Simulation of growth and yield of various rice varieties (*Oryza sativa* L.) as influenced by seedling age and harvesting schedules

Sameera Qayoom
(208-D-2008)

Division of Agronomy

Faculty of Post-Graduate Studies

Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir

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DEDICATED

TO MY

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Sher-e-Kashmir
University of Agricultural Sciences and Technology of Kashmir
Division of Agronomy, Shalimar Campus Srinagar
191121

Certificate - I

This is to certify that the thesis entitled "**Simulation of growth and yield of various rice varieties (*Oryza sativa* L.) as influenced by seedling age and harvesting schedules**" submitted in partial fulfillment of the requirements for the award of the degree of **Doctor of Philosophy in Agriculture (Agronomy)** to the **Faculty of Post-graduate Studies**, **Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir** is a record of bonafide research work carried out by **Ms. Sameera Qayoom (Registration No. 208-D-2008)** 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. B. A. Khanday)
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Advisory Committee

Endorsed

Professor & Head
Division of Agronomy

Sher-e-Kashmir
University of Agricultural Sciences and Technology of Kashmir
Division of Agronomy, Shalimar Campus Srinagar
191121

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We, the members of Advisory Committee of **Ms. Sameera Qayoom (Registration No. 208-D-2008)**, a candidate for the degree of **Doctor of Philosophy in Agriculture (Agronomy)**, have gone through the manuscript of the thesis entitled, "**Simulation of growth and yield of various rice varieties (*Oryza sativa* L.) as influenced by seedling age and harvesting schedules**" and recommend that it may be submitted by the student in partial fulfillment of the requirements for the degree.

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Sher-e-Kashmir
University of Agricultural Sciences and Technology of Kashmir
Division of Agronomy, Shalimar Campus Srinagar
191121

Certificate - III

This is to certify that the thesis entitled "**Simulation of growth and yield of various rice varieties (*Oryza sativa* L.) as influenced by seedling age and harvesting schedules**" submitted by **Ms. Sameera Qayoom (Registration No. 208-D-2008)** to the **Faculty of Post-graduate Studies, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir**, in partial fulfillment 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)

Professor & Head
Division of Agronomy

Director
Resident Instruction-cum-Dean
Post-graduate Studies, **SKUAST (K)**

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Dated: ________________

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Division of Agronomy, Shalimar Campus, Srinagar 191121

Name of the student	:	**Sameera Qayoom**
Registration No.	:	**208-D-2008**
Major Subject	:	**Agronomy**
Minor Subject	:	Soil Science and Plant Physiology
Major Advisor	:	**Dr. B. A. Khanday** Professor & Head, Dry Land (Karewa) Agricultural Research Station, Budgam
Title of thesis	:	**Simulation of growth and yield of various rice varieties (*Oryza sativa* L.) as influenced by seedling age and harvesting schedules**

ABSTRACT

A field experiment entitled "Simulation of growth and yield of various rice varieties (*Oryza sativa* L.) as influenced by age of seedling and harvesting schedules" was conducted at Agronomy Farm of Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir, Shalimar during *Kharif* 2010 and 2011 to simulate the effect of age of seedling on growth and yield of rice and to simulate the proper time of harvesting of three rice varieties viz. Jhelum, SKUA-403 and SR-1. The soil of the experimental field was silty clay loam with neutral pH, low in available nitrogen and medium in available phosphorus and potassium. The crop management was done as per recommended package of practices and only non-monetary inputs viz. age of seedling (20, 30, 40 days old) and harvesting schedules (35, 42 and 49 days after flowering) were altered. Among varieties, Jhelum recorded highest grain yield and harvest index as compared to other cultivars whereas straw yield was highest in SKUA-403. As far as the time taken to different phenological stages is concerned, Jhelum took lesser days as compared to other varieties. Except for plant height, leaf area index and 1000-grain weight, other growth and yield attributing characters were also significantly highest in Jhelum as compared to SKUA-403 and SR-1.

40 days old seedlings performed better than 30 and 20 days old seedlings in all respect. Their growth and yield attributing characters were significantly higher than young aged seedlings. The time taken by 40 days old seedlings to different phenological stages was also lesser than that of 30 and 20 day old seedlings. Performance in terms of grain, straw, biological yield and harvest index was significantly better than 30 and 20 day old seedlings.

As far as the harvesting schedule is concerned, it could not cause any significant variation in growth and yield attributes. Highest grain yield was however, obtained from the crop harvested at 35 DAF while as highest straw yield was obtained in the crop harvested at 49 DAF among all three cultivars. Head recovery was highest in the crop harvested at 49 DAF. Simulation studies gave similar results with permissible deviations.

Regarding simulation studies similar results were obtained with permissible deviations. Simulation studies with respect to age of seedling and sowing time showed better results in terms of crop growth and yield when the crop was sown earlier with 40 DAS old seedlings. Thus sowing earlier with aged seedling gave better results in terms of growth and yield as compared with late sown with younger seedlings.

Thus it could be concluded that for realizing optimum rice yields, 40 day old seedlings of rice cultivar Jhelum should be transplanted in the field by 10-11 June and harvest at 35 days after flowering.

Key words: Age of seedling, Harvesting schedule, Rice, Simulation.

Signature of Student | Signature of Major Advisor
Dated: ____________ | Dated: ____________

Chapter 1

INTRODUCTION

Rice (*Oryza sativa* L.) one of the most important staple food crops of the world accounts for more than 20 per cent of daily calorie intake of about 2.48 billion people. It is cultivated in the world over an area of about 158 million hectares with a production of 700 million tonnes annually (470 million tonnes of milled rice), IRRISTAT, 2012. However, the projected demand for rice is about 800 million tonnes by 2030 (FAOSTAT, 2003).

In India, rice is cultivated over an area of 36.95 million hectares with a production of 120.6 million tonnes, contributing about 23 per cent to the world rice production. However, average yield of rice in India is 3.26 t ha^{-1} as against that of 4.37 t ha^{-1} in the world (FAO, 2010). The increased pressure on the land resources with ever-increasing population provides limited possibility of further horizontal expansion under rice cultivation. As such, in future, gains in production will mainly accrue through enhancement of productivity, which will be possible through the introduction of high yielding cultivars to a limited magnitude and better management practices to a large extent.

In the State of Jammu and Kashmir, rice is cultivated in temperate, intermediate and subtropical zones over an area of 2.59 lakh hectares with a production of 55.74 lakh quintals. Contribution from Kashmir is 37.33 lakh quintals from an area of 1.43 lakh hectares with a productivity of 21.41 q ha^{-1} (Economic Survey, 2009). The growth period of rice crop in Kashmir valley is limited by low temperature in spring and autumn and temperature fluctuation at flowering and grain filling stage results in high spikelet sterility. Temperature can not be manipulated easily under field conditions but seeding time can be adjusted to meet the specific requirement for physiological stage of crop growth cycle. 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. Understanding phenology of rice crop is important to develop better adapted calendars for a particular agro-ecological system, as rice phenology depends on photothermal environments. Changing the planting date may shift thermo-sensitive phenological stages of the rice crop into thermally critical environments which could lead to a prolonged duration, a delay in flowering and severe reduction in yield is due to poor source sink relationship.

Among management practices, efficient use of non-monetary inputs such as water management, time and method of fertilizer application, selection of cultivar, plant density, seedling age, transplanting and harvesting schedules are some of the important means to enhance the rice productivity. Padali (1980) reported that 'half of the success of rice cultivation depends upon the seedling' and as such the ideal age of seedling used for transplanting is of primary importance for uniform stand and seedling establishment. Transplanting is the major method of growing rice in which rice seedlings grown is a nursery are uprooted and transplanted into well puddled field. For transplanted seedlings, age of seedling is the major factor in determining yield. Transplanting shock is a setback to growth due to uprooting and replanting of seedlings. It increases with increased age of seedling. Transplanting rice at optimum period is critical to achieve high grain yield. However, optimum rice planting dates are regional and vary with location and genotypes (Bruns and Abbas, 2006). The ideal age of transplanting is governed by duration of varieties and field condition. Time of planting and age of seedling are two cultural practices which influence the growth and yield of transplanted rice. Furthermore, most of the rice varieties have a tendency to shed grains if harvested late. Timely harvest may minimize the gap between attainable and realized yield levels. Thus, it is important to select suitable seedling age contributing towards increased rice production and resolve the problem posed by non-optimal harvesting schedule, which otherwise leads to high seedling mortality after transplanting as well as low grain yield.

Crop simulation models are mathematical, computer based representations of crop growth and environmental interaction. They are widely used to describe systems and processes at the levels of genotype, the crop, the farming system, the region and the global environment. They provide output data to describe attributes of the crop at different points in time (Mathews *et al.,* 2002). Models have several practical uses in agriculture. Since certain agricultural activities require advanced information of certain stages of crop development, output results from the crop models can be used-

- to determine time of sowing, chemical use, irrigation etc.,
- to predict maturity dates, yield and quality of crops,
- to determine limits of geographical areas suitable for production of various crops, specially new and non-native,
- to select the crop varieties specific to a region to minimize risk of damage due to unfavourable conditions, and

- to estimate the magnitude of ongoing and expected shifts in phenophases occurrence due to global warming.

Thus crop models have been used for determining the production potential in different climatic regions, analyzing the precise reasons for yield gap, determining strategies for higher yield potential, studying the short and long term consequences of climatic variability and climatic change on agriculture. These simulation models can be used as research tools helpful in decision making on location specific agro-techniques. The present investigation was, therefore, taken up with following objectives:

- To simulate the effect of age of seedling on growth and yield of rice, and
- To simulate the proper time of harvesting of various rice varieties.

Chapter 2

REVIEW OF LITERATURE

The present investigation includes three factors viz. three varieties and three seedling ages in the main plot and three harvesting schedules in sub-plot. A brief resume of work done on the effect of these factors on growth, yield and simulation studies of rice in India and abroad has been reviewed and presented in this chapter under appropriate heads.

2.1 Effect of varieties

Rice varieties show considerable variation with respect to growth characteristics and yielding ability. Spectacular production growth, initially through combined growth of productivity and area and later largely through productivity enabled the country to attain self sufficiency by the early eighties and sustain same since then. Variability indices of different varieties showed that certain indigenous cultivars possess some better desirable characters which could be used as donor for improvement programme (Devi and Borua, 2002).

2.1.1 Growth characters

Kanungo and Koul (1994) found that rice variety 'Daya' was significantly superior to 'Parifat' for basal tillers hill^{-1}.

Working under temperate environment of Kashmir, Bali *et al.* (1995) reported that amongst different genotypes 'Jhelum' at par with 'K-39' was recorded significantly taller than 'Chenab'. Jhelum cultivar also recorded significantly higher LAI than both 'K-39' and 'Chenab' varieties.

A field experiment with 30 IET lines and few varieties raised on clay loam soil in Banglore noticed significantly differential LAI (Nanja Reddey *et al.*, 1995).

Miah *et al.* (1996) indicated that high yielding varieties show higher accumulation of dry matter (assimilates) during grain filling compared to low yield varieties.

Hari Om *et al.* (1997) observed that hybrid rice variety 'PMS-2A/IR31802' recorded highest number of productive tillers m^{-2} which was at par with 'ORI 161' but significantly higher than 'PMS 10A/PRC05' and 'HKR 126'. The variety 'ORI 161' recorded significantly higher plant height than other varieties.

Hussaini *et al.* (1998) while studying the performance of 04 rice cultivars viz. 'ITA 306', 'ITA 123', 'ITA 230' and 'TDS 103' reported that 'ITA 306' was significantly superior to other rice varieties in respect of growth characters especially LAI.

Working under China conditions Mao Kihao *et al.* (1998) found that the number of seedlings established was higher in cultivar 'Bing 93-390' which also produced higher number of tillers ha^{-1} as compared to rice cultivars 'Jiayu-293', 'Jiazoa-305' and 'Xinxiu-293'.

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

Rice cultivar 'Suraksha' recorded maximum plant height of 110.0 cm and the lowest height (98.0 cm) was observed in cultivar 'R296-260' (Siddiqui *et al.*, 1999).

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

Sitaramaiah *et al.* (1998) observed that rice hybrids 'MTUHR 203'. 'MTUHR 2020' and 'MTUHR 2037' produced significantly higher biomass than other genotypes. Further, the hybrids recorded higher LAI from 30 DAP compared to the varieties viz. 'Samba Mahesuri' and 'Chritanya'.

Peng *et al.* (1998) and Ying *et al.* (1998) reported that early vigor of hybrid rice in temperate areas was mainly attributed to tillering rate which is higher than that of conventional varieties.

In another study Siddiqui *et al.* (1999) observed that tillers plant^{-1} were highest in rice genotype 'Surakha' compared to 'Karanti', Mahamaya' and 'R 296-260'.

In two years study at Karimganj, Assam Chaudhary (1999) recorded highest LAI in rice variety 'Karsahah' (5.0 in 1994 and 3.8 in 1995) followed by 'IR 36' and 'Rasi'.

A field experiment conducted to study the performance of hybrids 'CNHR-2' and 'CNHR-3' and high yielding cultivars 'IR-36' and 'IR-64' showed that cultivar 'CNHR-2' was superior in respect of number of tillers (Bhowmick and Nayak, 2000).

Lalitha *et al.* (2000) conducted field investigation in Hyderabad during *kharif* and *rabi* seasons and reported that during *kharif* season three rice varieties 'Sambamahsue', 'Rajaradhu' and 'Tellahamsa' attained maximum tillering stage in 32-36 DAP, whereas during *rabi* season the maximum tillering stage was attained in 55, 48 and 46 DAP, respectively.

Singh and Singh (2000) recorded significantly higher plant height in cultivar ‘Pan Dhan Majhera-7’ (102.7 cm) followed by ‘VL Dhan 206’ (100.7 cm) and ‘Majera-3’ (98.8 cm).

The study conducted at IRRI, Philippines revealed that the tillering rate of hybrid rice was significantly lower or equal than conventional varieties between transplanting and mid tillering and between mid tillering and panicle initiation in different years and seasons (Laza *et al.*, 2001).

Ghosh (2001) working in West Bengal observed higher values of plant height in rice hybrids. Among different hybrids plant height was significantly highest for ‘ORI-161’.

High yielding hybrid combinations exhibited LAI of 6.5-7.0 at full heading and 3.4-4.0 at maturity (Xu *et al.*, 2001).

The cultivar ‘JND-13’ recorded higher leaf area index after heading compared with ‘JND-3’ (Yang *et al.*, 2001).

De *et al.* (2002) recorded variation in the plant height of 14 aromatic rice cultivars ranging from 80.0 to 132.0 cm.

Yang *et al.* (2002a) observed that both new plant type and inter sub-specific hybrids rice recorded higher dry matter accumulation from heading to harvest compared to 3 line indica hybrid ‘Shanyon-63’.

Experiment conducted in China revealed that the capacity of dry matter production before and after heading was markedly higher in rice cultivar ‘Xieyou-9308’ (yield up to 12.0 t ha^{-1}) than ‘Xieyou-63’ (Zhai *et al.*, 2002).

Suresh *et al.* (2001) observed that the number of tillers were significantly higher in cultivar 'PMK-2' compared to 'ASD-17', RMAS-2003', 'AS-33773' and 'AS-33714'.

The above ground dry matter of Japonica/indica hybrids was 12.3 Mg ha^{-1} at heading which was 38.2 and 1.6 per cent higher than that of their parents and inter-varietal hybrids, respectively. Further, the dry matter accumulation of Japonica/indica hybrids during ripening phase was 9.4 Mg ha^{-1} during ripening phase which was 52.9 and 73.8 per cent higher than that of their parents and inter-varietal hybrids, respectively (Yang *et al.,* 2002b).

Working in Chattisgarh, Yadav and Rao (2003) reported that amongst different rice cultivars tested, 'IET-7564' attained the highest plant height of 110.2 cm.

At IRRI, Philippines Peng and Khush (2003) found that amongst indica inbred and indica/indica rice cultivars developed up to 1999, maximum plant height of 141.0 cm was recorded in 'IRS' followed by 'IR4' (126.0 cm) and 'IR-48' (124.0 cm). Significant differences in the plant height were also observed by Laza *et al.* (2004) at IRRI, Philippines.

2.1.2 **Yield attributes**

Bali *et al.* (1995) observed that rice variety 'Jhelum' produced higher number of panicle per unit area (342.5 m^{-2}), higher number of grains $panicle^{-1}$ (80.3) than 'Chenab' and 'K-39'. However, the differences were non-significant.

Singh and Pillai (1995) recorded maximum panicles in rice variety 'Katarim' followed by 'Karnal local' and 'Basmati 370'. The lowest number of panicles was observed in 'Ranbir basmati'.

Dhiman *et al.* (1997) recorded significantly highest number of grains panicle^{-1} in 'HKR-228' (99.0) and lowest in 'RP-2144' (85.0). The panicle number was also highest in 'HKR-228'.

Behra (1998) reported that amongst test varieties of Basmati rice, 'HKR-228' showed superiority for panicles m^{-2}.

Gangwar and Sharma (1998) found that the difference in the number of panicle m^{-2} among test varieties was non-significant in first year but differed significantly during second year.

Kanungo and Koul (1994) reported that rice genotype 'Daya' was significantly superior to 'Parigat' for panicle length and filled grains panicle^{-1}.

Hussaini *et al.* (1998) found that rice variety 'ITA-306' was significantly superior in grain weight panicle^{-1} and 1000-grain weight compared to 'ITA-123', 'ITA-230' and 'TOS-103'.

Working under China conditions, Mao Kiho *et al.* (1998) reported that rice cultivars 'Bing 95-503', 'Jiayu-293' and 'Jiazao' recorded higher number of grains panicle^{-1} than other varieties, whereas 1000-seed weight remained highest in 'Xinxiu 922'.

Singh *et al.* (1998b) reported that rice cultivar 'IET 8002' produced higher number of panicles m^{-2} than 'IET 5760', 'IET 5194', Rajshree', 'Radha' and 'Pankaj'. In another experiment, they recorded the highest number of panicle m^{-2} in rice variety ‘Barh Avarwdhi’ followed by ‘NOGR-24’, ‘Madhukar’ and ‘Chakia 59’.

Sitaramaiah *et al.* (1998) recorded higher number of grains panicle^{-1} in hybrids compared to ‘Samba Mahsuri’ and ‘Chaitanya’.

Dhiman *et al.* (1997) observed highest number of grains per panicle in ‘HKR-126’ compared to other rice cultivars.

The mean maximum panicle number (335m^{-2}) in rice cultivar ‘Vikas’ was recorded by Singh *et al.* (1999).

Surekha *et al.* (1999) reported that amongst rice hybrids ‘MGRI’ produced the highest number of panicles m^{-2}. Vange *et al.* (1999) reported that the panicle number, grains panicle^{-1} and 1000 grain weight in 10 early duration, rainfed lowland rice varieties ranged from 140 to 233, 116 to 155 and 22.4 to 30.9 g respectively.

Under low hill conditions of Uttranchal rice cultivar ‘Pant Dhan Majhera-7’ produced significantly higher number of panicles m^{-2}, higher panicle length, grains panicle^{-1} and 1000-grain weight compared to ‘Majhera-3’ and ‘VL Dhan 206’ (Singh and Singh, 2000).

A field study conducted to find out the performance of hybrids viz. ‘CNHR-2’ and CNHR-3’ and high yielding cultivars viz. ‘IR-36’ and ‘IR-64’ revealed that ‘CNHR-2’ recorded higher number of filled grains panicle^{-1} (111.0) than other genotypes (Bhowmick and Nayak, 2000).

