2) :261-264.

Ookawa, T., Naruoka, Y., Yamazaki, T., Suga, J. and Hirasawa, T. 2003. A comparison of the accumulation and partitioning of nitrogen in plants between two rice cultivars, Akenohoshi and Nipponbare, at the ripening stage. *Plant Production Science* **6**(3) : 172-176.

Osaki, M. 1995. Ontogenetic changes of N, P and K contents in individual leaves of field crops. *Soil Science and Plant Nutrition* **41**(3) : 429-438.

- Oteng, D.P., Kyei-Baffour, N. and Ofori, E. 2012. Simulating rice yields under climate change scenarios using the Ceres-Rice Model. *African Crop Science* **20**(2) : 401-408.
- Paliwal, A.K., Khandalkar, V.S., Paraye, P.M. and Tomar, N.S. 1996. Effect of transplanting time on grain yield and its attributes in dwarf scented rice. *Indian Journal of Agronomy* **66**(1) : 48-50.
- Pandey, N., Verma, A.K. and Tripathi, R.S. 2001. Effect of planting time and nitrogen on tillering pattern, dry matter accumulation and grain yield of hybrid rice(*Oryza sativa*. *Indian Journal of Agricultural Sciences* **71**(5) : 337-338.
- Pandey, R. and Agarwal, M.M. 1991. Influence of fertility levels, varieties and transplanting time on rice. *Indian Journal of Agronomy* **36**(4) : 459-463.
- Parihar, S.S., Verma, V.K., Shukla, R.K., Pandey, D. and Sharma, R.B. 1995. Response of transplanted rice to planting time and nitrogen schedule. *Indian Journal of Agronomy* **40**(3) : 402-406.
- Parry, M., Rosenzweig, C., Iglesias, A., Fischer, G. and Livermore, M. 1999. Climate change and world food security: a new assessment, *Global Environmental Change* **9** : 51-67.
- Parry, M.L., Rosenzweig, C., Iglesias, A., Livermore, M. and Fischer, G. 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change* **14** : 53-67.
- Patel, J.R. 1999. Response of rice (*Oryza sativa*) to time of transplanting, spacing and age of seedlings. *Indian Journal of Agronomy* **44**(2): 344-346.

- Pathak, H., Ladha, J.K., Aggarwal, P.K., Peng, S., Das, S., Singh, Y., Singh, B., Kamra, S.K., Mishra, B., Sastri, A.S.RAS., Aggarwal, H.P., Das, K.K. and Gupta, R.K. 2003. Trends of climatic potential and on farm yields of rice and wheat in the Indo-Gangetic plains. *Field Crops Research* **80**: 223-234.
- Patnaik, R.N., Pande, K., Ratho, S.N. and Jachuck, P.J. 1991. Consistent performance of rice hybrids. *Crop Research* **4** : 272-279.
- Pattar, P.S., Masthana Reddy, B.G. and Kuchanur, P.H. 2001. Yield and yield parameters of rice (*Oryza sativa*) as influenced by date of planting and age of seedlings. *Indian Journal of Agricultural Sciences* **71**(8): 521-522.
- *Peng, J., Liu, Q., Rong, X., Xie, G. and Zhu, H. 2003. Effect of plant growth regulator on accumulation and translocation of nitrogen and protein contents of rice. *Journal of Hunan Agricultural University* **29**(5) : 368-371 [c.f. CAB Abstracts CD-ROM, 2002/08-2003/10].
- Peng, S. and Khush, G.S. 2003. Four decades of breeding for varietal improvement of irrigated lowland rice in the International Rice Research Institute. *Plant Production Science* **6**(3) : 157-164.
- Peng, S., Cassman, K.G. and Kropff, M.J. 1995. Relationship between leaf photosynthesis and nitrogen content of field-grown rice in tropics. *Crop Science* **35**(6) : 1627-1630.
- Peng, S., Huang, J., Sheehy, J.E., Laza, R.C., Visperas, R.M., Zhong, X., Centeno, G.S., Khush, G.S. and Cassman, K.G. 2004. Rice yields decline with higher night temperature from global warming. *Proceedings of National Academy of Science, U.S.A.* **101**(27) : 9971-9975.

- Peng, S., Laza, R.C., Visperas, R.M., Sanico, A.L., Cassman, K.G. and Khush, G.S. 2000. Grain yield of rice cultivars and lines developed in the Philippines since 1966. *Crop Science* **40** : 307-314.
- Peng, S., Yang, J., Garcia, F.V., Laza, R.C., Visperas, R.M., Samico, A.L., Chavez, A.Q. and Virmani, S.S. 1998. Physiology based management for yield maximization of hybrid rice. In S.S. Virmani, E.A. Siddiq and K. Muralidharan eds., *Advances in Hybrid Rice Technology, IRRI*. 157-176.
- Piper, C.S. 1966. *Soil and Plant Analysis*. Hans Publishers, Bombay.
- Pirdashfy, H., Sarvestani, Z., Narsiri, M. and Fallah, V. 2000. *Seed and plant* **16** : 164-158.
- Porter, C.H., Hoogenboom, G., Batchelor, W.D., Jones, J.W. and Gijsman, A.J. 2003. DSSAT v 4.0 Crop Models : Overview of changes relative to DSSAT v 3-5, University of Florida, Gainesville, USA.
- Poussin, J.C., Wopereis, M.C.S., Debouzie, D. and Maeghat, I.L. 2003. Determinants of irrigated rice yield in the Senegal River Valley. *European Journal of Agronomy* **19** : 341-356.
- Rahman, H. U., Malik, S. A., Saleem, M. and Hussain, F. 2007. Evaluation of seed physical traits in relation to heat tolerance in upland cotton. *Pakistan Journal of Botany* **39**(2): 475-483.
- Rahman, H.U., Malik, S.A. and Saleem, M. 2004. Heat tolerance of upland cotton during the fruiting stage evaluated using cellular membrane thermostability. *Field Crop Research* **85**(2): 149-158.
- Rahman, M.M., Ferdousi, N., Sato, Y., Kusunoki, S. and Kitoh, A. 2012. Rainfall and temperature scenario for Bangladesh using 20 km mesh

AGCM. *International Journal of Climate Change Strategies and Management* **4**(1) : 66-80.