Ganajaxi *et al.* (2001) recorded significantly higher number of panicles m^{-2} in genotype ‘IET-13549’ compared to ‘Pusa basmati-1’ and ‘Taraori basmati’.

Ghosh (2001) studied the performance of 04 rice high yielding cultivars and 04 rice hybrids and reported that hybrids recorded higher values for panicle length and filled grains panicle^{-1} than other cultivars.

Suresh *et al.* (2001) recorded significantly higher number of grains panicle^{-1} and 1000-grain weight in rice cultivar 'IET-13549' compared to 'Pusa basmati' and 'Taraori basmati'.

The results of a field study conducted at Jilin, China by Yang *et al.* (2001) revealed that rice cultivar 'JND-3' recorded higher panicles than 'JND-13'.

A significant difference in panicle number amongst different rice cultivars was observed by Laza *et al.* (2004) in which 'IR-58' and 'IR-60' produced about 40 per cent more panicles than 'PSBRc-54' and 'PSBRc-80'.

2.1.3 **Grain and straw yield**

Grain yield of rice cultivars varied significantly (Sitaramaiah *et al.*, 1998; Dhiman *et al.*, 1999; Vange *et al.*, 1999; Singh *et al.*, 2000 and Ghosh, 2001).

Working under temperate conditions of Kashmir Bali *et al.* (1995) reported that the grain yield of rice genotypes 'K-39' (56.7 q ha^{-1}), 'Chenab' (57.3 q ha^{-1}) and 'Jhelum' (53.6 q ha^{-1}) showed insignificant variation. Straw yield also followed a similar trend.

In Hyderabad, Singh and Pillai (1995) observed that the grain yield of traditional scented varieties differed significantly during 1st year and 3rd year of investigation. '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 maximum grain yield from variety 'Swat 3' (6.42 t ha^{-1}) followed by 'JP5' (5.79 t ha^{-1}) and 'IR-25865-124-3-3' (5.14 t ha^{-1}).

Hari Om *et al.* (1997) found that rice hybrid 'ORI-161' produced 7, 23 and 13 per cent and 12, 27 and 21 per cent higher grain yield than 'PMS-2A/PR31802', 'PMS-10A/PR-106' and 'HKR-126' in 1993 and 1994, respectively. A similar trend was also noticed in the straw yield.

Hussaini *et al.* (1998) studied the performance of 04 rice varieties and reported that 'ITA-306' produced grain yield of 20.85 q ha^{-1} compared to 16.04, 11.30 and 5.9 q ha^{-1} in 'ITA-123', 'ITA-230' and 'TOS-103', respectively.

Working under China conditions Mao Khao *et al.* (1998) reported that the grain yield ranged from 132.5 kg mu^{-2} in cultivar 'Bing-93-390' to 330 kg mu^{-2} in 'Bing 95-503'.

Sitaramaiah *et al.* (1998) recorded significantly higher harvest index in hybrids 'MTUHR-2033', 'MTUHR-2020' and 'MTUHR-2037' than other genotypes.

Singh *et al.* (1998a) reported that average grain yield of rice cultivar 'Barh avaradhi' (22.8 q ha^{-1}) was significantly higher than 'NDGR-24', 'Madhukar' and 'Chakia-59'. In another experiment, Singh *et al.* (1998b) found that rice variety 'IET-8002' produced the highest grain yield (46.2 q ha^{-1}) during 1st year and 'Rajshree' (57.2 q ha^{-1}) during 2nd year.

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

Surekha *et al.* (1999) working in Andhra Pradesh reported that amongst the varieties in short duration group 'MGRI' emerged as most promising with respect to the grain yield.

Peng *et al.* (2000) recorded higher grain yield and harvest index in modern rice cultivars under favourable growing conditions with high solar radiation.

Singh *et al.* (2000) found significantly higher straw yield in rice genotype 'Sugandha' (40.4 q ha^{-1}) than other genotypes. However, grain yield and harvest index was higher in 'Pusa basmati'.

Bhowmick and Nayak (2000) recorded higher grain and straw yield in rice cultivar 'CNHR-2' compared to 'CNHR-3', 'IR-36' and 'IR-64'.

Ganajaxi *et al.* (2001) tested 03 genotypes at Mugad in which 'IET-13549' recorded significantly higher grain yield (30.8 q ha^{-1}) compared to 'Pusa basmati' (24.2 q ha^{-1}) and 'Taraori baxmati' (19.2 q ha^{-1}). 'IET-13549' also produced significantly higher straw yield (43.1 q ha^{-1}) when compared with 'Taraori basmati' (36.3 q ha^{-1}) and 'Pusa basmati' (33.5 q ha^{-1}).

Reddy *et al.*(2001) found that rice hybrid 'KRH-2' recorded 16.7 and 41.3 per cent higher grain yield than 'IR-60' during 1998 and 1999, respectively.

Singh *et al.* (2001) noticed that rice varieties showed significant grain yield difference. 'IET-13548' and 'Pusa basmati', produced significantly higher grain yield than 'Taraori basmati'.

Suresh *et al.* (2001) observed that rice variety 'PKK-2' recorded the highest straw yield of 42.8 q ha^{-1}, while the lowest straw yield was recorded in 'AS-33714'.

Amongst 36 Japonica/indica hybrids tested 'O2428/ yangdao', 'PC-311/IR-36' and 'PC-311/ Minghi-63' recorded higher grain yields ranging from 12.6-12.9 Mg ha^{-1} (Yang *et al.,* 2002b).

Laza *et al.* (2003) recorded the highest grain yield of 546 g m^{-2} in 'IR-73409H' during 1998 (wet season), whereas 'IR-71623H' recorded maximum grain yield of 719 g m^{-2} in 1999 (dry season).

Laza *et al.* (2004) reported that rice cultivars 'PSBRc26H' and 'PSBRc72H' produced the highest grain yield in 2000 (wet season) whereas 'PSBRc26H' and 'PSBRc80' produced the highest grain yield in 2001 (dry season). The average harvest index was significantly highest in 'PSBRc 10' (49.9%) and lowest in 'PSRBc30' (36.3%).

2.2.1 **Effect of seedling age**

2.2.2 **Growth characters**

Garcia and Nakano (1995) reported that old aged seedlings produced more tillers than young seedling from 14 days after transplanting to maximum tillering stage.

Tahir *et al.* (2004) reported that increase in seedling age decreased the plant height and days taken to 50 per cent flowering and maturity.

Amin *et al.* (2007) observed that 35 day old seedling took significantly lesser number of days to reach 50 per cent flowering. However, it produced better growth characters compared to 15, 25, 45 or 65 days old seedling.

The results of a field study conducted in China by Liyanli *et al.* (2007) revealed significant increase in the plant height when old aged rice seedlings were transplanted having 3.5 or 4.5 leaves per seedling was transplanted.

Mobaseer *et al.* (2007) recorded significantly higher number of tillers m^{-2} in 25 day old seedling compared to 35 or 45 day old seedling.

Chandrakar *et al.* (2008) observed that 21 day old seedling took significantly lower number of days to reach 50 per cent flowering (98.33) compared to 28, 35 and 42 day old seedling.

Krishna *et al.* (2008) recorded 4-5 days earlier flowering when 8 day old seedling was transplanted compared to 25 day old seedling. However, 12 day old seedling produced more number of tillers $plant^{-1}$ than other seedling ages.

In an experiment conducted at Gangavati, Karnataka, Krishna and Biradarpatil (2009) observed that 12 day old seedling produced more tillers per plant compared to 8, 16 and 23 day old seedling.

Working under Kashmir condition, Chand and Hassan (2007) reported that 20 day old seedling proved superior over 40 day seedling in terms of number of tillers $plant^{-1}$.

Paraye and Kandalkar (1994) found that with increase in the age of seedling reduced in the plant height of rice.

Increase in the age of rice seedlings resulted in longer flowering cycles (Poragantia, 1996).

Kin *et al.* (1999) working in Korea reported that 10 day old seedling had more vigorous elongation of plant height and higher tillering ability compared to 35 and 40 day old seedling. Leaf area index, top dry weight and CGR were lower up to 40 DAT and thereafter remained at par with other seedling ages. However, RGR was highest in 10 day old seedling up to 40 DAT and thereafter it decreased compared to RGR recorded in 35 and 45 days old seedlings.

Qiu *et al.* (1999) reported that the plant height and number of tillers plant^{-1} decreased with increase in the leaf age of transplanted rice seedlings.

Molla (2001) found the transplanting 28 days old rice seedling produced more number of tillers plant^{-1} compared to 21 days old seedling.

Singh *et al.* (1999) observed that transplanting 40 and 50 days old seedling produced significantly taller plants than 60 days old seedling.

Makara *et al.* (2000) reported that transplanting 60 days old seedlings delayed the flowering of rice genotypes compared to 30 days old seedling.

2.2.3 **Yield attributes**

Working under Pakistan conditions, Jamil *et al.* (2006) reported that 42 day old rice seedling produced the highest number of fertile tillers plant^{-1} (20.93), grains panicle^{-1} (87.80) and 1000-grain weight (19.61 g) compared to 21, 28, 35 and 49 day old seedling.

Kumar *et al.* (2002) found that transplanting 20 day old seedlings exhibited higher growth parameters viz. plant height, tiller number and LAI compared to 25 and 30 day old seedlings.

Chand and Hassan (2007) working under Kashmir condition found that transplanting 20 day old seedling produced higher panicle length than 40 day old seedling.

Working under West Bengal conditions, Banik *et al.* (1997) reported that 40 day old seedling at par with 30 day seedling produced significantly higher number of effective tillers m^{-2} compared to 50 and 60 day old seedling, whereas 1000-grain weight remained unaffected by seedling age.

Increase in the transplanting age of seedlings from 30 to 50 days significantly decreased the number of effective tillers m^{-2}, panicle weight and 1000-grain weight (Paraye and Kandalkar, 1994).

In two years trial, transplanting 25, 32, 39, 46 and 53 days old seedling recorded 224, 251, 249, 260 and 250 number of panicles m^{-2} and 22.1, 21.5, 21.4, 21.6 and 22.0 g 1000-grain weight, respectively (Joseph, 1991).

Krishnan and Nayak (1997) found that transplanting 45 days old seedling recorded higher yield components and yield of rice compared to 30 days old seedlings.

Kim *et al.* (1999) working in Korea reported that transplanting 10 days old seedling produced higher number of panicle m^{-2}, whereas 40 days old seedling recorded the highest number of spikelets $panicle^{-1}$.

Increase in the age of seedlings from 25 to 45 days significantly decreased the yield components of rice (Singh and Singh, 1998).

Transplanting 28 days old seedling produced significantly higher number of panicle m^{-2} compared to 21 days old seedling (Molla, 2001).

Pattar *et al.* (2001) observed that planting of 35 or 45 days old seedling produced significantly higher grain weight and number of filled grains $panicle^{-1}$ compared to 25 days old seedlings.

Rajesh and Thamunathan (2003) noticed that transplanting 40 days old seedling recorded higher growth characters, yield attributes and yield of rice compared to 30 and 50 days old seedling.

Yield attributes viz. panicle length, number of panicle m^{-2} and panicle weight of 30 and 45 days old seedlings were significantly higher than 60 days old seedling (Singh *et al.*, 1999).

Chopra *et al.* (2002) recorded higher number of panicle $hill^{-1}$, panicle length, 1000-seed weight from transplanting 25 days old seedling compared to 35, 45, 55 and 65 days old seedling.

Guilani *et al.* (2003) obtained the highest number of grains $panicle^{-1}$ from 25 days old seedling, however, grain fertility percentages were not significantly affected by seedling age. 1000-grain weight increased with increasing seedling age from 25 to 45 days.

2.2.4 Grain and straw yield

Tahir *et al.* (2004) studied the performance of rice genotypes under varying seedling ages and reported that increase in the seedling age from 25 days to 35, 45, 55 and 65 days significantly decreased rice grain yield.

Jamil *et al.* (2006) working in Pakistan reported that 35 and 42 days old seedlings recorded higher grain yield of 3.72 and 3.74 t ha^{-1}, respectively compared to 21, 28 or 49 days old seedlings.

Garcia and Nakano (1995) working in Japan found that seedling age did not affect the grain yield of rice.

Bhuser and Adhikari (1997) reported that seedling age up to 65 days did not reduce the grain yield of rice genotypes.

Transplanting older seedlings realized lower yields in many experiments. Grain yield was higher for younger seedlings with a difference of 1.00 t ha^{-1} when seedlings of various varieties with 7 to 21 days age were transplanted (Pasuquin and Tubaba, 2008).

The results of a study conducted by Khusrul and Haque (2009) in Bangladesh revealed that 35 days old seedling of four rice varieties gave significantly higher yield than 15, 25 and 45 days old seedling.

Transplanting 20 days old seedling recorded higher grain and straw yield of rice than 40 days old seedling (Chand and Hassan, 2007).

Khakwani *et al.* (2005) reported that younger seedlings performed better in shallow waters than older seedlings.

Banik *et al.* (1997) found that 40 days old seedling gave the maximum grain yield with superiority of 21.86, 18.89 and 46.50 per cent over 30, 50 and 60 days old seedling. 40 days old seedling also recorded higher straw yield than other seedling ages.

Reddy and Reddy (1994) reported that higher grain yields of rice were obtained by transplanting 35 days old seedling compared to 45 or 60 days old seedling.

Older rice seedlings reduced rice grain yields as compared to earlier ones. The best yield was achieved with use of 28 day old seedlings (Villela and Junior, 1996).

Grain yields and yield components of rice were generally greater with transplanting 45 day old seedlings compared to 30 day old seedlings (Krishnan and Nayak, 1997).

Kumar *et al.* (1995) reported that rice grain yield was not affected by seedling age from 25 to 40 days.

Working under Bangladesh conditions, Ali *et al.* (1995) found that rice grain yield was higher in transplanting 60 and 75 day old seedlings compared to 30 and 45 day old seedlings. Gross returns, gross margin and benefit cost ratio were also highest in 75 day old seedlings.

Patel (1999) observed decrease in rice grain yield with increase in seedling age from 30 to 50 days.

Kim *et al.* (1999) working in Korea found that the milled rice yield did not vary significantly with different seedling ages viz. 10, 20, 25, 35 and 40 days.

Singh and Singh (1999) recorded the grain yields of 4.92, 4.64 and 4.22 t ha^{-1} from 25, 35 and 45 day old seedlings, respectively.

Yield and yield component in rice decreased with increasing seedling age from 25 to 45 days (Singh and Singh, 1998).

Channabasappa *et al.* (1997) found that 35 day old rice seedlings recorded higher grain yield compared to 25 and 45 day old seedlings.

In wet and dry seasons, transplanting 30 and 40 day old seedlings recorded higher rice yields and benefit cost ratio compared to 20 day old seedlings (Sanbagavalli and Kandasamy, 1998).

Transplanting 40 day old seedlings is highly productive compared to 50, 60 and 70 day old seedlings (Anita and Dasgupta, 1998).

Molla (2001) working in Philippines reported that 28 day old seedlings produced higher grain yield than 21 day old seedlings.

Transplanting 35 or 45 day old seedlings produced significantly higher grain yields when transplanted on first fortnight of August but when transplanting was delayed to 2^{nd} fortnight of August, the performance of both 35 and 45 day old seedlings was greater than that of 25 day old seedlings. In general, there was drastic reduction in yield when planting was done in first fortnight of September irrespective of seedling age (Pattar *et al.*, 2001).

Nandal *et al.* (1999) reported that grain yields of 30 and 40 day old seedlings did not differ but were significantly higher than those of 50 day old seedlings. In 30 and 40 day old seedlings net returns (Rs. 20,958 ha^{-1} and Rs. 20,433 ha^{-1}, respectively) and benefit cost ratios (Rs. 1.51 and Rs. 1.47, respectively) were significantly higher than in 50 day old seedlings.

Rajesh and Thamunathan (2003) observed that 40 day old seedlings recorded higher rice yield than 30 and 50 day old seedlings.

The maximum grain yield (4.10 t ha^{-1}) was recorded in 45 day old seedlings followed by 30 day old seedlings (4.03 t ha^{-1}). The mean maximum gross returns (Rs. 10,445 ha^{-1}) and benefit cost ratio (Rs. 0.65) were recorded by 45 day old seedlings followed by 30 day old seedlings (Rs. 10,262 ha^{-1} and Rs. 0.58, respectively) (Singh *et al.*, 1999).

Transplanting 35 day old seedlings produced higher grain yield than 55 to 65 day old seedlings (Chopra *et al.*, 2002).

Guilani *et al.* (2003) working in Iran recorded decrease in the rice grain yield by 12-16 per cent with increase in seedling age from 25-40 days.

Kumar *et al.* (2002) found that transplanting of 20 day old seedlings exhibited higher growth and yield parameters and registered 11.6 per cent higher grain yield over 30 day old seedlings.

Transplanting of 21 and 28 day old seedlings recorded significantly higher grain and straw yields, net monetary returns and benefit cost ratio than transplanting thin and lanky 14 day old seedlings.

2.3 Effect of harvesting schedule

2.3.1 Growth and yield

Surek and Neemi (1998) found that 49 days after flowering is optimum time for harvesting rice as early harvesting causes both quantitative and qualitative losses.

Pachongchit *et al.* (2008) conducted microscopic study of rice development in Thailand and reported that the maturation period of rice seeds was about 30 days after flowering.

Siebenmorgen *et al.* (1995) observed that harvesting schedule affects moisture content of grains which in turn affects per cent milled rice, per cent head rice, field yield and drying costs. Significant losses in gross income could be incurred if rice is harvested at moisture content less than 15 per cent or more than 22 per cent.

Field studies under Kashmir conditions revealed that harvesting rice 35 days after flowering recorded highest grain yield compared to 25 or 45 days after flowering (Bali *et al.*, 2002).

2.4 Temperature

In temperate environments, a major limitation to rice growth is temperature around flowering time. Rice is particularly susceptible to chilling injury immediately before heading when low night temperatures can damage developing pollen cells leading to poor fertilization of florets and low grain set.

Lee *et al.* (1987) reported that two rice cultivars viz. 'Tongil' and 'Jinheung' showed lowest filled grain ratio of 30 per cent and 70 per cent, respectively at 10 days before heading.

A daily mean temperature exceeding 26^{O}C restricted the duration of tillering period to 05 weeks after planting and duration increased even up to 08 weeks after planting with temperature decreasing from 25.8 to 22.9^{O}C (Lalitha *et al.*, 2000).

Kumar (2002) reported that under low temperature condition, a significant reduction in the rate of photosynthesis (36.68%), canopy photosynthesis (44.14%), transpiration (29.30%), stomatal conductance (76.80%) and level of photosynthetic pigments (52.51%), nitrate reduction activity (51.61%) was observed at grain filling stage. Besides, a reduction in the grain filling rate was also noticed under low temperature.

Poussin *et al.* (2003) found that cold temperatures at the onset of the dry season induced slower development rate and lower above ground biomass despite higher plant and tiller density at panicle initiation.

Slaton *et al.* (2003) working under two geographical areas viz. Crowley and Stuttgart in USA reported that average daily high and low air temperatures for the predicted optimum sowing dates were 20 and 8^{O}C in Crowley and 24 and 11^{O}C in Stuttgart.

Kotera *et al.* (2004) reported that time from emergence to heeding was largely different between winter-spring season crop grown under low temperature condition (95-106 days) and rainy season crop grown under hot conditions (73-84 days).