Rakesh, K. and Sharma, H.I. 2004. Effect of dates of transplanting and varieties on dry matter accumulation, yields attributes and yields of rice (*Oryza sativa* L.) *Himachal Journal of Agricultural Research* **30**(1): 1-7.

Ramasamy, S. 2000 Prediction of potential yield of rice across India through simulation modelling. *Madras Agricultural Journal* **87**(4-6) : 210-217.

Rao, GSLHVP and Subash, N. 1996. Use of CERES-Rice model to assess potential yield. *International Rice Research Notes* **21**(2-3): 87.

Rashid, M.H. and Islam, M.S. 2007. Adaptation to climate change for sustainable development of Bangladesh agriculture. *Bangladesh Country Paper*, APCAEM.

Rauf, S., Khan, T. M., Naveed, A. and Munir, H. 2007. Modified path to high lint yield in upland cotton (*Gossypium hirsutum* L.) under two temperature regimes. *Turkish Journal of Biology* **31**: 119-126.

Reddy, C.S. 2002. Performance of rice varieties under different time of planting. *Indian Journal of Agronomy* **47**(2) : 199-202.

Reddy, D.R., Sreenivas, G., Sudhakar, T.R. and Rao, S.B.S.N. 2004. Growth of rice varieties in terms of degree days under South Telangana agroclimatic conditions. *Journal of Agrometeorology* **6**(2) : 274-277.

Reddy, K.S. and Reddy, B.B. 1992. Effect of transplanting time, plant density and seedling age on growth and yield of rice. *Indian Journal of Agronomy* **31**(1): 18-21.

- Reddy, K.S. and Reddy, B.B. 1994. Effect of planting time, population density and seedling age on yield and yield parameters of rice. *Indian Journal of Agricultural Research* **28**(3) :171-176.
- Reid, S., Smit, B., Caldwell, W. and Belliveau, S. 2007. Vulnerability and adaptation to climate risks in Ontario agriculture. *Mitigation and Adaptation Strategies for Global Change* **12**(4) : 609-637.
- Reid, S., Smit, B., Caldwell, W. and Belliveau, S. 2007. 'Vulnerability and adaptation to climate risks in Ontario agriculture'. *Mitigation and Adaptation Strategies for Global Change* **12**(4) : 609-637.
- Reinke, R.F., Lewina, L.G. and Williams, R.L. 1994. Effect of sowing time and nitrogen on rice cultivars of different growth duration in New South Wales. 1. Yield and yield components. *Australian Journal of Experimental Agriculture* **34**(7) : 933-938.
- Rimi, R.H., Rahman, S.H., Karmakar, S. and Hussain, S.G. 2009. Trend Analysis of Climate Change and Investigation on its Probable Impacts on Rice Production at Satkhira, Bangladesh. *Pakistan Journal of Meteorology* **6**(11) : 37-50.
- Ritchie, J.T. 1998. Soil water balance and plant stress. In : Tsuji, G.Y., Hoogenboom, G., Thornton, P.K.(Eds) "Understanding options for agricultural production". Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 41-54.
- Ritchie, J.T. and Algarwamy, G. 1989a. Simulation of sorghum and pearl millet phenology. *ICRIST Bulletin* **12**:24-26.
- Ritchie, J.T. and Algarwamy, G. 1989b. Genetic coefficient for CERES models. *ICRIST Bulletin* **12**:27-29.

- Ritchie, J.T., Singh, U., Godwin, D.C., Bowen, W.T. 1998. Cereal growth, development and yield. In : Tsuji, G.Y., Hoogen boom, G., Thornton, P.K.(Eds.), Understanding options for Agricultural Production. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 79-98.
- Rosenzweig, C. and Tubiello, F. 2007. Adaptation and mitigation strategies in agriculture: an analysis of potential synergies. *Mitigation and Adaptation Strategies for Global Change* **12**(5) : 855-873.
- Rosenzweig, C. and Hillel, 1995. Implications of climate change for international agriculture: Crop modeling study. Washington DC, US Environmental Protection Agency, Climate Change Division.
- Rosenzweig, C. and Tubiello, F. 2007. Adaptation and mitigation strategies in agriculture: an analysis of potential synergies. *Mitigation and Adaptation Strategies for Global Change* **12**(5) : 855-873.
- Rosenzweig, C., Tubiello, F.N., Goldberg, R., Mills, E. and Bloomfield, J. 2002. Increased crop damage in the US from excess precipitation under climate change. *Global Environmental Change* **12**(3) : 197-202.
- Rosenzweig, C., Tubiello, F.N., Goldberg, R., Mills, E. and Bloomfield, J. 2002. 'Increased crop damage in the US from excess precipitation under climate change'. *Global Environmental Change* **12**(3) : 197-202.
- Roudier, P., Sultan, B., Quirion, P. and Berg, A. 2011. 'The impact of future climate change on West African crop yields: What does the recent literature say?'. *Global Environmental Change* **21**(3) : 1073-1083.
- Roy, B.C., Leihner, D.E., Hilger, T.H. and Steinmueller, N. 2004. Genotypic differences in nitrogen uptake and utilization of wet and dry season rice as

influenced by nitrogen rate and application schedule. *Pakistan Journal of Biological Sciences* **7**(6) : 129-1036.

Sahoo, C.R., Patro, B.B. and Kar, M. 1999. Yield and its attributes in rice as affected by different sowing dates. *Environment and Ecology* **17**(4) : 922-925.

Sahu, D.K. 1994. Effect of date of transplanting and potassium on growth and yield of lowland rice. *Oryza* **31**(1): 38-39.

Saikia, L. and Mahanta, T.C. 1996. Effect of dates and sequential planting of tillers on yield of rice (*Oryza sativa*) under post-flood situation of Assam. *Journal of Agronomy* **41**(2) : 221-225.

*Saitoh, K., Kasiwagi, S., Kinoshita, T. and Ishihara, K. 1991. Characteristics of dry matter production process in high yielding rice varieties. iv. Dry matter accumulation in the panicle. *Japanese Journal of Crop Science* **60** : 255-263 [c.f. CAB Abstracts CD-ROM, 1990-1991].

Samdhia, S. 1996. Relative performance of hybrids rice under different dates and densities of planting. *IRRN* **21**(2) : 81-82.

Samonte, S.O.P.B., Wilson, L.T., Medley, J.C., Pinson, S.R.M., Mc-Clung, A.M. and Lales, J.S. 2006. Nitrogen utilization efficiency: relationships with grain yield, grain protein, and yield-related traits in rice. *Agronomy Journal* **98** : 168-176.

Samonte, S.O.P.B., Wilson, L.T., Medley, J.C., Pinson, S.R.M., Mc-Clung, A.M. and Lales, J.S. 2006. Nitrogen utilization efficiency: relationships with grain yield, grain protein, and yield-related traits in rice. *Agronomy Journal* **98**: 168-176.

- Sanghi, A. and Mendelsohn, R. 2008. The impacts of global warming on farmers in Brazil and India. *Global Environmental Change* **18**(4) : 655-65.
- Sarkar, R. and Kar, S. 2006. Evaluation of management strategies for sustainable rice-wheat cropping system, using DSSAT seasonal analysis. *Journal of Agricultural Science* **144**:421-434.
- Saseendran, S.A., Hubbard, K.G., Singh, K.K., Mendiratta, N., Rathore, L.S. and Singh, S.V. 1998. Optimum transplanting dates for rice in Kerala, India, Determined using both CERES V 3.0 and Clim prob. *Agronomy Journal* **90**(2) : 185-190.
- Saseendran, S.A., Rathore, L.S., Rao, G.S.L., Prasad, H.V. and Singh, S.V. 2001. Rice crop simulation model studies. *Journal of Agriculture and Physics* **1**(1) : 48-51.
- Saseendran, S.A., Singh, K.K., Rathore, L.S., Singh, S.V. and Sinha, S.K. 2000. Effects of climate change on rice production in the tropical humid climate of Kerala, India. *Climatic Change* **44**: 495-514.
- Satake, T. 1976. Sterile-type cool injury in paddy rice plants. In climate and rice pp. 281-301, IRRI : Los Banos, Philippines.
- Shah, L.M. and Bhurer, K.P. 2005. Response of wet seeded rice varieties to sowing dates. *Nepal Agricultural Research Journal* **6**: 35-38.
- Shahzad, M.A., Wasi-ud-Din, S., Sahi, M.T., Khan, M.E. and Ahmad, M. 2007. Effect of sowing date and quality of wheat. *Pakistan Journal of Agricultural Sciences* **44**(4): 581-583.
- Sharief, A.E., El-Hinidi, M.H., Abd El-Rahman, A.A. and Abdo, G.M. 2000. Rice productivity as influenced by planting dates and seedling. *Agronomy Journal Sciences, Mansoura University* **3**: 1511-1521.

- Sheehy, J.E. and Mitchell, P.L. 2013. Designing rice for the 21st century: the three laws of maximum yield. Discussion Paper Series No. 48. International Rice Research Institute.
- Sheehy, J.E., Mnzara, M., Cassman, K.G., Mitchell, P.L., Pablico, P., Robles, R.P., Samonte, H.P., Lales, J.S. and Ferrer, R.B. 2004a. Temporal origin of nitrogen in the grain of irrigated rice in the dry season : the outcome of uptake, cycling, senescence and competition studied using a ¹⁵N point placement technique. *Field Crops Research* **89**(2/3) : 337-348.
- Sheehy, J.E., Mnzara, M., Cassman, K.G., Mitchell, P.L., Pablico, P., Robles, R.P. and Ferres, A. 2004b. Uptake of nitrogen by rice studied with a ¹⁵N point placement technique. *Plant and Soil* **259**(1/2) : 259-265.
- Shimono, H., Kanno, H. and Sawano, S. 2010. Can the cropping schedule of rice be adapted to changing climate? A case study in cool areas of northern Japan. *Field Crops Research* **118**(2): 126-34.
- Shimono, I.T., Okada, H., Kanda, E. and Arakawa, I. 2007. Low temperature and induced sterility in rice: Evidence for the effects of temperature before panicle in initiation. *Field Crops Research* **101**(2) : 221-231.
- Shrestha, S., Asch, F., Dingkuhn, M. and Becker, M. 2011 Cropping calendar options for rice wheat production systems at high - altitudes. *Field Crops Research* **121** : 158-167.
- Shukla, V.K., Sharma, R.S. and Srivastava, S.K. 1995. Effect of planting geometry, weed management and N-levels on morphological growth pattern of rice. *Oryza* **32**(4) : 254-257.