2.5 **Phenology**

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.

The number of days from transplanting to maximum tillering decreased with delay in transplanting date (Lee *et al.*, 1994).

Bali *et al.* (1995) observed the maturity of Jhelum, Chenab and K-39 almost at the same time when transplanted in 1st week of June.

Results of field trials conducted in Wuling mountain area of China revealed that young panicle differentiation and heading dates were delayed at later sowing dates (Xie *et al.*, 1995).

Chaudhary *et al.* (1996) found that genotypic difference in the duration of grain filling was smaller than the duration of vegetative and reproductive phases. Among 12 rice genotypes duration from sowing to 50 per cent flowering varied from 66 days in ‘Poorva’ to 111 days in ‘Surekha’ cultivars.

Song *et al.* (1996) conducted studies in Korea and reported that delayed sowing decreased the number of days from sowing to heading in two rice cultivars.

In Korea, the experiment on the effect of sowing dates (from 25th April to 10th June at 15 days interval) on rice cultivar ‘Unbongbyeo’ and ‘Milyang’ showed that the number of days from sowing to emergence and sowing to heading decreased with delayed sowing in both cultivars (Song *et al.*, 1996).

During dry seasons of West Bengal, the time to flowering decreased in successive sowings (3 dates from November to January) for IR-42, Jaya and IR-36 (Sinha and Chatterjee, 1997).

The number of days between seedling emergence and 50 per cent heading declined linearly (Gravois and Helius, 1998). Generally the number of days between seedling emergence and 50 per cent heading among modern rice cultivars emerged on the same date and varied by < 7 days (McKenzie *et al.*, 1999).

Norman *et al.* (1999) reported that the seedling date primarily influences the length of vegetative period of rice with early seeded rice requiring a greater number of days to accumulate the same number of degree days units compared with later seeded rice.

Lalitha *et al.* (2000) conducted field investigation in Hyderabad during *kharif* and *rabi* seasons and reported that during *kharif* season 03 rice varieties ‘Sambamahsue’, ‘Rajavadhu’ and ‘Tellahumsa’ attained maximum tillering stage in 32-36 DAP, whereas during *rabi* season maximum tillering stage of the varieties was attained in 55, 48 and 46 DAP, respectively.

Peng *et al.* (2000) reported that the total growth duration of rice cultivars released between 1974-1983 was 10 days shorter than those released before and after this period.

Singh and Singh (2000) from Uttranchal reported that days taken to 75 per cent heading were not affected significantly by different sowing dates (15th March, 30th March and 15th April).

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

The time taken for maturity ranged from 116.2 to 120.8 days for different sowing dates and 105-127.3 days for different cultivars (Mandal and Ghosh, 2003).

A field experiment conducted in Maharashtra by Dixit *et al.* (2004) showed that panicle initiation stage started late in early sown crop (5th and 10th June) and 50 per cent flowering was earlier in late crop (25th June). Among different hybrids, 827-35-1-1-R required more number of days from flag leaf emergence, booting stage, 50 per cent flowering and maturity stage compared to other lines.

Halder *et al.* (2004) reported that the development of panicle initiation stage among cultivars differed only by one day.

Experiments conducted at two locations viz. Crowley and St. Joseph in Louisiana showed that days from seedling emergence to 50 per cent panicle emergence decreased at both locations as planting was delayed, whereas interaction of planting date x cultivars was not significant for number of Julian days from seedling emergence to 50 per cent panicle emergence at each location (Linscombe *et al.*, 2004).

2.6 **Growing degree days (GDD)**

The results of a field trial conducted by Jand *et al.* (1994) revealed that the number of growing degree days from floral induction to physiological maturity was highest in 13th June transplanting in cultivar PR-106 and Basmati-370 and in 27th June transplanting in PR-109.

The results of twelve genotypes grown by Chaudhary *et al.* (1996) at Raipur revealed that the accumulated degree days from sowing to 50 per cent flowering were lowest for Poorva (1127) and highest for Surekha (1999) cultivars.

Norman (1999) reported that although rice cultivars may have different cumulative degree day thresholds, the number of accumulated degree day units for development to specific growth stage (Panicle differentiation and 50 per cent heading) remains relatively constant for a given cultivar.

The results of a field experiment at West Bengal revealed that the growing degree days during the periods between sowing and first leaf emergence including fourth leaf emergence and flowering increased with successive delay in sowing (Mandal and Ghosh, 2003).

At Karnal, Haryana, the crop transplanted on 30th June took 3125.9 growing degree days from transplanting to maturity. A linear reduction in GDD was observed with delay in planting (Chopra and Chopra, 2004).

At Hyderabad, Reddy *et al.* (2004) observed that the accumulated degree days for the vegetative growth stage of rice were 1074 and 1128 during *kharif* and *rabi* seasons, respectively.

2.7 Crop simulation models

Crop growth simulation models provide a means to quantify the effects of climate, soil and management on crop growth, productivity and sustainability of agricultural production. These tools can reduce the need for expensive and time consuming field experimentation as they can be used to extrapolate the results of research conducted in one season or location to other season, locations or management. The development and application of system approaches and decision support methods can help to identify strategies for optimizing resource use, increasing productivity, identifying yield gaps and reducing adverse environmental impacts.

The CERES rice model under Punjab conditions predicted phenological stages quite close to observed stages for rice cultivar 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 per cent of the observed yield (Jand *et al.,* 1994).

Dingkunn (1995) performed simulation for key sowing dates, 38 sites and 3 genotypes based on 10-33 years of weather records. The model permits the zonation of the Sahel in terms of calendared options and cultivar requirements.

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

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

Williams *et al.* (1997) used a simplified process crop model in Australia to simulate grain yield in response to sowing date, nitrogen application and water depth during early stage of pollen microspore development. The average yield response over 4 years suggested that short growth duration led to a 1.0-2.2 t ha^{-1} lower yield than long duration for all sowing dates and water depth combinations. The optimal sowing date for growth duration was 18^{th} October and delayed sowing decreased the yield of long duration type at faster rate than short duration type.

The Oryza-1 model was coupled to 35-Beta model to optimize pre-flowering phenology of irrigated rice for high yield potential in 3 Asian environments. For each environment there was an optimal pre-flowering period that produced the highest yield (Yin *et al.*, 1997).

Mahmood (1997) applied a physically based parametric model, yield to estimate the impact of fluctuating air temperature on evapo-transpiration, water requirements and the length of growth stages of the irrigated boro rice in Bangladesh. It was found that the planting date plays an important role in the boro rice phenology.

A model was developed for dry matter accumulation in rice based on sowing date, temperature and number of sunshine hours. It was suggested that the model may be valuable in studies on the effects of ecological conditions on yield formation in rice (Gao *et al.,* 1998).

The effects of climate and soil characteristics on rice yield and irrigation requirement was explored at Hyderabad through growth model ORYZA-W. The results were useful in designing and optimizing cropping strategies and irrigation systems in different agro-ecosystems (Bouman *et al.,* 1998).

A simulation model, describing temperature and photoperiod effects on leaf number, growth duration and leaf appearance rates was developed by Sie *et al.,* (1998). The model was used to identify phenological stage and cultivar specific causes of variable crop duration.

In a study, Saseendran *et al.* (1998) determined optimum transplanting dates for rice at 5 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 23^{rd} to 26^{th} week for multiple cropping in a year and from 26^{th} to 32^{nd} week for rainfed monocrop.

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).

In Punjab, 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 transplanted 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 model.

Ramasamy (2000) determined the yield potential of the standard rice cultivar cv. IR-72 throughout India by using model Oryza-1. The potential grain yield varied from 9.34 to 13.98 t ha^{-1} between 9^{O}-08´ and 31^{O}25´ N latitude and it increased with increasing latitude (9^{O}-23^{O}N) and elevation (0 to 900-masl). Optimum time of sowing for most of the locations in India was worked out to be 15^{th} June. Growth duration varied from 100 to 146 days depending on geographical location.

A simulation model for phasic development and phenology in rice was developed using the scale of physiological development time based on the eco-physiological development processes. The stage 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).

Pathak *et al.* (2003) through crop simulation modeling approach reported that in Indo-Gangetic plains, the rate of change is in potential yield trend of rice from 1985 to 2000 ranged from -0.12 to 0.05 Mg ha^{-1} per year. The decrease in radiation and increase in minimum temperature were the reasons for yield decline.

Singh *et al.* (2003) using model Oryza1-N under temperate conditions of Kashmir predicted highest grain yield at 10^{th} June transplanting of rice. 35 days old seedling predicted higher yield for early (30 May) and normal (15 June) transplanting, whereas for late (30 June) transplanting 65 days old seedling was found suitable.

In 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 panicles/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 recorded that average potential yields of 6077 kg ha^{-1} and 4217 kg ha^{-1} when rice was transplanted on 15 July and 15 August, respectively (Mahmood *et al.*, 2004).

Chapter 3

MATERIAL AND METHODS

The methods employed and materials used for conducting study entitled ‘Simulation of growth and yield of various rice varieties (*Oryza sativa* L.) as influenced by age of seedling and harvesting schedules’ are detailed in this chapter.

3.1 Experimental site

Location: The field investigation was conducted at Agronomy Farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar during *kharif* 2010 and 2011. The site is about 16 KM from Srinagar city situated at 34^{O}-05′ N latitude and 74^{O}-89′ E longitude with an altitude of 1587 meters above mean sea level.

3.2 Climate and weather conditions

Climatically the experimental site is in mid to high altitude humid temperate zone characterized by hot summers and very cold winters. The average annual precipitation is 944.6 mm (average of past 30 years) most of which is received from December to April in the form of snow and rains as a result of western disturbance mainly. The mean meteorological data recorded during the cropping seasons at Meteorological Observatory, Division of Agronomy are presented in Appendix-1 and Fig.1. It is evident from the data that mean maximum and mean minimum temperatures were $27.89^{O}C$ and $14.80^{O}C$ and $29.86^{O}C$ and $15.83^{O}C$ during cropping seasons of 2010 and 2011, respectively, whereas mean maximum and mean minimum relative humidities during 2010 were 84.80 and 59.89 per cent and during 2011 79.93 and 51.34 per cent, respectively.

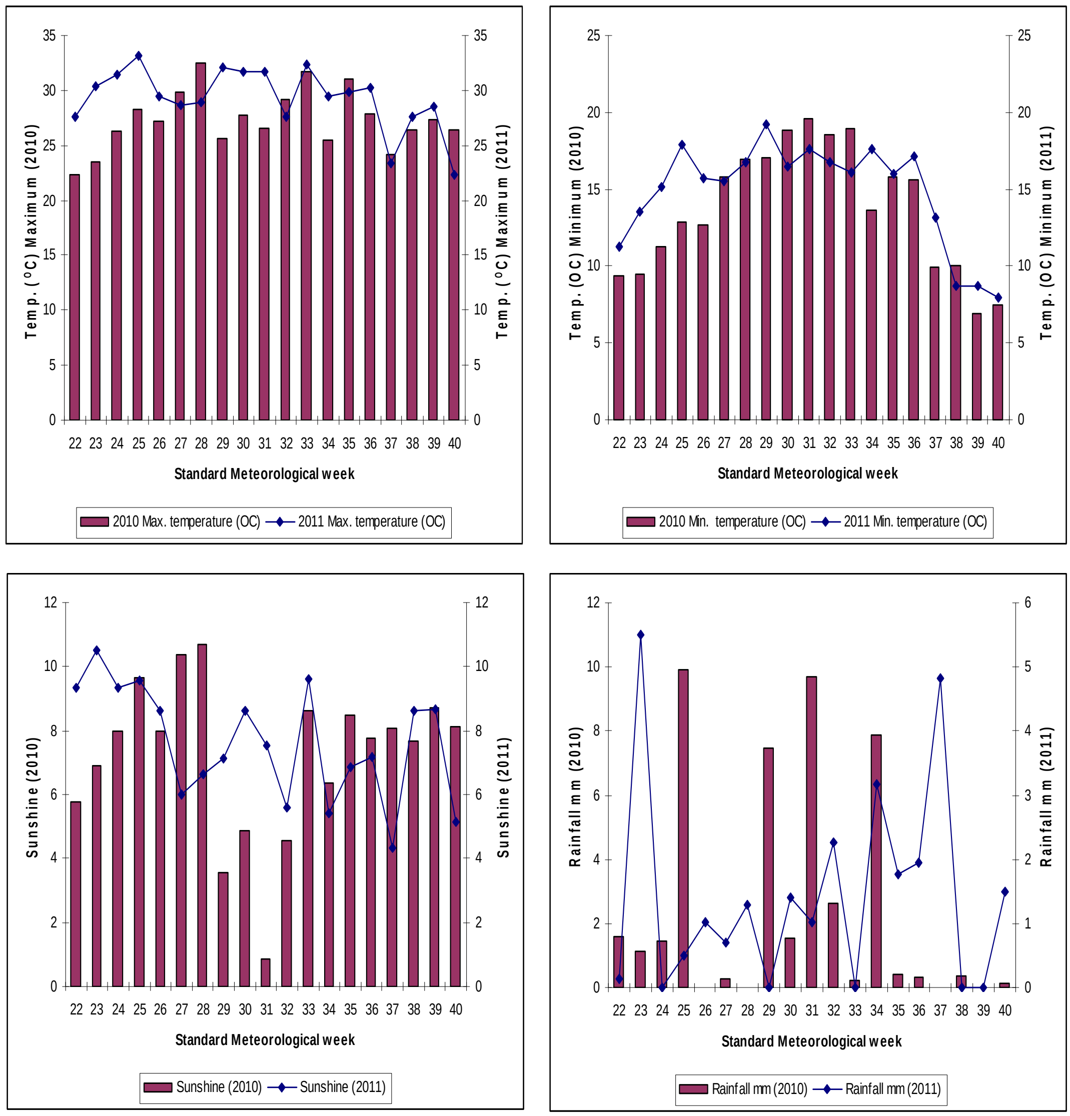


Fig. 1: The temporal change in weather parameters during the growing season of the experimentation crop

The total precipitation amounted to 34.40 and 27.06 mm and total sunshine hours were 847.70 and 917.20 during 2010 and 2011 cropping seasons, respectively.

3.3 Soil

Composite soil sample collected from 0-15 cm soil depth before the start of experiment was subjected to mechanical and chemical analysis. The results revealed that the soil was silty clay loam in texture, high in organic carbon, low in available nitrogen and medium in available phosphorus and potassium with neutral pH (Table 3.1).

3.4 Cropping history of the experimental field

The cropping history of the experimental field is given in Table-3.2. The crop was followed by brown sarson for two consecutive years.

3.5 Experimental details

The experiment comprising three factors (three rice varieties, three seedling ages and three harvesting schedules) was laid out in a split plot design with three replications as per layout plan shown in Fig.2. The details are given below:

3.5.1 Treatments

A	Variety	:	3 (main plot)
	Jhelum	:	V_1
	SKUA-403	:	V_2
	SR-1	:	V_3

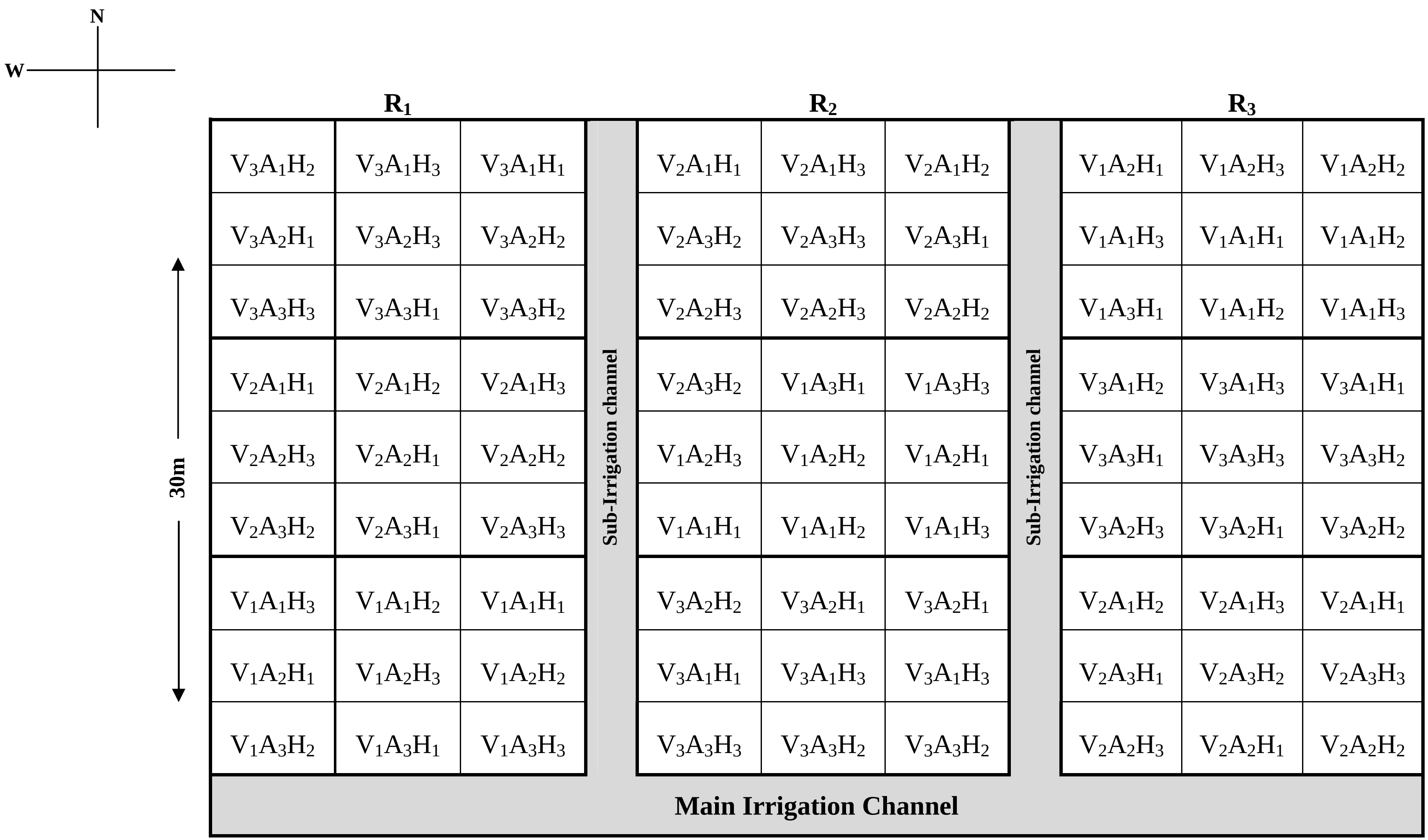


Fig. 2: Layout Plan of the Experimental Field

B	Age of seedling (Days)	:	3
	20	:	A_1
	30	:	A_2
	40	:	A_3
C	Harvesting schedule (Days after flowering)	:	3 (sub-plot)
	35	:	H_1
	42	:	H_2
	49	:	H_3
	Design	:	Split-plot
	Number of replications	:	3
	Number of treatment combinations	:	27
	Number of plots	:	81

Table 3.1: Physio-chemical properties of soil of the experimental field

Particulars		Rating	Method employed
A	**Mechanical characteristics**		
	Coarse sand (%)	1.7	International pipette method (Piper, 1966)
	Fine sand (%)	18.1	The textural class of the soil was determined from textural diagram (Black, 1965)
	Silt (%)	42.5	
	Clay (%)	37.7	
	Texture: Silty clay loam		
B	**Chemical characteristics**		
	pH	6.8	1:2.5 soil water suspension with Beckman's glass electrode pH meter (Jackson, 1973)
	Electrical conductivity (dsm^{-1}) at $25^{O}C$	0.26	Solubridge conductivity meter (Piper, 1950)
	Organic carbon (%)	0.81	Walkley and Black rapid titration method (Jackson, 1973)
	Available nitrogen (kg N ha^{-1})	368.0	Alkaline potassium per-mangonate method (Subbiah and Asija, 1956)
	Available phosphorus (kg P ha^{-1})	14.4	Extraction with 0.5 M $NaHCO_3$ (Olsen *et al.*, 1954)
	Available potassium (kg K ha^{-1})	160.0	Extraction with neutral normal ammonium acetate (Jackson, 1973)

Table 3.2: Cropping history of experimental field

Year	*Kharif*	*Rabi*
2005-2006	Rice	Oats
2006-2007	Rice	Brown sarson
2007-2008	Rice	Lentil
2008-2009	Rice	Brown sarson
2009-2010	Rice (Experimental)	Brown sarson
2010-2011	Rice (Experimental)	

3.6 Description of varieties

Jhelum

This is a semi-dwarf high yielding variety obtained from a cross between 'Jakkoku x IET-1444'. Average plant height is 117 cm. It is recommended for cultivation in lower belts (up to 1700m amsl) under irrigated and water logged agro-situations. Its yield potential is 6.5-7.0 t ha^{-1}. It matures in 125-135 days. Grains are medium bold with a good cooking quality (Table 3.3).