- Siadat, S.A., Fathi, G., Hamaity, S.S. and Bironvand, M. 2004. Effect of planting dates on paddy yield and yield components in three rice cultivars. *Indian Journal of Agricultural Sciences* **35**(1) : 227-234.
- Siddiqui, M.R.H., Lakepale, R. and Tripathi, R.S. 1999. Effect of spacing and fertilizer on medium duration rice(*Oryza sativa*) varieties. *Indian Journal of Agronomy* **44**(2) : 310-312.
- Sie, M., Dingkuhn, M., Wopereis, M.C.S. and Miezan, K.M. 1998. Rice crop duration and leaf appearance rate in a variable thermal environments. 1. Development of an empirically based model. *Field Crops Research* **57**(1) : 1-13.
- Singh, A.K., Kumar, A. and Mishra, S.S. 1998b. Performance of rice(*Oryza sativa*) varieties at different nitrogen levels under irrigated, lowland eco-system of North Bihar. *Indian Journal of Agronomy* **43**(2) : 273-277.
- Singh, C.B., Aujla, T.S., Sandhu, B.S. and Khera, K.L. 1996. Effect of transplanting date and irrigation regime on growth, yield and water use efficiency in rice in northern India. *Indian Journal of Agricultural Research* **66**(3): 137-141.
- Singh, G., Singh, O.P., Yadava, R.A., Singh, P.P. and Nayak, R. 1998a. Response of rice (*Oryza sativa*) varieties to nitrogen levels in flash flood conditions. *Indian Journal of Agronomy* **43**(3) : 506-510.
- Singh, H., Singh, K.N. and Hasan, B. 2007. Evaluation of CERES rice model(V. 4.0) under temperate conditions of Kashmir valley, India. *Cereal Research Communication* **35**:1723-1732.

- Singh, K.K., Kalra, N., Mohanty, U.C. and Rathore, L.S. 1997. Performance evaluating of medium-range weather forecast using crop growth simulator. *Environmental System* **25**(4):397-408.
- Singh, K.M., Pal, S.K., Verma, U.N. and Thakur, R. 1997. Effect of time and method of planting on performance of rice cultivar under medium land of Bihar plateau. *Indian Journal of Agronomy* **42**(3) : 443-445.
- Singh, K.N., Khan, G.M. and Aggarwal, P.K. 2003. Validation of model ORYZA 1-N under temperate conditions of Kashmir. *Indian Journal of Agricultural Sciences* **73**(5) : 261-265.
- Singh, K.N., Khan, G.M. and Shah, M.H. 2005. Effect of transplanting date and nutrient management on yield and spikelet sterility of rice in Kashmir. *Oryza* **42**(1) : 37-40.
- Singh, M.K., Thakur, R., Verma, U.N., Upasani, R.R. and Pal, S.K. 2000. Effect of planting time and nitrogen on production potential of basmati rice (*Oryza sativa*) cultivars in Bihar Plateau. *Indian Journal of Agronomy* **45**(2) : 300-303.
- Singh, M.V., Tripathi, H.N. and Tripathi, H.P. 1997. Effect of nitrogen and planting date on yield and quality of scented rice. *Indian Journal of Agronomy* **42**(4) : 602-606.
- Singh, M.V., Tripathi, H.N. and Tripathi, H.P. 1997. Effect of nitrogen and planting date on yield and quality of scented rice. *Indian Journal of Agronomy* **42**(4) : 602-606.
- Singh, M.V., Tripathi, H.N. and Tripathi, H.P. 1996. Effect of N fertilizers and time of planting on growth, yield and profitability of basmati rice. *Oryza* **33**(4) : 248-252.

- Singh, S.P. and Pillai, K.G.P. 1995. Effect of time of planting on grain yield and economic returns of traditional scented rice varieties. *Annals of Agricultural Research* **16**(1) : 74-78.
- Singh, S.P., Kushwah, Y.S. and Lal, S.S. 2004. Effect of nitrogen on productivity, soil fertility and economics of rice (*Oryza sativa*)-potato (*Solanum tuberosum*) – wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agricultural Sciences* **74**(7) : 385-387.
- Singh, T., Shivay, Y.S. and Singh, S. 2004. Effect of date of transplanting and nitrogen on productivity and nitrogen use indices in hybrid and non-hybrid aromatic rice. *Acta Agronomica Hungarica* **52**(3) : 245-252.
- Singh, T., Shivay, Y.S. and Singh, S. 2004. Effect of date of transplanting and nitrogen on productivity and nitrogen use indices in hybrid and non-hybrid aromatic rice. *Acta Agronomica Hungarica* **52**(3) : 245-252.
- Singh, U., Ritchie, J.T. and Godwin, D.C. 1993. 'A Users Guide to CERES-Rice V2.10, Simulation manual IFDC-SM-4, IFDC, Muscle Shoals, A1, U.S.A, p. 131.
- Singh, U., Wilkens, P.W., Chude, V. and Oikesh, S. 1999. Predicting the effect of nitrogen deficiency on crop growth duration and yield. In : Proceedings of the fourth international conference on precision Agriculture. ASA-CSSA-SSSA, Madison, Wisconsin, USA. pp. 1379-1393.
- Singh, U.P. and Prasad, A. 1999. *Annals of Agricultural Research* **20** : 296-300.
- Singh, V.P. and Prasad, A. 1999. Response of promising spring sown rice (*Oryza sativa* L.) varieties to sowing time and N levels under upland rainfed low hill valley situation of Uttar Pradesh. *Annals of Agricultural Research* **20**(3) : 296-300.

- Singh, V.P. and Singh, V.K. 2000. Effect of sowing date and nitrogen level on the productivity of spring sown rice (*Oryza sativa*) varieties in low hills of Uttaranchal. *Indian Journal of Agronomy* **45**(3) : 560-563.
- Sinha, S.K. and Chatterjee, S.D. 1997. Flowering behaviour of rainfed lowland rice varieties during dry season in West Bengal, India. *International Rice Research Notes* **22**(1) : 28-29.
- Sitaramaiah, K.V., Madhuri, J. and Reddy, N.S. 1998. Physiological efficiency of rice hybrids. *International Rice Research Notes* **23**(2) : 32-33.
- Slaton, N.A. 2001. Rice production handbook. Publication 192. Arkansas Cooperative Extension Service, University of Arkansas, Little Rock, A.R.
- Slaton, N.A., Linscombe, S.D., Norman, R.J. and Gbur, E.E. 2003. Seeding date effect on rice grain yields in Arkansas and Louisiana. *Agronomy Journal* **95** : 218-223.
- *Song, X., Agata, W. and Kawamitsu, Y. 1990. Studies on dry matter and grain production of F₁ hybrid rice in China. 1. characteristics of dry matter production. *Japanese Journal of Crop Science* **59** : 19-28 [c.f. CAB Abstracts CD-ROM, 1990-1991].
- Song, Y., Oh, N. and Hwang, C. 1996. Growth and response of yield characters of dry seeded rice at different seeding dates in plain area. *RDA Journal of Agricultural Science* **38**(2) : 20-31.
- Soomro, H., Soomro, A., Oad, F.C., Ansari, A.H. and Oad, N.L. 2001. Effect of transplanting Dates on Yield and Its related traits in rice(*Oriza sativa* L.). *Journal of Biological Science* **1** : 363-364.
- Sreenivas, G. and Reddy, D. Raji 2007. Assessment of modified weather on rice yields using CERES rice model in Andhra Pradesh. *ISPRS Archives*

XXXVIII-8/W3 Workshop Proceedings: Impact of Climate Change on Agriculture.

- Streck, N.A., Belle, R.A. and Rocha, E.K. 2005. Estimating leaf appearance rate and phyllochron in safflower (*Carthamus tinctorius* L.). *Ciencia Rural, Santa Maria* **35** : 1448-1450.
- Streck, N.A., Bosco, L.C. and Lago, I. 2008. Simulating leaf appearance in rice. *Agronomy Journal* **100** : 490-501.
- Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science* **25** : 259-260.
- Summerfield, F.J., Collison, S.T., Ellis, R.H., Robert, E.H. and Penning de Vries F.W.T. 1992. Photothermal responses of flowering in rice (*Oryza sativa*). *Annals of Botany* **69** : 101-112.
- Surekha, K., Reddy, M.N. and Kumar, R.M. 1999. Yield attributes and yield of rice (*Oryza sativa*) hybrids as influenced by nitrogen sources and its splits application. *Indian Journal of Agronomy* **44**(1) : 80-88.
- Suresh, K.K., Ramamoorthy, K and Pandian, J.S.R. 2001. Influence of sowing time and varieties on growth and yield of rainfed rice. *Madras Agricultural Journal* **88**(1-3) : 118-119.
- Tao, F., Yokozawa, M., Xu Y., Hayashi, Y. and Zhang, Z. 2006. Climate changes and trends in phenology and yields of field crops in China, 1981-2000. *Agricultural and Forest Meteorology* **138** : 82-92.
- Teixeira, E.I., Fischer, G., van Velthuisen, H., Walter, C. and Ewert, F. 2011. Global hot-spots of heat stress on agricultural crops due to climate change. *Agricultural and Forest Meteorology*, doi:10.1016/j.agrformet.2011.09.002.

- Thakur, R.B. 1993. Performance of summer rice(*Oryza sativa*) to varying levels of nitrogen. *Indian Journal of Agronomy* **38**(2) : 187-190.
- Timsina, J., Pathak, H., Humphreys, E., Godwin, D., Singh, B., Shukla, A.K. and Singh, U. 2004. Evaluation of, and yield gap analysis in rice using, CERES Rice ver. 4.0 in Northwest India. New directions for a diverse planet. **In** : *Proceedings of the 4th International Crop Science Congress Brisbane*. Indian Council of Agricultural Research.
- Timsina, J., Singh, U., Badaruddin, M. and Meisnar, C.1998. Cultivar, Nitrogen and moisture effects on Rice-Wheat Sequence: Experimentation and simulation. *Agronomy Journal* **90**: 19-130.
- Tirado, M., Clarke, R., Jaykus, L., McQuatters-Gollop, A. and Frank, J. 2010. 'Climate change and food safety: A review'. *Food Research International* **43**(7) : 1745-1765.
- Toit, A.S. and Prinsloo, M, 2001. El Niño-southern oscillation effects on maize production in South Africa: a preliminary methodology study. *ASA Special Publication* **63** : 77-86.
- Toit, A.S. and Toit, D.L. 2003. Short description of the model statistical package and weather analogue programme (DSSAT Manual V.4) University of Florida, Gainesville, USA.
- Tragoolram, J., Saenjan, P., Pannengpetch, K. and Takeuchi, K. 2011. Climate change impacts and adaptation assessment on rice production in Khon Kaen province of Thailand. **In** : *The 3rd International Conference on Science and Technology for Sustainable Development of the Greater Mekong Sub-region* (STGMS. Souphanouvong University, Luang Prabang, Lao PDR. 24-25 March, 2011.