SKUA-403

This is a pipeline variety derived from a cross between 'Javae x K-448'. The variety has a yield potential of 8.7-9.0 t ha^{-1} with average plant height of 110 cm (Table 3.3).

Shalimar rice-1

It is a low altitude rice variety recommended for cultivation in areas above 1650 m amsl. It is derived from a cross between 'Ch-1087 x IET-1444' released in 2004. The variety matures in 138-142 days and possesses high yielding capacity of 7.0-7.5 t ha^{-1}. It is moderately resistant to blast. Average height of plant is 140 cm. Grains are short and slender (Table 3.3).

3.7 Details of field operations

The details of field operations are given in Table-3.4.

3.7.2 Land preparation

The field was disc ploughed after the harvest of brown sarson. Subsequently two ploughings were given with tiller followed by one ploughing with rotavator to obtain desirable tilth. However, during 2011 previous year's plots were dug out manually after harvesting *rabi* crop. Well decomposed FYM at the rate of 10 t ha^{-1} was applied to each plot and thoroughly incorporated in the soil. Water was let in the plots for puddling operation. Proper leveling of plots was done before transplanting of seedlings. Field was laid out into treatment beds as per the layout plan (Fig.2) making 03 replications, borders, paths and irrigation channels as per requirement.

3.7.3 Fertilizer application

Full dose of phosphorus, potassium and zinc and half dose of nitrogen @ 60, 30, 20, 120 kg ha^{-1} of P_2O_5, K_2O, Zn and N, respectively through diammonium phosphate, murate of potash, zinc sulphate and urea, respectively was applied to each plot as basal dose 1-2 hours before

Table:3.3 Genetic description of the rice varieties used

Parameter	Variety		
	Jhelum	**Shalimar Rice-1**	**SKUA-403**
Parentage	Jakkoku x IET-1444	China-1007 x IET-1444	Javae x K-448
Yield potential (t ha^{-1})	6.5-7.0	7-7.5	8.7-9.0
Panicle length (cm)	18.2	18.2	23.5 cm
1000 grain weight (g)	23.5	25.0	29.0
Average plant height (cm)	117	140	110
Days to maturity	117	121`	136

transplanting of seedlings and mixed well into the soil. Remaining half dose of nitrogen through urea was top dressed in two equal splits, one each at tillering (20 DAT) and panicle initiation (38 DAT) stage.3.7.4 **Transplanting**

Three seedlings per hill were transplanted at a spacing of 15 x 20 cm as per the schedule.

3.7.5 **Application of butachlor**

Butachlor 1.5 kg a.i @ 30 kg ha^{-1} was applied to each plot on 3^{rd} day of transplanting and water was neither let in nor drained out of the plots for about 48 hours.

Table 3.4: Calendar of field operations

Operation	Date		Remarks
	2010	**2011**	
Nursery sowing	01.05.2010	01.05.2011	-
	11.05.2010	11.05.2011	
	22.05.2010	22.05.2011	
Tractor discing	05.06.2010	05.06.2011	During 2011, the plots were dug manually
Tractorization with tiller and rotavator (3 turns)	07.06.2010	-	-do-
Layout	08.06.2010	-	Manual labour was engaged. During 2011, no layout was needed
Irrigation for puddling	09.06.2010	09.06.2011	3-5 thin film of water was maintained
Final making of bunds and irrigation channels	10.06.2010	10.06.2011	Puddling, leveling of plots, streamlining of channels and bunds was done
Uprooting of seedlings	11.06.2010	11.06.2011	Seedlings of three different ages as per treatment were uprooted from nursery and their roots were cleaned with water. The seedlings were kept submerged away from direct sun radiation.

Application of fertilizers	11.06.2010	11.06.2011	Basal dose of N, P, K and Zn fertilizers through urea, DAP, MOP and $ZnSO_4$ was applied as per package of practices to each plot.
Transplanting of seedlings	11.06.2010 12.06.2010	11.06.2011 12.06.2011	Three robust seedlings per hill of three varieties with different ages were transplanted at a spacing of 15cm x 15cm as per treatment
Application of herbicide	13.06.2010	13.06.2011	Butachlor 1.5 kg a.i @ 30 kg ha^{-1} was applied to each plot and water was neither let in nor drained out of plots for 48 hours
First hand weeding	02.07.2010	02.07.2011	Weeding cum hoeing was done manually
First top dressing of nitrogen	02.07.2010	02.07.2011	Nitrogen was top dressed through urea as per package to each plot
Second top dressing of nitrogen	20.07.2010	20.07.2011	Top dressing of nitrogen to each plot through urea was done at panicle initiation stage as per package
Irrigation and drainage	-	-	3-5 cm thin film of water was maintained. Water was withheld for 3-4 days after tillering and again at panicle initiation stage till

			hair like cracks appeared for aeration to the roots. After semi dough stage, alternate wetting and drying was done. However, water was withheld about one week before harvesting
Harvesting	-	-	Harvesting of crop was done manually as per treatment
Threshing	-	-	Threshing was done by mechanical thresher.

3.7.6 **Irrigation**

A water level of 5cm±2 was maintained in the beds throughout the vegetative phase except at tillering (20 DAT) and panicle initiation stage (38-40 DAT) when fertilizer was applied. After flowering, alternate wetting and drying was followed till dough stage.

3.7.7 **Plant protection measures**

No plant protection measures with regard to disease/ insect pest control were taken due to non-observance of any infestation.

3.7.8 **Harvesting and threshing**

The crop was harvested at 35, 42 and 49 days after flowering as per treatment leaving two crop rows from all sides of plot. The harvested crop which was allowed to sun-dry in the field for about 72 hours was piled in bundles and biological weight of each bundle (plot wise) was recorded using spring balance. Threshing was done by using mechanical thresher. After winnowing, the cleaned grain of each net plot was weighed as kg/net plot and expressed in q ha^{-1}.

3.8 Details of observations recorded

Leaving the border and penultimate rows from two sides of each plot constituted net plot. The penultimate rows were used for growth studies. They were used for destructive sampling for studying different parameters like plant dry weight at various intervals. Also six hills per plot were pegged/ tagged to record observations at various stages/ intervals.

3.8.1 Pre-harvest studies

3.8.1.1 Plant height

Plant height was taken from 06 randomly selected plants at two marked spots in the penultimate rows of each plot at 7 days interval from the day of transplanting till harvest. Height was measured from soil surface to the apex of tallest leaf during vegetative period and up to tip of panicle after panicle emergence in cm.

3.8.1.2 Tiller production

Tiller number was recorded from the date of transplanting till harvest at 7 days interval from 06 randomly selected hills at two market spots in the penultimate rows of each plot. Primary, secondary and tertiary tillers were separately counted from each hill and subsequently number was transformed to primary, secondary and tertiary tillers m^{-2}.

3.8.1.3 Leaf area index

Leaf area index was recorded from each plot at 7 days interval from the date of transplanting till 98 DAT with canopy analyser Accupar LP-80 (Decagon Devices USA).

3.8.1.4 **Dry matter production**

Plant samples were collected from penultimate row on either side of each plot at 7, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77, 84, 91 and 98 DAT and at harvest from each plot. After sun-drying for 4-5 days, the samples were oven dried at 60-65^{O}C$^{\pm 2}$ for 48 hours to a constant weight. The dry weight of samples was recorded in gram and then converted into q ha^{-1} at each interval.

3.8.1.5 **Phenology**

Number of days taken by the crop from each plot to reach mid tillering, panicle initiation, anthesis, milking, dough and maturity stage from the days after transplanting were keenly observed and recorded. Panicle initiation was determined by dissecting five main stems of plants from penultimate rows of each plot every other day after mid tillering to check for the primordial growth. When 90 per cent of the main stems showed primordial growth, it was considered as the panicle initiation stage. Anthesis was determined when 50 per cent of the panicles were present in the centre of the plot.

3.8.2 **Post harvest studies**

3.8.2.1 **Number of panicles**

Number of panicles from 06 randomly selected hills at two marked spots in the penultimate rows of each plot was counted one day before harvesting and the number was converted into panicles m^{-2}.

3.8.2.2 **Number of spikelets panicle^{-1}**

Total number of spikelets of 10 panicles selected randomly from each plot was recorded and then averaged to number of spikelets panicle^{-1}.

3.8.2.3 **Number of grains panicle^{-1}**

Number of filled grains of 10 randomly selected panicles from each plot was recorded and their average was calculated and expressed as grains panicle^{-1}.

3.8.2.4 **Sterility percentage**

This was calculated from the number of fully developed grains and sterile spikelets (unfilled) as a ratio between unfilled grains to total number of spikelets per panicle on the basis of following formula:

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

3.8.2.5 **1000 grain weight (g)**

Grain samples from each plot collected separately at threshing time were dried properly 1000-grains from each of these samples were taken and their weight was recorded in grams.

3.8.2.6 **Biological yield**

The bundle weight of each net plot was recorded 3 days after harvest and converted into q ha^{-1} to express biological yield.

3.8.2.7 **Grain yield**

The grain yield of each net plot was thoroughly cleaned and sun dried. The yield from each plot was recorded separately in kg plot^{-1} and then converted into q ha^{-1}.

3.8.2.8 **Straw yield**

The straw yield of each net plot was computed by deducting grain yield from biological yield and expressed in q ha^{-1}.

3.8.2.9 **Harvest index**

It was calculated by the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \text{ x } 100$$

3.8.2.10 **Moisture content**

Grain samples from each plot were collected separately at threshing time. Moisture content in grain was determined by moisture meter and expressed in per cent (INDOSAW digital moisture testing machine, OSAW Industrial Products Pvt. Ltd.)

3.8.2.11 **Head recovery**

The milled grain samples from each plot were taken and the whole grains + 75 per cent whole grains were counted separately. The per cent head recovery was determined as

$$\text{Head recovery (\%)} = \frac{\text{Number of whole grains} + 75\% \text{ whole grains}}{\text{Total number of grains}} \text{ x } 100$$

3.8.2.12 **Growing degree days (GDD)**

GDD was calculated for different phenophases using the formula given by Summerfield *et al.* (1992)

$$\text{GDD} = \sum_{i=1}^{n} \frac{\text{Tmax} + \text{Tmin}}{2} - \text{T base}$$

where Tmax is the maximum temperature

Tmix is the minimum temperature.

Tbase is the base temperature = ^{O}C for rice

3.9 Statistical analysis and interpretation

Analysis of variance technique as discussed by Gomez and Gomez (1984) was used to analyse the data. Analysis of the data was done by using INDOSTAT software programme.

3.10 SIMULATION STUDIES

3.10.1 CERES-Rice module description

To simulate growth and yield of rice under temperate Kashmir CERES-Rice model was used.

The CERES-Rice model simulate the growth, development and yield of a component crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil water, C and N that take place under the cropping system over time. 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. Figure-3 shows a schematic diagram of CERES-Rice module (Crop environment and resource synthesis).

The phenology component of CERES-Rice has been described elsewhere (Ritchie *et al.,* 1998). The model describes the progress through the crop life cycle (Fig.3).

Using degree day accumulation (heat sums) with a base temperature of 9^{O}C, optimal temperature of 33^{O}C and a maximum temperature 40^{O}C.

The duration of certain stages varies with cultivars and coefficients are used as inputs to describe these differences. A development phase

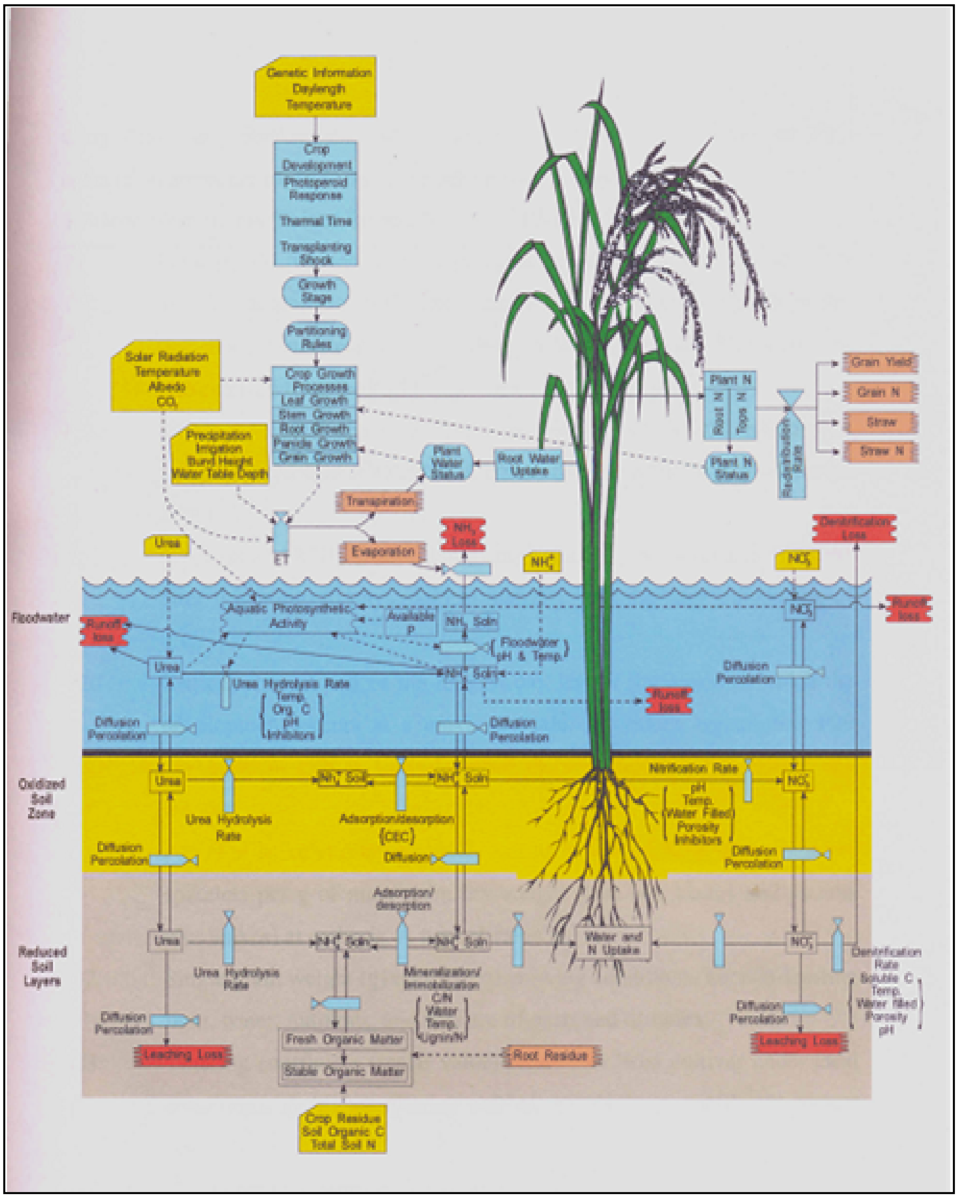


Fig.3: Schematic diagram of theCERES-Rice model

(Juvenile stage) occurs where the crop is not sensitive to photoperiod. After this stage, sensitivity to photoperiod as well as temperature determine the time to panicle initiation. Coefficients describing this sensitivity to photoperiod as well as thermal time required for key growth stages are used to define differences between cultivars. The growth stages simulated by CERES-Rice are: germination, emergence, end of Juvenile panicle initiation, 50 per cent heading, 50 per cent flowering beginning grain fill, maturity harvest. The suites of genetic coefficient used in phenology and growth simulation are shown in Table-3.5. The phenology component also simulates the effect of water or N deficit on 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 beginning of grain filling stage.

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 CO_2 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. Cultivar differences in yield components, tillering and temperature tolerance are captured by the model using a suite of coefficient specific to a cultivar.

The soil water balance model of DSSAT is a one dimensional model and computes the daily changes in soil water content by soil layer

Table-3.5: Genetic coefficient for the DSSAT CERES-Rice

$\mathbf{P_1}$	Time period (expressed as growing degree days [GDD] in ^{O}C above a base temperature of 9^{O}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
$\mathbf{P_2R}$	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in ^{O}C) for each hour increase in photoperiod above P_{20}
$\mathbf{P_5}$ **50**	(Time period in GDD in ^{O}C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with the base temperature of 9^{O}C
$\mathbf{P_{20}}$	Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate. At values higher than P_{20} development rate is slowed, hence there is delay due to longer day lengths
$\mathbf{G_1}$	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.
$\mathbf{G_2}$	Single grain weight (g) under ideal growing conditions, i.e. non-limiting light, water, nutrients and absence of pests and diseases.

G_3	Tillering coefficient (scalar value) relative to IR-64 cultivar under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.0.
G_4	Temperature tolerance coefficient. Usually 1.0 for varieties grown in normal environments. G_4 for Japonica type rice growing in a warmer environment would be 1.0 or greater. Likewise, the G_4 value for Indica type rice in very cool environments or season would be less than 1.0.

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).

3.10.2 **Evaluation of the model**

The Decision Support System for Agrotechnology 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), follow a systems approach to agronomic research. The Cropping System Model (CSM) released with DSSAT v 4.5 used in this study, represents a major departure from previously released DSSAT crop model (Jones *et al.,* 2003; Porter *et al.,* 2003).

Figure-4 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.