- Tubiello, F.N., Rosenzweig, C. Goldberg, R.A., Jagtap, S. and Jones, J.W. 2000. U.S. National Assessment Technical Report: Effects of Climate Change on U.S. Crop Production, Part I: Wheat, Potato, Corn, and Citrus. <http://www.usgcrp.gov/usgcrp/nacc/agriculture/TubielloEtal-2000.pdf>
- Uchijima, T. 1976. Some aspects of the relation between low air temperature and the number of sterile spikelets in rice plants. *Journal of Agricultural Meteorology* **31** : 199-202.
- Van Lanen, H.A.J., Van Diepen C.A., Reinds, G.J., De Koning, G.H.J. and Bregt, A.K. 1992. Physical land evaluation methods and GIS to explore the crop growth potential and its effects within the European Communities. *Agriculture System* **39**: 307-328.
- Vang, T. and Obi, I.U. 2006. Effect of planting date on some agronomic traits and grain yield of upland rice varieties at Makurdi. Benue states and grain yield of upland rice varieties at Makurdi, Benue State, Nigeria. *Journal of Sustainable Development of Agricultural Environment* **2**(1): 1-9.
- Vange, T. and Obi, I.U. 2009. Influence of sowing date on rice grain yield in Benue state of Nigeria. Online. Crop Management doi:10.1094/CM-2009-0629-01-RS.
- Vange, T., Ojo., A.A. and Bello, L.L. 1999. Genetic variability, stability and correlation studies in lowland rice (*Oryza sativa*) genotypes. *Indian Journal of Agricultural Sciences* **69**(1) : 30-33.
- Varshneya, M.C. and Karande, B.I. 1996. Effect photoperiod on the phyllochron of sorghum. *Journal of Maharashtra Agriculture Universities* **21**(2):276-281.

- Verma, A.K., Pandey, N. and Tripathi, R.S. 2004. Leaf growth, chlorophyll, nitrogen content and grain yield of hybrid rice as influenced by planting times and nitrogen levels. *Annals of Agricultural Research* **25**(3) : 456-458.
- Vilayvong, S., Banterng, P., Patanothai, A. and Pannangpetch, K. 2012. Evaluation of CSM-CERES-Rice in simulating the response of lowland rice cultivars to nitrogen application. *AJCS* **6**(11):1534-1541.
- *Villalobos, R. and Retana, J.A. 1997. Possible effects of global warming on dry land rice in the North pacific regions of Costa Rica. *Agronomica Constarricense* **21**(2) : 179-188 [c.f. CAB Abstracts CD-ROM, 1996-1998/07].
- Walkley, A. and Black, C.A. 1934. An examination of the Degtisareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37** : 29-39.
- Wallace, D.H. and Yan, W. 1998. Plant breeding and whole-system crop physiology : improving crop maturity, adaptation, and yield Oxon, UK, New York, NY, USA : Cab International.
- *Wang, W.J. 1994. Studies on the uptake and distribution of ¹⁵N fertilizer in different indica rice cultivars at different growth stages. *Acta Agronomica Sinica* **20**(4) : 476-480 [c.f. CAB Abstracts CD-ROM, 1993-1994].
- Wassmann, R. and Achim D. 2007. Climate Change Adaptation through Rice Production in Regions with High Poverty Levels SAT eJournal| ejournal.icrisat.org|Volume 4|Issue 1.
- Wassmann, R., Jagdish, S.V.K, Heuer, S., Ismail, A., Redona, E., Serraj, R., Singh, R.K., Howell, G., Pathak, H. and Sumfleth, K. 2009. Climate

change affecting rice production. The physiological and agronomic basis for possible adaptation strategies **In** : *Advances in Agronomy* (Ed D.L Sparks), pp. 59-122.

Watanabe, T. and Takashi, K. 2009. A general adaptation strategy for climate change impacts on paddy cultivation : special reference to the Japanese context. *Paddy Water Environment* **7** : 313-320.

Watanabe, Y. 1997. Phylogeny and geographical distribution of genus *Oryza*. **In** : “*Science of the Rice Plant*” (T. Matsuo, Y. Futsuhara, F. Kikuchi and H. Yamaguchi, Eds.) pp. 29-39, Food and Agriculture Policy Research Center, Tokyo.

Wikarmpapraharn, C. and Kositsakulchai E. 2010. Evaluation of ORYZA2000 and CERES-Rice Models under Potential Growth Condition in the Central Plain of Thailand. *Thai Journal of Agricultural Science* **431** : 17-29.

Williams, J.R., Jones, C.A. and Dyke, P.T. 1984. A modeling approach to determining the relationship between erosion and soil productivity. *Trans. ASAE* **27** : 129-144.

Williams, R.L., Fukai, S., Cooper, M. and Salisbuy, J. 1997. Effect of growth duration, nitrogen and sowing date on grain yield of Australian rice : a modeling approach. **In**: *Breeding strategies for rainfed lowland rice in drought prone environments : proceedings of an International Workshop*. Ubon Ratchathain, Thailand, 5-8 Nov. 1997 239-244.