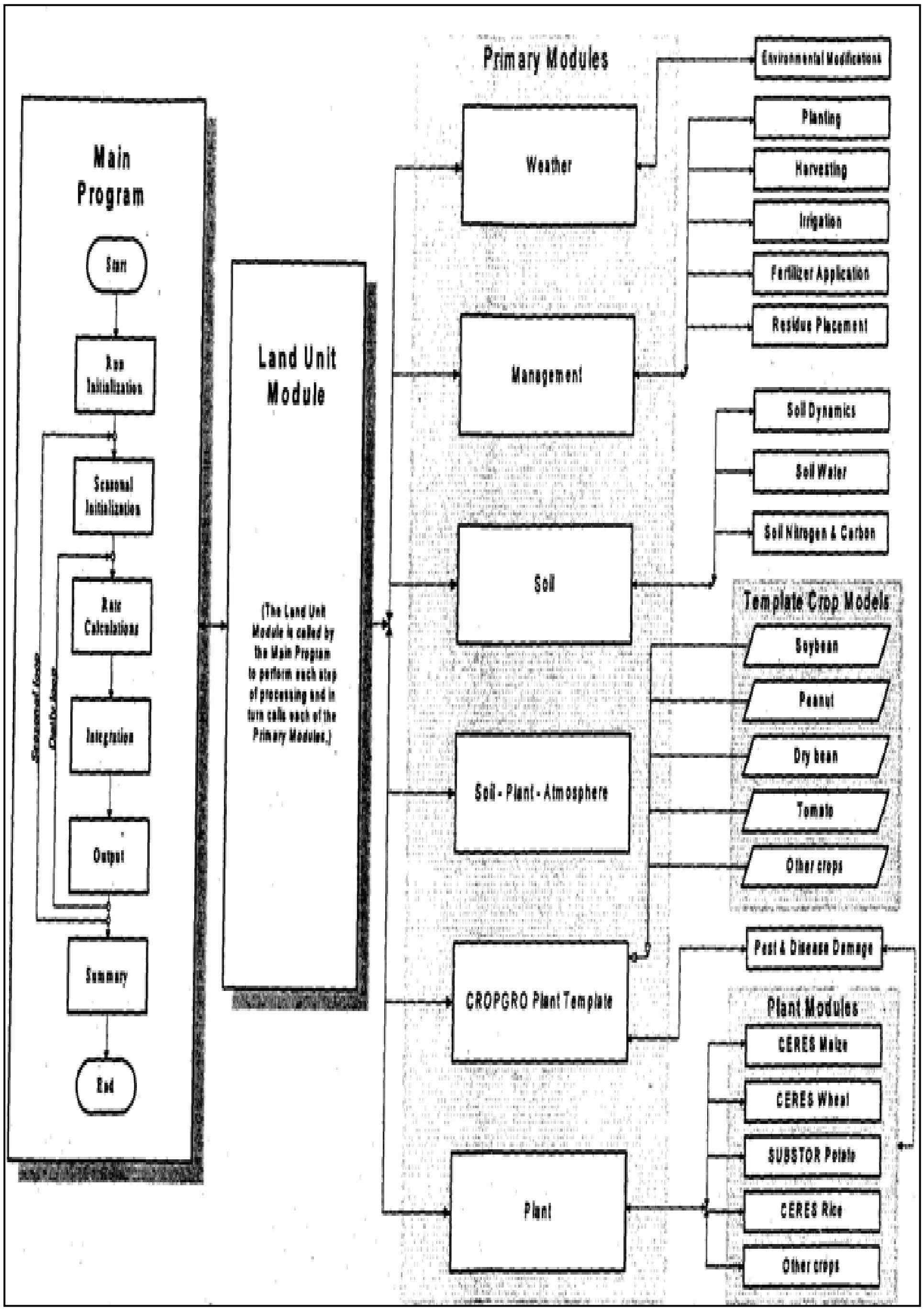


Fig.4: **Overview of the components and modular structure of DSSAT-CSM**

- 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 routine (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, milled 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.

3.10.3 **Model calibration**

Observed weather data of Shalimar Main Campus of the University for Growing Seasons 2010 and 2011 was used for calibrating the coefficients of 03 rice varieties using set of data of one treatment of field experiment (22 May sowing). The coefficients for varieties was estimated from field experiment by adjusting coefficients until close match were achieved between simulated and observed phenology and yield.

The available data included anthesis day, grain yield and above ground crop biomass, grain number per unit of ground area, individual grain weight, maximum LAI and final grain yield. Genetic coefficients (Table-3.6) of 03 varieties were estimated using crop data of all varieties i.e. phenological dates (anthesis and maturity), yield and yield components.

3.10.4 **Model validation**

To assess the accuracy of the model simulation compared with the observations, data generated from three ages of seedlings and three varieties of rice over two years (2010 and 2011) was used for validating the performance of CMS-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), straw yield and top weight (biological weight).

Sensitivity test

Sensitivity means rate of change in output variable per unit change in input variable or parameter (Pathak *et al.,* 2003). Weather parameters were selected for sensitivity analysis. These included ambient temperature (±3^{O}C) and concentration of carbon dioxide (350-700 ppm). Detailed treatment combinations are given in Table-3.6.

3.10.5 **Simulations**

Yearly data base of Kashmir (Shalimar) from 2009-10 to 2010-11 was run to simulate response of rice variety (Jhelum) found most suitable under existing agro-climatic condition out of three cultivars tested in the field experiments i.e. Jhelum, Shalimar Rice-1 and SKUA-403, different sowing dates including extrapolated dates (from 20th April to 1st June).

Growth behaviour in terms of yield, top weight, stem weight and days to anthesis LAI, single grain weight of varieties were simulated.

Table-3.6: Combination of weather parameters selected for sensitivity analysis

Treatment	Max. Temperature (^{O}C)	Min. Temperature (^{O}C)	Carbon dioxide Concentration (ppm)
C_1	Normal (Ambient)	Normal (Ambient)	Normal (330 ppm)
C_2	+3	+3	Normal
C_3	-3	-3	Normal
C_4	Normal	Normal	350
C_5	+3	+3	450
C_6	Normal	Normal	700
C_7	+3	+3	700
C_8	-3	-3	700

Chapter 4

EXPERIMENTAL FINDINGS

This chapter deals with interpretation of data generated during the course of investigation and simulation results of the model. The experimental findings are summarized in tables and figures and described in the text under appropriate heads. Only the important significant interaction effects have been interpreted.

4.1 Growth characters

4.1.1 Plant height

Data presented in Table-4.1, 4.2 and Fig.5 for the year 2010 and 2011, respectively, indicated that the plant height increased consistently up to harvest. However, the magnitude of increase was highest from 35 to 63 DAT viz. the period coinciding with late tillering to flowering.

Variety SR-1, at par with SKUA-403, recorded significantly taller plants than Jhelum at all growth periods except at 7 and 14 DAT. However, the plant height recorded with SKUA-403 and Jhelum varieties remained statistically similar at all growth periods during both years.

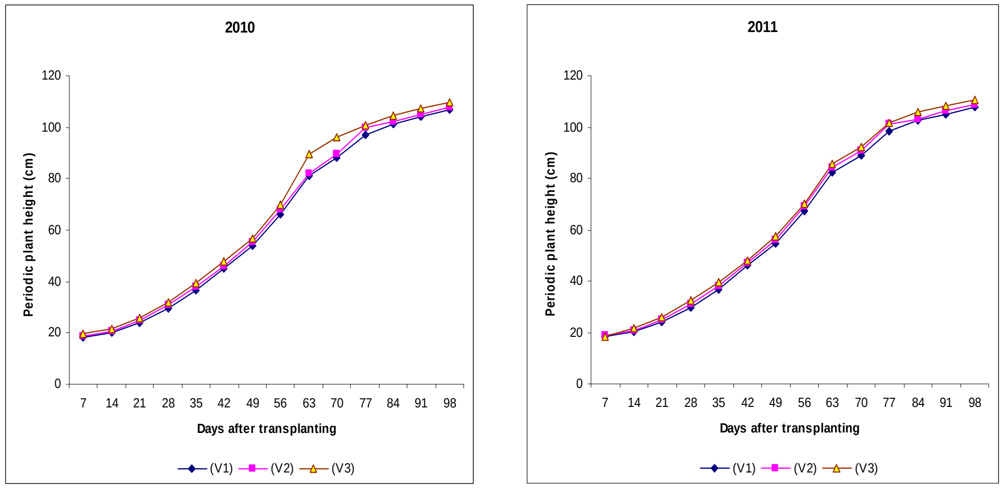
It was found that during both years of experimentation, 40 days old seedling produced significantly taller plants than both 30 and 20 days old seedling at all growth periods. However, 40 and 30 days old seedling remained at par at 35, 49, 63, 70, 90 and 98 DAT during both years. It was also inferred from the results that 30 days old seedling produced significantly taller plants at all crop growth periods than 20 days old seedling.

Table 4.1: Periodic plant height (cm) as influenced by rice cultivars, age of seedling and harvesting schedule (2010)

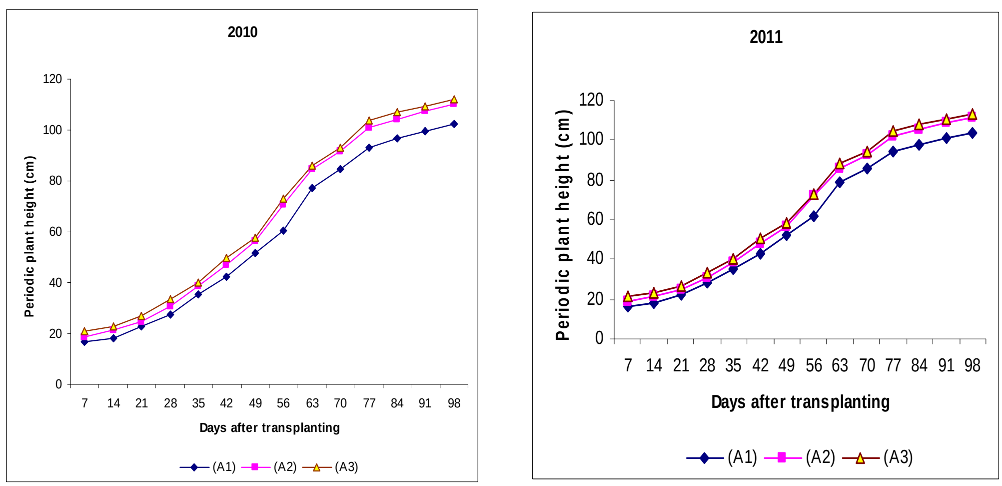
Treatment		Days after transplanting													
		7	**14**	**21**	**28**	**35**	**42**	**49**	**56**	**63**	**70**	**77**	**84**	**91**	**98**
Varieties															
Jhelum	(V_1)	18.31	20.21	23.88	29.33	36.44	45.14	53.83	66.11	81.11	88.01	97.10	101.25	104.10	106.85
SKUA-403	(V_2)	18.80	20.80	24.75	30.75	37.83	46.15	55.16	68.11	82.17	89.72	99.91	102.10	105.19	107.89
SR-1	(V_3)	19.50	21.60	25.67	32.03	39.23	47.60	56.62	69.63	89.68	96.23	100.73	104.73	107.23	109.88
SEm±		0.25	0.30	0.37	0.46	0.57	0.50	0.63	0.70	0.87	1.06	0.93	1.05	0.99	1.00
CD ($p \leq 0.05$)		NS	NS	1.12	1.38	1.72	1.47	1.89	2.10	2.53	3.12	2.79	3.15	2.98	3.01
Age of seedling (Days)															
20	(A_1)	16.68	18.36	22.64	27.64	35.16	42.18	51.75	60.43	77.43	84.43	93.18	96.88	99.74	102.44
30	(A_2)	18.81	21.24	24.80	30.78	38.52	46.93	56.10	70.53	84.42	91.42	100.92	104.32	107.52	110.22
40	(A_3)	21.12	23.01	26.86	33.59	39.82	49.58	57.76	72.89	86.11	93.11	103.64	106.88	109.26	111.96
SEm±		0.25	0.30	0.37	0.46	0.57	0.50	0.63	0.70	0.87	1.06	0.93	1.05	0.99	1.00
CD ($p \leq 0.05$)		0.74	0.89	1.12	1.38	1.72	1.49	1.89	2.10	2.53	3.18	2.79	3.15	2.98	3.01
Harvesting schedule (Days after flowering)															
35	(H_1)	18.83	20.83	24.68	30.54	37.84	46.12	55.16	67.71	82.41	89.41	99.20	102.45	105.35	108.05
42	(H_2)	18.94	20.94	24.95	30.73	37.91	46.34	55.36	67.93	82.63	89.63	99.32	102.75	105.45	108.15
49	(H_3)	18.84	20.84	24.67	30.74	37.75	46.23	55.08	68.21	82.92	89.92	99.22	102.88	105.72	108.42
SEm±		1.03	0.28	0.35	0.43	0.54	0.47	0.59	0.66	0.82	1.00	0.88	0.99	0.93	0.94
CD ($p \leq 0.05$)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.2: Periodic plant height (cm) as influenced by rice cultivars, age of seedling and harvesting schedule (2011)

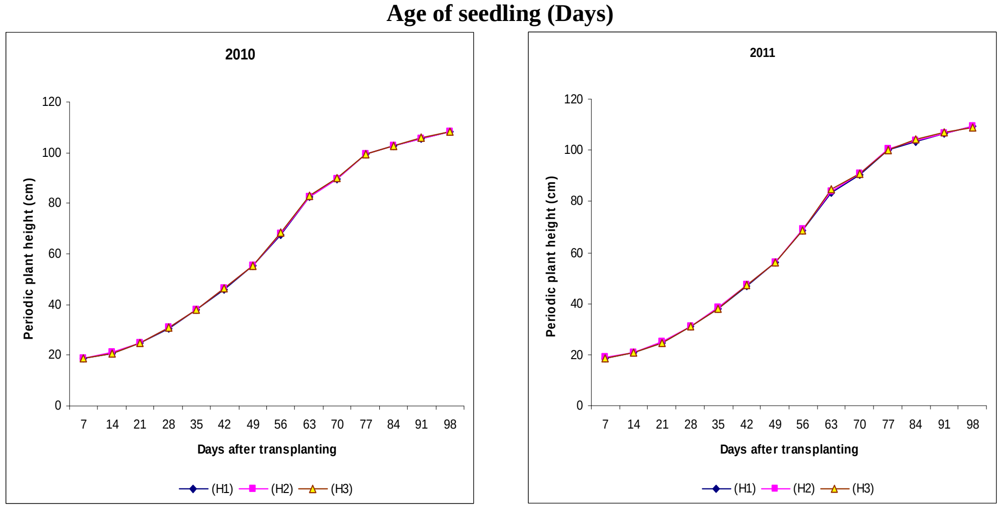
Treatment		Days after transplanting													
		7	**14**	**21**	**28**	**35**	**42**	**49**	**56**	**63**	**70**	**77**	**84**	**91**	**98**
Varieties															
Jhelum	(V_1)	18.24	20.24	23.91	29.63	36.84	45.93	54.73	67.10	82.12	89.01	98.19	102.37	105.13	107.70
SKUA-403	(V_2)	18.71	20.83	24.81	30.95	38.19	47.00	56.04	69.10	84.23	90.72	100.96	103.27	106.23	108.74
SR-1	(V_3)	18.42	21.65	25.74	32.32	39.65	48.20	57.50	70.14	85.72	92.23	101.77	105.86	108.29	110.72
SEm±		0.26	0.29	0.39	0.47	0.54	0.57	0.65	0.73	0.84	0.99	1.04	0.88	0.99	1.00
CD ($p \leq 0.05$)		NS	NS	1.18	1.41	1.62	1.69	1.94	2.18	2.50	2.98	3.10	2.62	2.97	2.89
Age of seedling (Days)															
20	(A_1)	16.61	18.40	22.71	27.96	35.56	42.98	52.65	61.72	78.45	85.43	94.22	98.00	100.80	103.29
30	(A_2)	18.73	21.26	24.87	31.10	38.88	47.86	57.00	71.85	85.46	92.44	101.96	105.34	108.48	111.06
40	(A_3)	21.03	23.06	26.88	33.84	40.24	50.29	58.62	72.77	88.17	94.09	104.74	108.16	110.37	112.81
SEm±		0.26	0.29	0.39	0.47	0.54	0.57	0.65	0.73	0.84	0.99	1.04	0.88	0.99	1.00
CD ($p \leq 0.05$)		0.78	0.87	1.18	1.41	1.62	1.69	1.94	2.18	2.50	2.98	3.10	2.62	2.97	2.89
Harvesting schedule (Days after flowering)															
35	(H_1)	18.75	20.87	24.75	30.87	38.22	46.93	56.06	68.70	83.43	90.41	100.25	103.54	106.37	109.22
42	(H_2)	18.87	20.99	25.02	31.03	38.31	47.15	56.18	68.90	83.66	90.64	100.37	103.81	106.42	109.27
49	(H_3)	18.75	20.86	24.69	31.00	38.15	47.05	56.03	68.74	84.99	90.91	100.30	104.15	106.86	108.67
SEm±		0.24	0.27	0.36	0.44	0.51	0.54	0.61	0.69	0.79	0.93	0.98	0.83	0.93	0.94
CD ($p \leq 0.05$)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS



Varieties



Age of seedling (Days)



Harvesting schedule (Days after flowering)

Fig.5: Periodic plant height (cm) as influenced by rice cultivars, age of seedling and harvesting schedule (2010 and 2011)

The results, further, indicated that harvesting of crop at 35, 42 and 49 days after flowering (DAF) did not cause any significant variation in the plant height at any crop growth period during both the years.

4.1.2 **Leaf area index**

Data presented in Table-4.3, 4.4 and Fig.6 revealed that the leaf area index, a vital photosynthetic character, increased up to 63 DAT (anthesis), thereafter decreased gradually up to harvest irrespective of treatments.

Data revealed that except at 7, 14 and 21 DAT, leaf area index recorded with variety SR-1 was significantly higher than Jhelum at all crop growth periods during both the years. However, SKUA-403 remained at par with SR-1 at all growth periods. Further, during 2010 SKUA-403 recorded significantly higher values of LAI at 28, 35 and 42 DAT over Jhelum but at later growth periods both SR-1 and Jhelum were statistically similar. Similar trend was observed for LAI of all the three varieties during 2011.

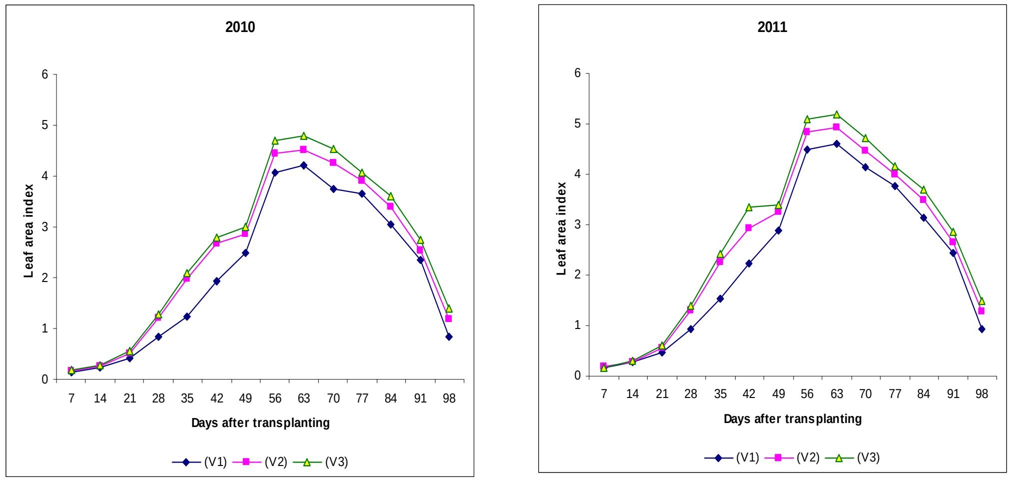
It was found that 40 days old seedling recorded significantly higher leaf area index than 20 days old seedling up to 84 DAT and at 91 and 98 DAT LAI recorded with 40 and 20 days old seedling remained statistically similar. Further, LAI recorded with 40 days old seedling was at par with 30 days old seedling from 7 to 98 DAT except at 91 DAT. It was also noticed that except at 7-21 and 84 DAT, LAI recorded with 30 days old seedling was significantly higher than 20 days old seedling during both the years.