Wu, G. and Wilson, L. 1996. Rice dry matter partitioning and grain yield. *Rice Technical Working Group Meeting Proceedings*.

www.ricepedia.org

- Xian-Qing, L.I.N., De-Feng, Z.H.U., Wei-Jun, Z.H.O.U. and Yu-Ping, H.A.N.G. 2003. Relationship between specific leaf weight and photosynthetic rate at panicle initiation stage in super hybrid rice. [J]., **17**(3): 281-283.
- *Xie, G.H., Su, B.L. Wang, S.L., Ma, X.C. and Wu, Q.F. 1995. A study on growth and dry matter production of rice in Wuling mountain area. 1. Effects of sowing dates on growth and development of rice. *Acta Agriculture Universitatis Pekinensis* **21**(3) : 259-264 [c.f. CAB Abstracts CD-ROM, 1995].
- Xie, Z.R., Guo, Y.Q., Shen, X.M., Zhu, X.F., Chen, Q., Jing, X.Y., Huang, X.M., Wang, J.F. and Xu, Q.H. 2000. Preliminary study on influences of various rice varieties and sowing dates on growth periods and actual yield in Taihu farming region. *Acta Agriculture Shanghai* **16**(1) : 28-32.
- Xu, F.X., Zheng, J.K., Zhu, Y.C. and Wang, G.X. 2001. Sink-source characteristics at seed filling stage of high yielding hybrids of mid season rice. *Journal of Southwest Agricultural University* **23**(2) : 120-122.
- Yadav, R.K. and Rao, U.P. 2003. Performance of very early advance lines of rainfed rice in Chattisgarh. *Indian Journal of Dry land Agricultural Research and Development* **18**(2) : 199-200.
- Yang, F., Wang, X., Ma, J. and Ling, F. 2001. A comparative analysis of yield component factors of the two rice varieties of JND3 and JND13. *Journal of Jilin Agricultural University* **23**(4) :21-24.
- Yang, J., Zhang, W., Wang, Z., Liu, Li. and Zhu, Q. 2002a. Source-sink characteristics and their translocation of assimilates in new plant type and intersubspecific hybrid rice. *Agricultural Sciences in China* **1**(2) : 155-162.

- Yang, J., Peng, S., Zhang, Z., Wang, Z., Visperas, R.M. and Zhu, Q. 2002b. Grain and dry matter yields and partitioning of assimilates in Japonica/indica hybrid rice. *Crop Science* **42**(3) : 766-772.
- Yao, F., Xu, Y., Feng, Q., Lin, E. and Yan, X. 2005. Simulation and validation of CERES-rice model in main rice ecological zones in China. *Acta Agron Sin* **31**:545-550
- Yin, X. 1996. Quantifying the effects of temperature and photoperiod on phenological development to flowering in rice. WAU dissertation no. 2083.
- Yin, X., Kropff, M.I., Aggarwal, P.K., Peng, S. and Horie, T. 1997. Optimal pre-flowering phenology of irrigated rice for high yield potential in three Asian environments : A simulation study. *Field Crops Research* **51**(1-2) : 19-27.
- Yin, X., Kropff, M.J. and Goudriaan, J.A.N. 1996. Differential Effects of Day and Night Temperature on Development to Flowering in Rice. *Annual Botany* **77** : 203-213.
- Ying, J., Peng, S., He, Q.R., Yang, H., Yang, C.D., Visperas, R.M. and Cassman, K.G. 1998. Comparison of high yield rice in tropical and subtropical environments, I. Determinates of grain and dry matter yields. *Field Crops Research* **57** : 71-84.
- Yoshida, H., Horie, T., Ohnishi, M. and Katsura, K. 2003. Analysis of genotype by environment interaction in yield formation processes of rice grown under a wide environmental range in Asia. 2. A model explaining genotypic and environmental variation in spikelet number per unit area. *Japanese Journal of Crop Science* **72** : 90-91.

- Yu, W., Alam, M., Hassan, A., Khan, A.S., Ruane, A.C., Rosenzweig, C., Major, D.C. and Thurlow, J. 2010. Climate change risk and food security in Bangladesh, EarthScan, London.
- Zada, A., Said, A., Derawada., Khan, D.R. and Tahir, M. 1996. Rice genotypes responses to environmental stresses in term of yied and yield components in sub-mountainous regions of Swat. *Sarhad Journal of Agriculture* **12**(6) : 619-624.
- Zelensky, G.L. 2001. High grain quality rice breeding in Russia. **In** : *Specialty rices of the world* (Eds. R.C. Chaudhary, D.V. Tran and R.Duffy). Science Publishers Inc. Food and Agricultural Organization of the United Nations Rome.
- Zhai, H.Q., Cao, S.Q., Wan, J.M., Zhang, R.X., Lu, W., Li, L.B., Kuang, T.Y., Min, S.K., Zhu, D.F. and Cheng, S.H. 2002. Relationship between leaf photosynthetic function at grain filling stage and yield in super high yielding hybrid rice (*Oryza sativa* L.). *Science in China Series, C. Life Sciences* **45**(6) : 637-646.
- *Zhang, C., Wang, Y., Long, Y., Dong, G. and Yang, L. 2004. Study on the characteristics of sink potential formation in different types of conventional indica rice varieties. *Journal of Yangzhou University and Life Science* **25**(1) : 51-54. [c.f. CAB Abstracts CD-ROM, 2004].
- Zhang, L., Lin, S., Bouman, B.A.M., Xue, C., Wei, F., Tao, H., Yang, H., Wang, D.Z. and Dittert, K. 2009. Response of aerobic rice growth and grain yield to N fertilizer at two contrasting sites near Beijing, China. *Field Crops Research* **114**: 45-53.