Table 4.3: Leaf area index as influenced by rice cultivars, age of seedling and harvesting schedule (2010)

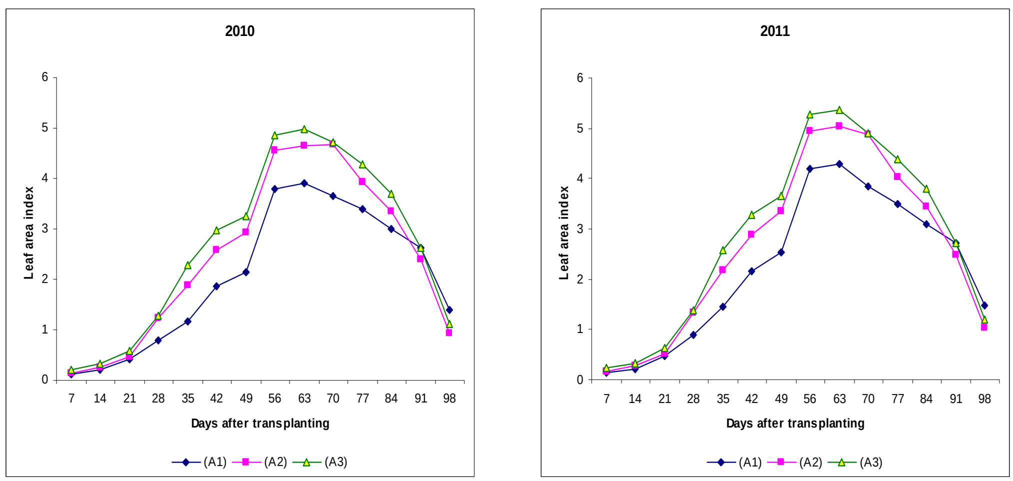
Treatment		Days after transplanting													
		7	**14**	**21**	**28**	**35**	**42**	**49**	**56**	**63**	**70**	**77**	**84**	**91**	**98**
Varieties															
Jhelum	(V_1)	0.15	0.24	0.42	0.83	1.24	1.94	2.48	4.08	4.20	3.74	3.66	3.04	2.34	0.84
SKUA-403	(V_2)	0.16	0.26	0.51	1.20	1.97	2.67	2.86	4.44	4.52	4.26	3.91	3.39	2.54	1.19
SR-1	(V_3)	0.18	0.29	0.55	1.29	2.10	2.80	3.00	4.69	4.79	4.53	4.06	3.60	2.75	1.40
SEm±		0.03	0.04	0.05	0.10	0.15	0.20	0.32	0.19	0.13	0.16	0.17	0.13	0.08	0.12
CD ($p \leq 0.05$)		NS	NS	NS	0.30	0.45	0.61	0.67	0.57	0.38	0.47	0.51	0.39	0.25	0.36
Age of seedling (Days)															
20	(A_1)	0.12	0.21	0.42	0.80	1.16	1.86	2.14	3.79	3.90	3.64	3.40	3.00	2.62	1.40
30	(A_2)	0.15	0.26	0.47	1.23	1.88	2.58	2.94	4.55	4.64	4.68	3.94	3.34	2.39	0.92
40	(A_3)	0.22	0.32	0.59	1.29	2.27	2.97	3.26	4.87	4.97	4.71	4.29	3.69	2.62	1.11
SEm±		0.03	0.04	0.05	0.10	0.45	0.20	0.32	0.19	0.13	0.16	0.17	0.13	0.08	0.12
CD ($p \leq 0.05$)		0.10	0.11	0.14	0.30	0.45	0.61	0.67	0.57	0.38	0.47	0.51	0.39	0.23	0.36
Harvesting schedule (Days after flowering)															
35	(H_1)	0.16	0.25	0.50	1.05	1.75	2.44	2.73	4.38	4.52	4.18	3.86	3.34	2.66	1.14
42	(H_2)	0.16	0.26	0.48	1.09	1.76	2.52	2.75	4.47	4.48	4.24	3.94	3.41	2.54	1.17
49	(H_3)	0.17	0.28	0.50	1.17	1.79	2.45	2.86	4.36	4.51	4.31	3.83	3.28	2.49	1.12
SEm±		0.028	0.037	0.047	0.09	0.14	0.19	0.30	0.18	0.12	0.15	0.16	0.12	0.07	0.11
CD ($p \leq 0.05$)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.4: Leaf area index as influenced by rice cultivars, age of seedling and harvesting schedule (2011)

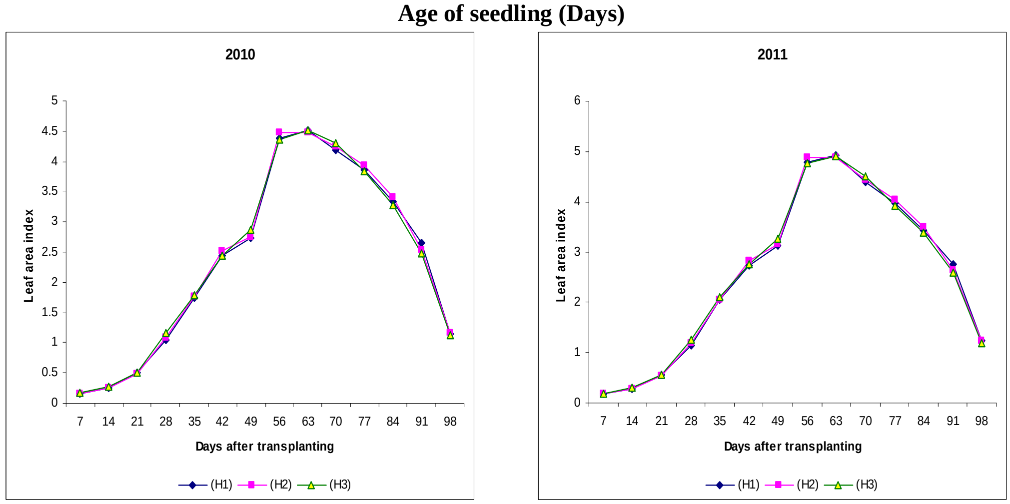
Treatment		Days after transplanting													
		7	**14**	**21**	**28**	**35**	**42**	**49**	**56**	**63**	**70**	**77**	**84**	**91**	**98**
Varieties															
Jhelum	(V_1)	0.17	0.27	0.47	0.93	1.54	2.24	2.88	4.48	4.60	4.14	3.76	3.14	2.44	0.94
SKUA-403	(V_2)	0.18	0.28	0.56	1.30	2.25	2.92	3.26	4.84	4.92	4.46	4.01	3.49	2.64	1.27
SR-1	(V_3)	0.17	0.31	0.60	1.39	2.42	3.35	3.40	5.09	5.19	4.73	4.16	3.70	2.85	1.48
SEm±		0.03	0.04	0.05	0.10	0.16	0.27	0.29	0.20	0.16	0.15	0.11	0.13	0.08	0.12
CD ($p \leq 0.05$)		NS	NS	NS	0.29	0.48	0.51	0.57	0.59	0.48	0.44	0.31	0.39	0.24	0.35
Age of seedling (Days)															
20	(A_1)	0.14	0.22	0.47	0.90	1.46	2.16	2.54	4.19	4.30	3.84	3.50	3.10	2.72	1.48
30	(A_2)	0.17	0.29	0.52	1.33	2.18	2.88	3.34	4.95	5.04	4.88	4.04	3.44	2.48	1.02
40	(A_3)	0.24	0.33	0.64	1.39	2.57	3.27	3.66	5.27	5.37	4.91	4.39	3.79	2.73	1.19
SEm±		0.03	0.04	0.05	0.10	0.15	0.17	0.12	0.20	0.16	0.15	0.11	0.13	0.08	0.12
CD ($p \leq 0.05$)		0.10	0.11	0.14	0.29	0.45	0.51	0.57	0.59	0.48	0.44	0.31	0.39	0.24	0.35
Harvesting schedule (Days after flowering)															
35	(H_1)	0.18	0.27	0.55	1.15	2.05	2.74	3.13	4.78	4.92	4.38	3.96	3.44	2.76	1.24
42	(H_2)	0.18	0.28	0.53	1.19	2.06	2.82	3.15	4.87	4.87	4.44	4.04	3.51	2.64	1.23
49	(H_3)	0.19	0.31	0.56	1.27	2.09	2.75	3.26	4.76	4.91	4.51	3.93	3.38	2.59	1.20
SEm±		0.028	0.037	0.047	0.09	0.14	0.16	0.11	0.19	0.15	0.14	0.10	0.12	0.07	0.11
CD ($p \leq 0.05$)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS



Varieties



Age of seedling (Days)



Harvesting schedule (Days after flowering)

Fig.6: **Leaf area index as influenced by rice cultivars, age of seedling and harvesting schedule (2010 and 2011)**

Harvesting of crop at 35, 42 or 49 days after flowering could not produce any significant variation in LAI during both the years of investigation.

4.1.3 Periodic tiller production m^{-2}

During both 2010 and 2011, there was a non-significant different in tiller production m^{-2} in all the three varieties up to 14 days after transplanting after which tiller production m^{-2} increased consistently up to 49 days after transplanting. After this period all the three varieties showed a decrease in tiller production m^{-2}.

As far the varietal difference is concerned, significantly highest tiller production m^{-2} was observed in Jhelum at all intervals followed by SR-1, during both the years (Table 4.5, 4.6 and Fig. 7).

It was observed that during both the years 40 days old seedlings had significantly higher tiller production m^{-2} as compared to 30 day old seedlings which in turn had significantly higher tiller production m^{-2} than 20 days old seedlings at all growth periods.

The data further reveals that harvesting the crop at 35, 42 and 49 days after flowering did not cause any significant variation in the periodic tiller production m^{-2} during both the years.

4.1.4 Dry matter production

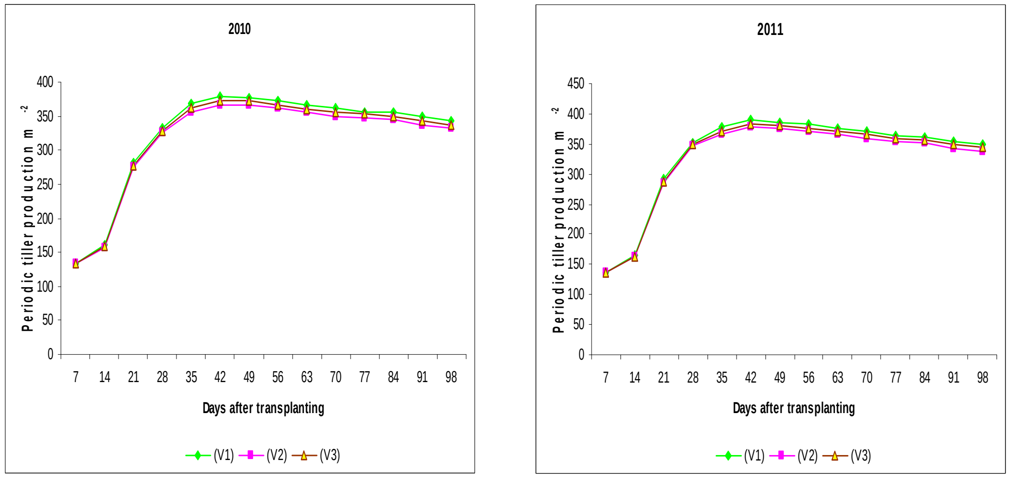
Dry matter production varied significantly among rice cultivars during both years (Table-4.7, 4.8 and Fig. 8). At 7 and 14 DAT, dry matter produced by the rice cultivars was at par with one another. However, at 21 and 28 DAT variety Jhelum which was at par with SR-1 accumulated significantly higher dry matter than SKUA-403, whereas

Table 4.5: Periodic tiller production m^{-2} as influenced by rice cultivars, age of seedling and harvesting schedule (2010)

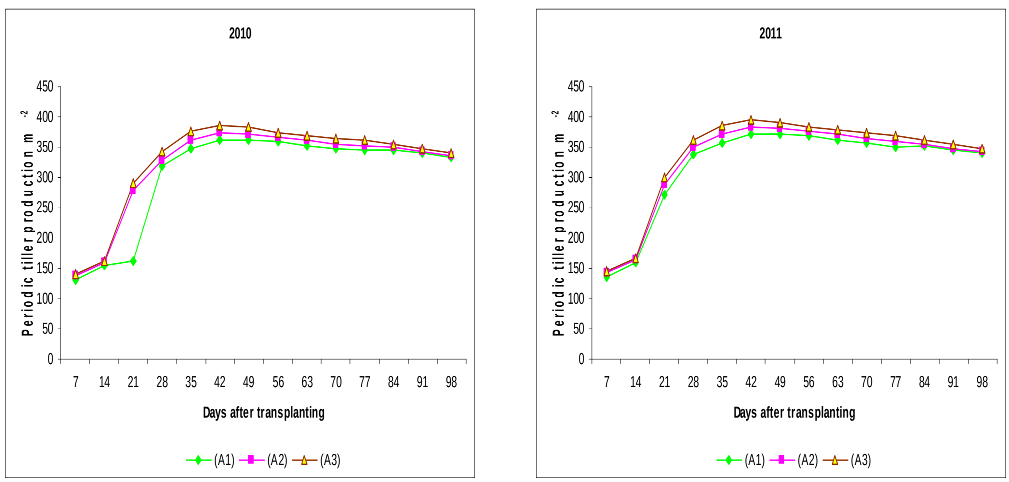
Treatment		Days after transplanting													
		7	14	21	28	35	42	49	56	63	70	77	84	91	98
Varieties															
Jhelum	(V_1)	133.4	160.1	282.4	332.2	367.4	379.6	376.4	371.6	365.9	361.7	354.5	356.5	349.4	343.2
SKUA-403	(V_2)	133.3	157.5	275.6	326.5	355.1	367.1	366.1	361.1	355.4	349.9	347.2	344.2	337.3	331.3
SR-1	(V_3)	133.2	158.9	278.3	329.1	362.1	373.2	371.5	366.3	360.8	355.1	353.2	350.2	343.1	337.1
SEm±		0.58	0.63	0.71	0.75	1.40	1.30	1.64	1.56	1.62	1.56	1.52	1.25	1.32	1.14
CD ($p \leq 0.05$)		NS	NS	2.13	2.25	4.19	3.90	4.90	4.67	4.85	4.68	4.72	3.74	3.95	3.40
Age of seedling (Days)															
20	(A_1)	131.4	155.5	162.6	319.5	347.1	362.1	361.1	359.1	352.4	346.9	344.2	345.4	339.5	333.5
30	(A_2)	138.2	159.9	278.3	329.1	362.1	373.2	371.5	366.3	360.8	355.2	352.8	349.9	342.7	336.5
40	(A_3)	140.3	161.1	289.4	342.2	375.4	384.6	383.4	373.6	368.9	364.6	362.4	355.6	347.6	341.6
SEm±		0.58	0.63	0.71	0.75	1.40	1.30	1.64	1.56	1.62	1.56	1.58	1.25	1.32	1.14
CD ($p \leq 0.05$)		1.75	1.89	2.13	2.25	4.19	3.90	4.90	4.67	4.85	4.88	4.72	3.74	3.95	3.40
Harvesting schedule (Days after flowering)															
35	(H_1)	133.4	158.6	277.8	328.9	360.8	372.6	371.8	365.0	360.8	355.8	354.0	350.6	340.2	336.9
42	(H_2)	133.2	158.8	278.9	329.6	361.7	371.9	372.9	366.3	362.0	356.9	352.9	351.0	339.1	337.4
49	(H_3)	133.2	159.1	279.6	329.3	362.1	375.4	369.3	367.7	359.3	354.0	352.5	349.3	340.5	337.3
SEm±		0.55	0.60	0.68	0.71	1.33	1.24	1.56	1.49	1.54	1.49	1.50	1.19	1.26	1.09
CD ($p \leq 0.05$)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.6: Periodic tiller production m^{-2} as influenced by rice cultivars, age of seedling and harvesting schedule (2011)

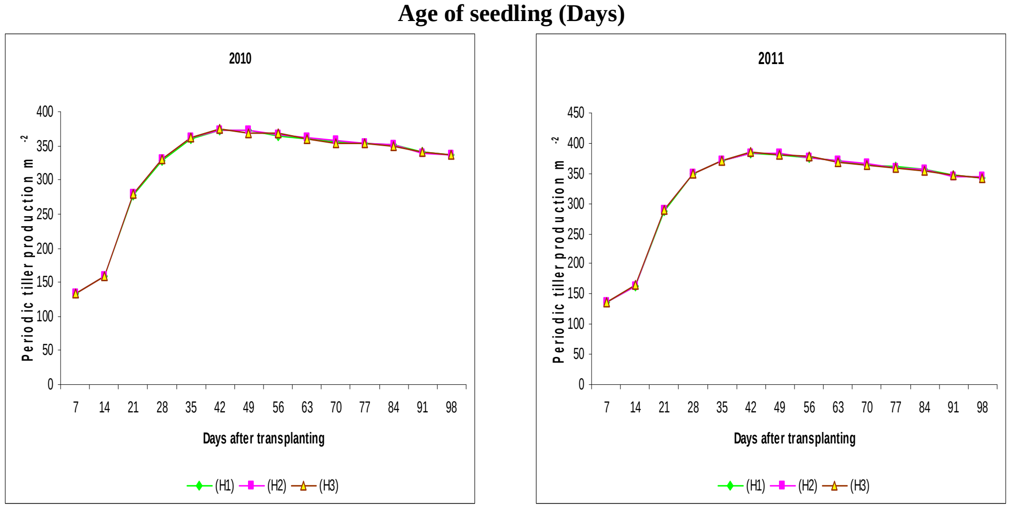
Treatment		Days after transplanting													
		7	14	21	28	35	42	49	56	63	70	77	84	91	98
Varieties															
Jhelum	(V_1)	137.2	165.9	292.6	352.1	377.4	389.8	386.1	381.8	376.2	371.9	365.0	362.1	355.1	349.0
SKUA-403	(V_2)	137.4	162.5	285.3	346.5	365.2	377.0	376.2	371.0	365.4	359.1	353.1	350.7	343.2	337.0
SR-1	(V_3)	137.3	163.1	288.4	349.2	372.0	383.1	381.7	376.2	370.5	365.7	359.3	356.1	349.5	343.6
SEm±		0.57	0.65	0.74	0.82	1.50	1.29	1.30	1.52	1.64	1.58	1.50	1.24	1.27	1.08
CD ($p \leq 0.05$)		NS	NS	2.20	2.45	4.50	3.87	3.90	4.55	4.92	4.72	4.50	3.70	3.80	3.22
Age of seedling (Days)															
20	(A_1)	135.2	160.1	272.3	339.1	357.4	372.0	371.6	369.9	362.8	357.4	350.0	351.6	345.4	339.4
30	(A_2)	142.4	164.5	288.6	349.5	372.2	383.0	381.0	376.0	370.3	365.0	358.6	355.9	348.8	342.6
40	(A_3)	144.3	166.9	299.4	362.2	385.0	394.9	391.4	383.1	379.0	374.3	368.8	361.4	353.6	347.6
SEm±		0.57	0.65	0.74	0.82	1.50	1.29	1.30	1.52	1.64	1.58	1.50	1.24	1.27	1.08
CD ($p \leq 0.05$)		1.70	1.93	2.20	2.43	4.50	3.87	3.90	4.55	4.92	4.72	4.50	3.70	3.80	3.22
Harvesting schedule (Days after flowering)															
35	(H_1)	137.2	163.8	287.6	348.3	370.8	382.8	381.4	375.3	370.3	365.0	360.5	356.0	346.5	342.4
42	(H_2)	137.4	163.6	288.9	349.9	371.8	382.7	382.9	376.6	372.0	366.8	358.5	357.6	345.0	343.9
49	(H_3)	137.3	164.1	289.8	349.6	372.0	384.4	379.7	377.1	369.8	364.9	358.4	355.3	346.3	343.3
SEm±		1.54	0.62	0.70	0.78	1.43	1.23	1.24	1.45	1.56	1.50	1.43	1.18	1.21	1.03
CD ($p \leq 0.05$)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS



Varieties



Age of seedling (Days)



Harvesting schedule (Days after flowering)

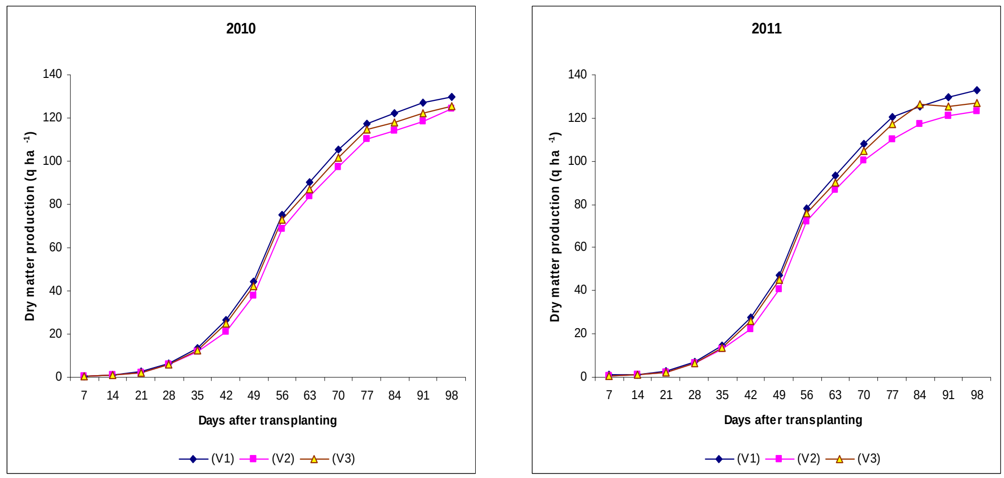
Fig.7: Periodic tiller production m^{-2} as influenced by rice cultivars, age of seedling and harvesting schedule (2010 and 2011)

Table 4.7: Periodic dry matter production (q ha^{-1}) as influenced by rice cultivars, age of seedling and harvesting schedule (2010)

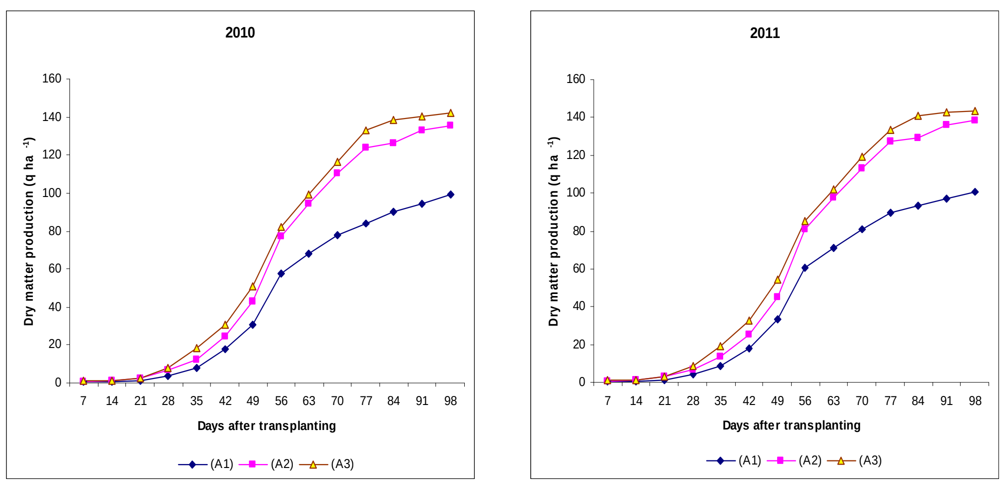
Treatment		Days after transplanting													
		7	**14**	**21**	**28**	**35**	**42**	**49**	**56**	**63**	**70**	**77**	**84**	**91**	**98**
Varieties															
Jhelum	(V_1)	0.73	0.97	2.47	6.54	13.68	26.52	44.32	75.32	90.48	105.30	117.22	122.34	126.89	129.89
SKUA-403	(V_2)	0.78	0.90	2.10	5.88	12.10	21.17	37.90	68.82	83.88	97.34	110.10	114.22	118.40	124.37
SR-1	(V_3)	0.75	0.94	2.29	6.20	12.59	25.07	41.98	73.06	87.14	101.87	114.34	118.10	122.37	125.40
SEm±		0.026	0.04	0.13	0.20	0.27	0.23	0.59	0.75	0.83	0.91	0.89	1.03	1.29	1.31
CD ($p \leq 0.05$)		NS	NS	0.38	0.59	0.81	0.69	1.78	2.24	2.48	2.72	2.66	3.10	3.87	3.94
Age of seedling (Days)															
20	(A_1)	0.42	0.48	1.22	3.92	7.92	17.63	30.52	57.32	67.90	77.70	84.23	90.10	94.18	99.18
30	(A_2)	0.82	0.96	2.69	6.45	12.27	24.24	42.69	77.49	94.40	110.13	124.11	126.22	133.13	135.35
40	(A_3)	1.02	1.37	2.75	8.25	18.18	30.89	50.99	82.39	99.20	116.68	133.32	138.34	140.35	142.13
SEm±		0.026	0.04	0.13	0.20	0.27	0.23	0.59	0.75	0.83	0.91	0.89	1.03	1.29	1.31
CD ($p \leq 0.05$)		0.08	0.12	0.38	0.59	0.81	0.69	1.78	2.24	2.48	2.72	2.66	3.10	3.387	3.94
Harvesting schedule (Days after flowering)															
35	(H_1)	0.74	0.90	2.34	6.15	12.60	24.00	41.10	71.80	86.65	101.13	113.50	121.87	122.10	125.22
42	(H_2)	0.76	0.96	2.30	6.20	13.11	24.42	41.60	72.74	87.43	102.07	114.14	121.20	122.12	125.18
49	(H_3)	0.76	0.95	2.22	6.27	12.66	24.34	41.50	72.66	87.42	101.31	114.02	121.59	122.44	126.26
SEm±		0.024	0.037	0.12	0.18	0.25	0.21	0.56	0.70	0.78	0.86	0.84	0.97	1.22	1.24
CD ($p \leq 0.05$)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.8: Periodic dry matter production (q ha^{-1}) as influenced by rice cultivars, age of seedling and harvesting schedule (2011)

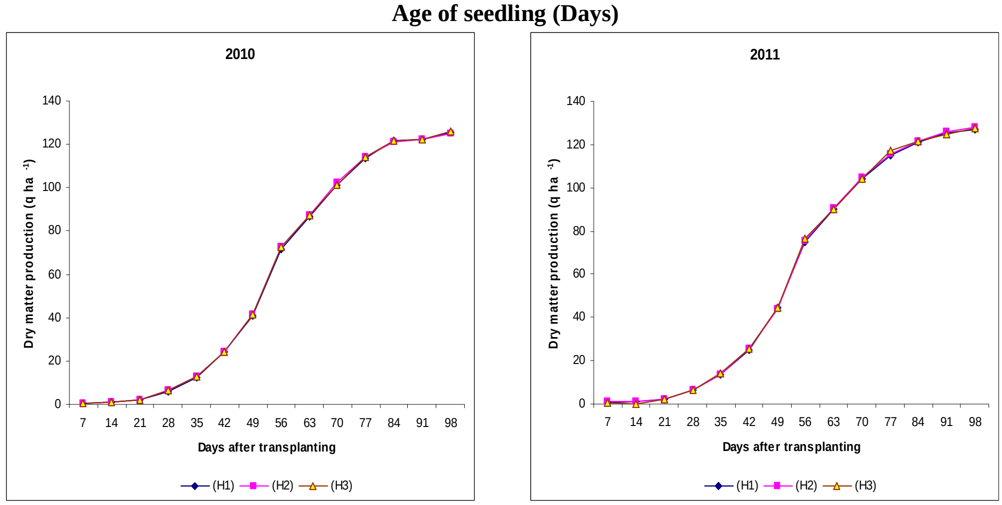
Treatment		Days after transplanting													
		7	**14**	**21**	**28**	**35**	**42**	**49**	**56**	**63**	**70**	**77**	**84**	**91**	**98**
Varieties															
Jhelum	(V_1)	0.83	1.01	2.57	6.94	14.70	27.78	47.20	78.40	93.60	108.20	120.42	125.12	129.64	132.80
SKUA-403	(V_2)	0.81	0.93	2.15	6.30	12.80	22.10	40.70	71.90	86.94	100.14	110.15	117.32	121.20	123.01
SR-1	(V_3)	0.78	0.98	2.44	6.62	13.64	26.17	44.78	76.20	90.24	104.67	117.20	126.19	125.17	127.00
SEm±		0.026	0.046	0.14	0.20	0.25	0.31	0.61	0.73	0.84	0.94	0.97	1.08	1.30	1.33
CD ($p \leq 0.05$)		NS	NS	0.41	0.61	0.75	0.93	1.82	2.20	2.52	2.82	2.90	3.25	3.91	3.98
Age of seedling (Days)															
20	(A_1)	0.46	0.55	1.37	4.32	8.90	18.15	33.20	60.40	71.05	80.90	89.33	93.20	97.10	101.00
30	(A_2)	0.86	0.99	2.79	6.85	13.29	25.32	45.19	80.65	97.50	112.83	127.21	129.32	136.03	138.20
40	(A_3)	1.10	1.38	3.00	8.68	18.95	32.58	54.29	85.45	102.23	119.28	133.33	141.11	142.88	143.61
SEm±		0.026	0.046	0.14	0.20	0.25	0.31	0.61	0.73	0.84	0.94	0.97	1.08	1.30	1.33
CD ($p \leq 0.05$)		0.08	0.14	0.41	0.61	0.75	0.93	1.82	2.20	2.52	2..82	2.90	3.25	3.87	3.98
Harvesting schedule (Days after flowering)															
35	(H_1)	0.80	0.99	2.39	6.60	13.60	25.20	44.30	74.87	90.10	104.20	114.90	120.84	125.08	127.20
42	(H_2)	0.82	0.97	2.36	6.58	13.54	25.40	44.14	75.21	90.80	104.60	115.60	121.49	125.90	128.10
49	(H_3)	0.80	0.26	2.41	6.68	14.00	25.45	44.24	76.42	89.88	104.21	117.27	121.30	125.03	127.51
SEm±		0.025	0.044	0.13	0.19	0.23	0.29	0.57	0.69	0.79	0.89	0.91	1.02	1.23	1.25
CD ($p \leq 0.05$)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS



Varieties



Age of seedling (Days)



Harvesting schedule (Days after flowering)

Fig.8: **Periodic dry matter production (q ha^{-1}) as influenced by rice cultivars, age of seedling and harvesting schedule (2010 and 2011)**

from 35 to 98 DAT Jhelum recorded significantly higher dry matter than both SKUA-403 and SR-1. Further, SR-1 recorded significantly higher dry matter than SKUA-403 at various growth periods during 2010 and 2011.

It was found that 40 days old seedlings accumulated significantly more dry matter than 30 and 20 days old seedling at all crop growth periods from 7 to 98 DAT during both years. Further, it was noticed that 30 days old seedling also recorded significantly higher dry matter accumulation than 20 days old seedling at all growth periods during both years.

The crop harvested at 35, 42 or 49 days after flowering could not cause any significant variation in the dry matter accumulation at any crop growth period during both years of study.

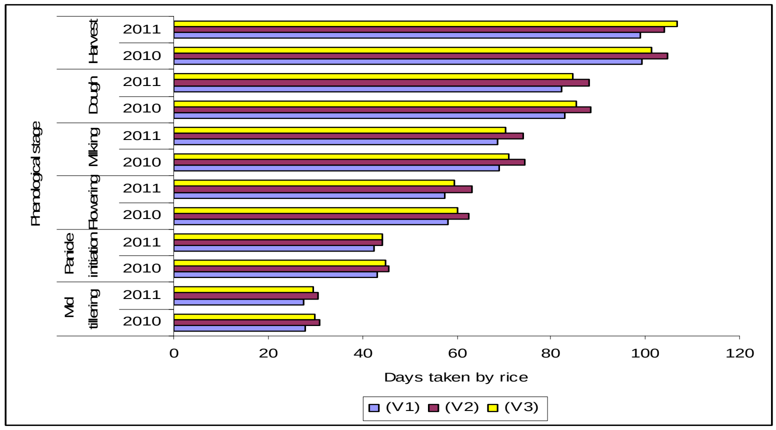
4.2 Phenology

Table-4.9 and Fig. 9 indicated that different phenological stages of rice viz. mid tillering, panicle initiation, anthesis, milking, dough and maturity varied significantly due to the effect of various treatments.

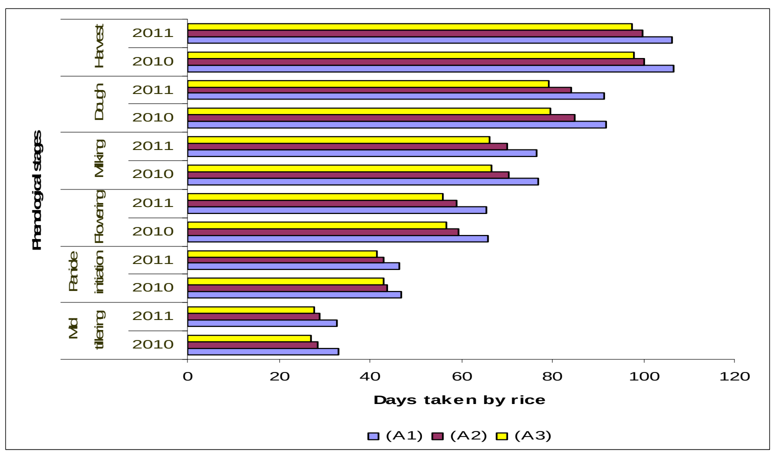
Varieties behaved differentially to the number of days taken to reach various phenological stages. Variety Jhelum, at par with SR-1, took significantly lowest number of days to reach mid tillering (28.01 and 27.70), panicle initiation (43.16 and 42.64), anthesis (58.09 and 57.60), milking (69.10 and 68.70), dough (82.78 and 82.34) and maturity (99.25 and 98.84) stages from the day of transplanting during 2010 and 2011, respectively, whereas SKUA-403 took significantly highest number of days to reach these phenological stages.

Table 4.9: Days taken by rice varieties to reach different phenological stages during 2010 and 2011

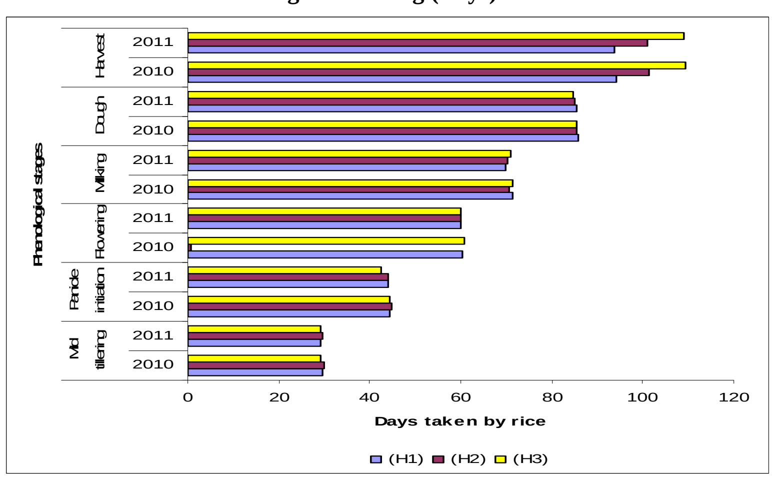
Treatment		Mid tillering		Panicle initiation		Flowering		Milking		Dough		Harvest	
		2010	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Varieties													
Jhelum	(V_1)	28.01	27.70	43.16	42.64	58.09	57.60	69.10	68.70	82.78	82.34	99.25	98.84
SKUA-403	(V_3)	30.96	30.62	45.66	44.14	62.54	63.13	74.41	74.01	88.42	88.01	104.54	100.13
SR-1	(V_2)	29.85	29.42	44.91	44.20	60.04	59.63	70.88	70.46	85.22	84.78	101.15	160.74
SEm±		0.62	0.61	0.72	0.51	0.80	0.91	0.86	0.87	0.93	0.98	1.06	1.10
CD ($p \leq 0.05$)		1.87	1.82	2.12	1.52	2.38	2.70	2.54	2.58	2.74	2.91	3.12	3.24
Age of seedling (Days)													
20	(A_1)	33.12	32.88	46.83	46.41	65.81	65.42	77.10	76.71	91.93	91.51	106.83	106.42
30	(A_2)	28.51	29.12	43.73	43.19	59.25	58.87	70.56	70.15	84.79	84.28	100.25	99.83
40	(A_3)	27.18	27.74	43.16	41.38	56.61	56.07	66.72	66.31	79.70	79.24	97.86	97.46
SEm±		0.62	0.61	0.72	0.51	0.80	0.91	0.86	0.87	0.93	0..98	1.06	1.10
CD ($p \leq 0.05$)		1.87	1.82	2.12	1.52	2.38	2.70	2.54	2.58	2.74	2.91	3.12	3.24
Harvesting schedule (Days after flowering)													
35	(H_1)	29.56	29.10	44.55	44.10	60.51	60.11	71.47	70.03	85.70	85.31	94.35	93.94
42	(H_2)	29.90	29.54	44.69	44.19	0.59	60.17	70.50	70.07	85.41	85.00	101.33	100.91
49	(H_3)	29.36	29.10	44.49	42.69	60.57	60.08	71.42	71.07	85.31	84.82	109.26	108.86
SEm±		0.59	0.58	0.68	0.49	0.76	0.87	0.82	0.83	0.89	0.93	1.01	1.05
CD ($p \leq 0.05$)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	2.99	3.10



Varieties



Age of seedling (Days)



Harvesting schedule (Days after flowering)

Fig.9: Days taken to various phenological stages during 2010 and 2011.

The results also revealed that 40 days old seedling took significantly lowest number of days to reach mid tillering (27.18 and 27.74), panicle initiation (43.16 and 41.28), anthesis (56.61 and 56.07), milking (66.72 and 66.31), dough (79.70 and 79.24) and maturity (97.86 and 97.46) stages during 2010 and 2011, respectively. Highest number of days to reach different phenological stages was taken by 20 days old seedling.

Harvesting of crop at 35, 42 or 49 days after flowering could not cause any significant variation in the days taken to reach different phenological stages during both the years.