- Zhang, X., Friedl, M.A., Schaaf, C.B. and Strahler, A.H. 2004. Climate controls on vegetation phenological patterns in northern mid- and high latitudes inferred from MODIS data. *Global Change in Biology* **10**(7) : 1133-1145.
- Zheng, J., Ge, Q. and Hao, Z. 2002. Impacts of climate warming on plants phenophases in China for the last 40 years. *Chinese Scientific Bulletin* **47**(21) : 1826-1831.
- Zhong, X., Peng, S., Sheehy, J.E., Visperas, R.M. and Liu, H. 2002. Relationship between tillering and leaf area index : quantifying critical leaf area index for tillering in rice. *Journal of Agricultural Science* **138** : 269-279.

*** Original not seen**

APPENDIX – I**Standard weekly meteorological data for 2011 and 2012 SKUAST-Kashmir, Shalimar**

Met. weeks	Temperature (°C)		Wind speed (km/hr)	Rainfall (mm)	R H (%)	Sun shine hrs
	Max.	Min				
2011						
14	11.00	3.73	3.36	4.33	81.79	1.63
15	17.36	5.76	3.01	14.80	65.29	4.69
16	16.23	6.43	3.03	18.45	73.21	2.96
17	26.93	6.21	2.61	0.00	51.14	10.80
18	25.31	8.39	3.20	0.60	57.36	8.56
19	23.29	9.31	3.39	2.73	70.50	6.21
20	30.00	9.83	2.73	1.80	51.07	10.97
21	27.93	11.44	3.37	0.00	49.79	7.91
22	27.21	12.46	2.89	3.60	55.50	8.83
23	30.21	11.71	2.93	0.00	47.21	10.59
24	31.07	13.96	2.80	19.25	58.71	11.23
25	31.64	15.51	2.49	3.40	60.79	9.23
26	32.01	18.13	2.10	0.00	58.57	9.01
27	29.50	15.61	2.54	7.20	64.21	7.57
28	28.64	16.01	1.83	5.00	64.57	6.01
29	29.43	16.49	1.83	4.50	65.43	7.43
30	31.64	19.53	1.99	4.50	67.14	6.51
31	32.07	16.27	2.13	0.80	61.00	8.56
32	31.74	18.09	2.09	2.20	62.57	8.23
33	27.29	15.14	1.87	7.90	71.57	5.90
34	32.51	17.64	1.96	11.20	60.36	7.71
35	27.50	17.03	1.80	3.05	73.86	3.96
36	30.64	16.11	1.64	11.20	65.86	7.26
37	28.64	16.86	1.76	4.45	72.07	5.99
38	24.07	11.10	1.73	14.80	74.50	5.90
39	28.00	8.54	1.76	0.00	65.43	8.87
40	27.14	8.71	1.90	1.50	66.64	7.03
41	23.14	7.23	1.94	9.00	74.36	6.41
42	24.64	4.51	1.60	0.00	71.71	7.49
43	18.36	3.77	2.19	8.70	85.07	6.40
2012						
14	21.857	5.129	3.443	4.343	60.214	7.343
15	15.929	7.629	2.943	6.643	74.786	3.714
16	21.000	6.343	2.957	1.314	63.929	7.557
17	19.071	8.729	2.629	5.429	72.643	3.186
18	20.071	5.800	2.500	1.386	67.714	6.186
19	23.500	10.057	2.514	1.171	71.286	4.557
20	22.286	8.843	3.057	2.214	70.286	8.057
21	21.143	9.529	2.986	2.029	73.286	4.586
22	29.000	9.317	2.350	1.000	59.500	9.833
23	24.786	10.614	1.600	1.200	69.643	4.829
24	26.714	11.600	2.443	0.229	62.929	8.057
25	30.286	14.286	2.071	0.000	58.286	9.214
26	28.357	14.357	2.386	0.257	63.786	8.786
27	32.786	17.100	1.814	0.143	59.357	9.200
28	29.071	16.429	1.600	0.886	70.214	4.757
29	29.857	15.500	2.000	2.257	66.286	8.257
30	32.429	16.929	1.400	1.314	63.286	9.457
31	31.691	15.326	1.400	0.000	62.667	7.567
32	28.143	16.100	1.357	4.143	70.857	5.229
33	27.214	17.943	0.914	4.057	75.429	3.914
34	33.429	19.643	1.257	0.257	64.000	8.371
35	30.357	16.314	1.343	0.143	64.357	5.600
36	28.071	17.586	1.500	10.314	72.143	4.429
37	24.857	16.714	0.886	5.629	85.143	3.714
38	25.214	12.329	1.371	2.114	79.143	6.557
39	26.643	8.814	1.086	0.000	73.286	8.114
40	26.286	7.414	1.429	0.000	67.714	7.986
41	23.643	4.643	1.514	0.000	63.929	7.129
42	18.929	6.000	1.829	1.271	74.071	4.514
43	16.214	2.743	1.686	0.000	77.714	5.343

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Shalimar Campus Srinagar – 190 025

CERTIFICATE

Certified that all the corrections/amendments as suggested by External Examiner Dr. Suresh Chandra, Chief Scientist, Department of Agro-Technology, IIIM, CSIR, Jammu during Viva-Voce examination held on February 13, 2015 have been incorporated in the manuscript entitled **“Impact of Climate Change on Different Rice Varieties under Varied Agroecological Conditions of Kashmir Using CERES-Rice Model”** submitted by **Ms. Shabana Tabasum** (Regd. No. 2010-295-D).

(Dr. K.N. Singh)
Chairman
Advisory Committee