4.3 YIELD CONTRIBUTING CHARACTERS

4.3.1 Effective tiller/m^2

Data pertaining presented in Table-4.10 showed that variety Jhelum and SR-1 which were at par with one another produced significantly more effective tillers/m^2 than SKUA-403 during both the years of experimentation. SR-1 also recorded significantly more panicles m^{-2} than SKUA-403 during 2011 but was at par during 2010.

The results also revealed that 40 days old seedling produced significantly higher number of effective tillers/m^2 than 30 and 20 days old seedling during both the years of study. 30 days old seedling also recorded significantly higher number of effective tillers than 20 days seedling during both years.

Data further inferred that the crop harvested at 35 days after flowering recorded significantly higher number of effective tillers than the crop harvested at 49 days after flowering but was at par with harvested at

Table 4.10: Yield contributing characters as influenced by rice cultivars, age of seedling and harvesting schedule

Treatment		Effective tillers/m^2		Spikelets/ panicle		Grains/panicle		1000-seed weight (g)	
		2010	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Varieties									
Jhelum	(V_1)	324.1	327.4	95.7	96.8	79.2	81.1	24.4	24.4
SKUA-403	(V_2)	318.4	321.2	96.4	97.0	75.2	77.6	24.8	24.9
SR-1	(V_3)	322.1	326.9	97.2	98.5	79.0	81.0	24.4	24.5
SEm±		1.60	1.78	1.37	1.49	1.14	1.07	0.11	0.14
CD ($p \leq 0.05$)		4.80	5.32	NS	NS	3.41	3.21	0.34	0.31
Age of seedling (Days)									
20	(A_1)	294.6	296.6	90.8	91.8	63.4	65.5	24.3	24.4
30	(A_2)	325.4	329.6	94.7	95.8	81.3	83.4	24.4	24.5
40	(A_3)	344.3	349.0	103.8	104.6	88.8	90.9	24.9	24.9
SEm±		1.60	1.78	1.37	1.49	1.14	1.07	0.11	0.14
CD ($p \leq 0.05$)		4.80	5.32	4.12	4.47	3.41	3.21	0.34	0.41
Harvesting schedule (Days after flowering)									
35	(H_1)	324.7	327.8	97.1	98.0	79.8	81.9	24.6	24.7
42	(H_2)	320.4	323.9	96.5	97.6	78.6	80.6	24.5	24.6
49	(H_3)	319.5	323.8	95.7	96.7	78.1	80.3	24.5	24.5
SEm±		1.52	1.69	1.30	1.41	1.08	1.02	0.10	0.13
CD ($p \leq 0.05$)		4.60	5.10	NS	NS	NS	NS	NS	NS

42 days after flowering. However, effective tillers were statistically similar in the crop harvested after 42 or 49 days after flowering during both the years.

4.3.2 **Spikelets/panicle**

Spikelets/panicle were not influenced by the rice cultivars during both the years (Table-4.10). As such they showed a non-significant variation among one another.

Data revealed that 40 days old seedling produced significantly more number of spikelets/panicle than 30 and 20 days old seedling during both the years of investigation. However, 30 and 20 days old seedling remained statistically similar with respect to number of spikelets/panicle.

The results further, revealed that harvesting schedule did not affect the number of spikelets/panicle during both the years of investigation.

4.3.3 **Grains/panicle**

Rice variety Jhelum and SR-1 being at par with one another produced significantly more number of grains/panicle. Jhelum and SR-1 with a superiority of 5.31 and 5.05 per cent and 4.51 and 4.38 per cent over SKUA-403 during 2010 and 2011, respectively (Table-4.10).

Data also inferred that 40 days old seedling produced significantly higher number of grains/panicle with a superiority of 9.22 and 40.06 per cent and 8.99 and 38.77 per cent over 30 and 20 days old seedling during 2010 and 2011, respectively. 30 days old seedling also recorded significantly higher number of grains/panicle with an increase of 28.23 and 27.32 per cent over 20 days seedling during 2010 and 2011, respectively.

Harvesting schedule did not cause any significant effect on the number of grains/panicle during both the years of study.

4.3.4 **1000-seed weight**

Data showed that the 1000-seed weight remained significantly higher in SKUA-403 compared to Jhelum and SR-1 during both the years. Both Jhelum and SR-1 remained at par with one another in respect of 1000-seed weight (Table-4.10). Transplanting 40 days old seedling improved the 1000-seed weight over 30 and 20 days old seedling during 2010 whereas during 2011, 40 days old seedling at par with 30 days old seedling recorded significantly higher 1000-seed weight than 20 days old seedling. Harvesting of the crop at 35, 42 or 49 DAT did not cause any significant variation in 1000-seed weight during both the years.

4.3.5 **Sterility per cent**

Among different varieties during 2010 and 2011 the sterility was in the order of SKUA-403 (28.19 and 25.00) > SR-1 (23.03 and 21.60) > Jhelum (20.03 and 19.35), respectively during 2010 and 2011. Table-4.11 indicated that SKUA-403 had significantly higher sterility percentage than other varieties. All the varieties differed significantly with one another with lowest sterility percentage recorded in Jhelum.

The result inferred that 20 days old seedling produced significantly highest per cent of unfilled spikelets viz. 43.21 and 40.15 per cent during 2010 and 2011, respectively. Both 40 and 30 days old seedling produced statistically similar per cent of unfilled spikelets with significantly lowest in 30 days seedling viz., 16.48 and 14.98 during 2010 and 2011, respectively.

Table 4.11: Sterility (%) in rice cultivars as affected by seedling age and harvesting schedule

Treatment		Sterility (%)	
		2010	2011
Varieties			
Jhelum	(V_1)	20.03	19.35
SKUA-403	(V_2)	28.19	25.00
SR-1	(V_3)	23.03	21.60
SEm±		0.39	0.51
CD ($p \leq 0.05$)		1.17	1.52
Age of seedlings			
(Days)			
20	(A_1)	43.21	40.15
30	(A_2)	16.48	14.98
40	(A_3)	16.89	15.07
SEm±		0.39	0.51
CD ($p \leq 0.05$)		1.17	1.52
Harvesting schedule			
(Days after flowering)			
35	(H_1)	21.67	19.65
42	(H_2)	22.77	21.09
49	(H_3)	22.69	20.42
SEm±		0.38	0.46
CD ($p \leq 0.05$)		NS	NS

The data also revealed that harvesting the crop at 35, 42 or 49 days after flowering did not affect the percentage of unfilled spikelets during both the years of study.

In general, the sterility per cent remained marginally lower during 2011 compared to 2010 irrespective of treatments.

4.4 **YIELD STUDIES**

4.4.1 **Grain yield**

Grain yield of rice varied significantly due to the effect of different treatments (Table-4.12 and Fig.10).

Rice variety Jhelum at par with SR-1 recorded significantly higher grain yield than SKUA-403 with the increase of 3.97 and 4.93 per cent during 2010 and 2011, respectively. SR-1 recorded significantly higher grain yield than SKUA-403 during 2011.

As far as the age of seedling is concerned the data indicates that transplanting 40 days old seedling produced significantly higher grain yield over 30 and 20 days old seedling during both years of experimentation, whereas, 30 days old seedling also recorded significantly higher grain yield than 20 days old seedling. 40 days old seedling recorded 19.68 and 73.56 per cent higher yield during 2010 and 16.39 and 67.92 per cent during 2011 over 30 and 20 days old seedling, respectively.

Further, the crop harvested at 35 days after flowering recorded significantly higher grain yield over crop harvested at 42 and 49 days after flowering during both the years. Further, harvested crop at 42 days after flowering also produced significantly higher grain yield than at 49 days after flowering. The increase in the grain yield recorded with the crop harvested at 35 days after flowering over 42 and 49 DAF was to the tune of 4.18 and 9.27 per cent during 2010 and 3.73 and 10.13 per cent during 2011, respectively.

4.4.2 Straw yield

Among varieties, SKUA-403 recorded significantly higher straw yield than SR-1 and Jhelum during both the years (Table-4.12 and Fig.10). However, straw yields obtained with SR-1 and Jhelum were statistically similar and significantly lower than SKUA-403.

Transplanting 40 days old seedling produced significantly higher straw yield than 30 and 20 days old seedling during both years. However, 30 days old seedling also recorded significantly higher straw yield than 20 days old seedling during both the years.

It was found that during 2010, crop harvested at 49 days after flowering produced significantly higher straw yield than harvested at 35 days after flowering but was at par with crop harvested at 42 days after flowering. However, during 2011, crop harvested at 49 DAF recorded significantly higher straw yield than the crop harvested at 42 and 35 DAF. Further, 42 DAF harvested crop also registered significantly higher straw yield than harvested at 35 DAF during 2011.

4.4.3 Biological yield

Data presented in Table-4.12 and Fig.10 shows that the rice cultivars did not differ significantly as far as their effect on the biological yield of rice was concerned during both years of study. There was a non-significant difference in the biological yield of all the varieties viz. Jhelum, SKUA-403 and SR-1 during both the years.

Transplanting 40 days old seedling produced significantly higher biological yield than 30 and 20 days old seedling during 2010 and 2011. 30 days old seedling also recorded significantly higher biological yield than 20 days old seedling during both years.

Crop harvested at 35, 42 and 49 days after flowering did not cause any significant variation in the biological yield during both years of investigation as the treatment difference in the data was found to vary non-significant.

4.4.4 **Harvest index**

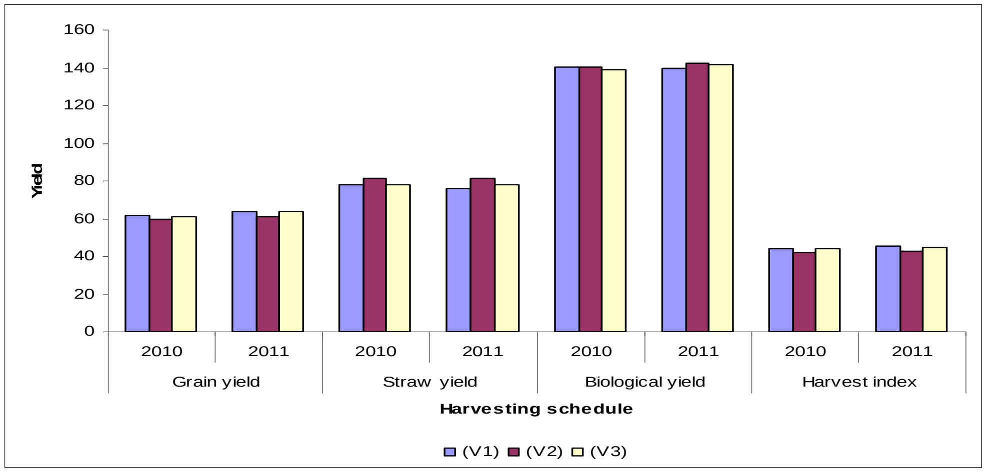
Harvest index which denotes the capacity of metabolites to translocate from source to sink varied significantly from 44.11 to 42.26 per cent during 2010 and 45.66 to 42.72 per cent during 2011 among different rice cultivars. Jhelum and SR-1 which were at par with one another recorded significantly higher harvest index than SKUA-403 during both years of 2010 and 2011 (Table-4.12 and Fig.10).

The data indicated that during 2010, 40 days old seedling significantly improved harvest index over 30 and 20 days old seedlings and 30 days old seedling in turn recorded significantly higher harvest index than 20 days old seedling. However, during 2011, 40 and 30 days old seedling which were at par with each other significantly improved harvest index over 20 days old seedling. The HI recorded with 40 and 30 day old seedlings were 45.56 and 45.31 per cent, respectively.

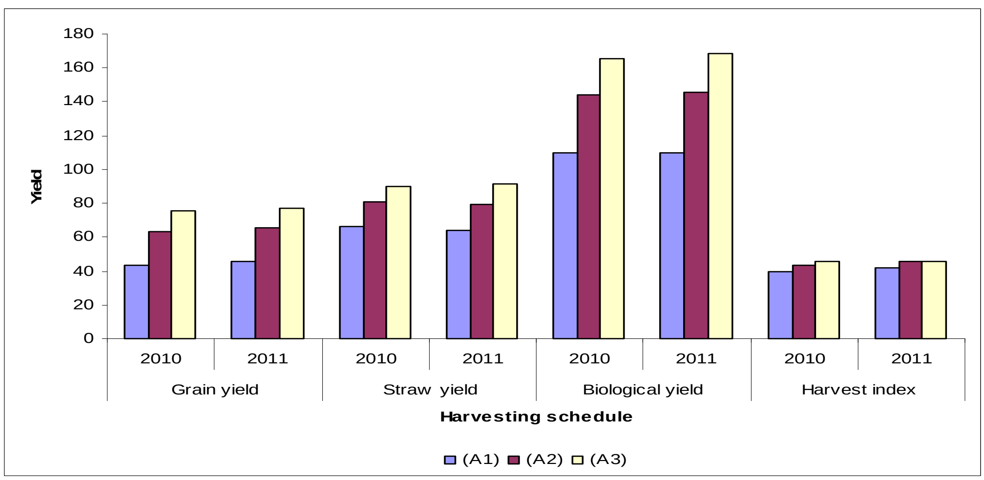
As regards the effect of harvesting schedule, it was found that the crop harvested at 35 DAF recorded 45.11 and 46.53 per cent harvest index during 2010 and 2011, respectively which was significantly higher than the crop harvested at 42 and 49 DAF (43.63 and 41.64% in 2010 and

Table 4.12: Grain, straw and biological yield (q ha^{-1}) and harvest index (%) as influenced by rice cultivars, age of seedling and harvesting schedule

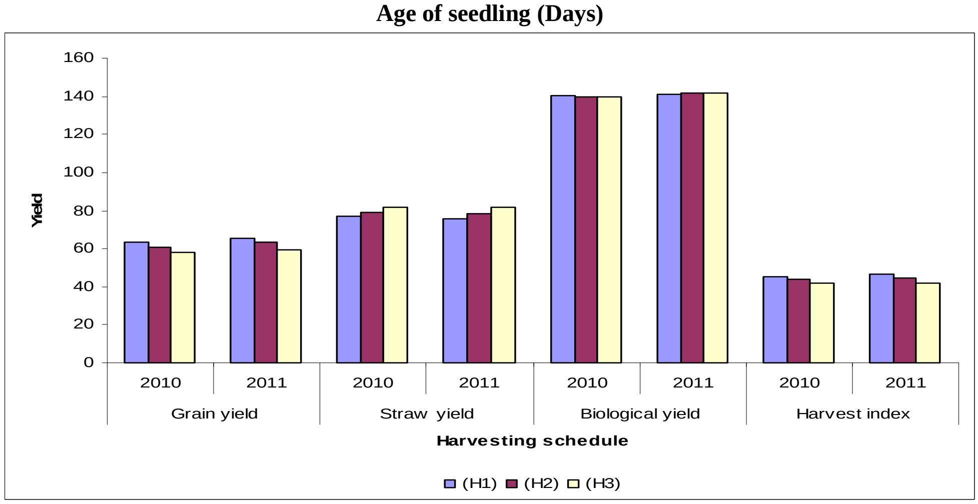
Treatment		Grain yield		Straw yield		Biological yield		Harvest index	
		2010	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Varieties									
Jhelum	(V_1)	61.79	63.82	78.26	75.95	140.05	139.77	44.11	45.66
SKUA-403	(V_2)	59.43	60.82	81.19	81.52	140.62	142.34	42.26	42.72
SR-1	(V_3)	61.32	63.81	77.92	78.15	139.24	141.96	44.03	44.94
SEm±		0.65	0.71	0.95	0.81	1.69	1.72	0.38	0.41
CD ($p \leq 0.05$)		1.95	2.12	2.82	3.40	NS	NS	1.12	1.24
Age of seedling (Days)									
20	(A_1)	43.61	45.67	66.53	64.01	110.14	109.88	39.59	41.56
30	(A_2)	63.24	65.97	80.98	79.61	144.22	145.58	43.84	45.31
40	(A_3)	75.69	76.82	89.85	91.78	165.54	168.60	45.72	45.56
SEm±		0.65	0.71	0.95	0.81	1.69	1.72	0.38	0.41
CD ($p \leq 0.05$)		1.95	2.12	2.82	2.40	4.78	4.87	1.12	1.24
Harvesting schedule (Days after flowering)									
35	(H_1)	63.49	65.62	77.23	75.38	140.72	141.00	45.11	46.53
42	(H_2)	60.94	63.26	78.73	78.30	139.67	141.56	43.63	44.68
49	(H_3)	58.10	59.58	81.41	81.93	139.51	141.51	41.64	42.10
SEm±		0.62	0.67	0.90	0.77	1.59	1.69	0.36	0.40
CD ($p \leq 0.05$)		1.87	2.03	2.70	2.30	NS	NS	1.07	1.19



Varieties



Age of seedling (Days)



Harvesting schedule (Days after flowering)

Fig.10: Grain yield, straw yield, biological yield (q ha^{-1}) and harvest index (%) as influenced by age of seedling and harvesting schedule

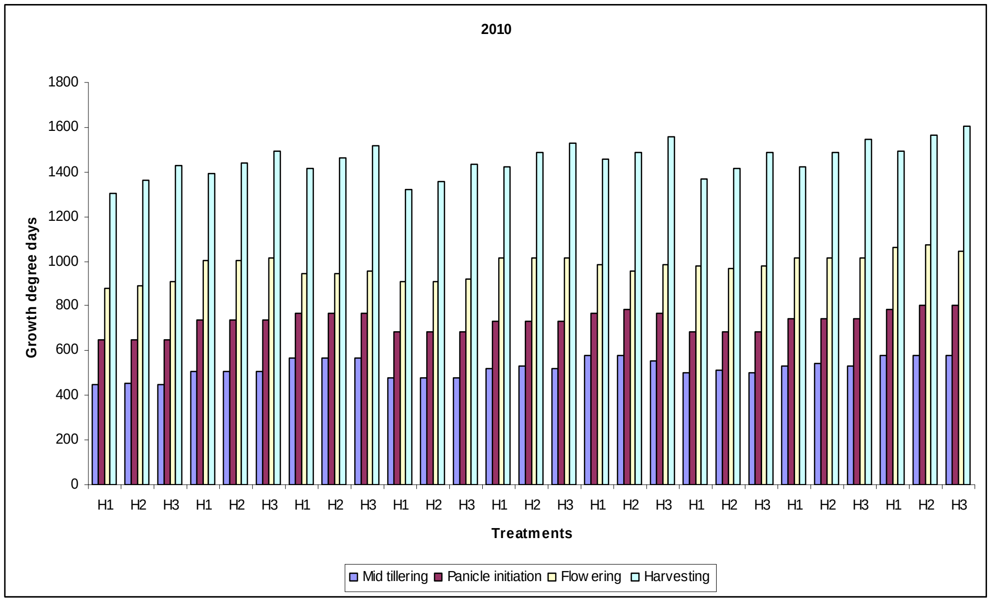
44.68 and 42.10% in 2011) respectively. Besides, the crop harvested at 42 DAF also recorded significantly higher harvest index than at 49 DAF during both the years.

4.4.5 **Interaction effect**

The interaction effect for seedling age x harvesting schedule on the grain yield during 2010 and 2011 was found significant (Table-4.13). At 20, 30 and 40 days old seedling, the grain yield varied significantly between crop harvest at 35 and 49 DAF and at 35, 42 and 49 DAF, the grain yield varied significantly among all the seedling ages. Significantly highest grain yield of 78.34 and 79.62 q ha^{-1} during 2010 and 2011, respectively was recorded with treatment combination having 40 day old seedling harvested 35 DAF.

4.5 **Growing degree days**

The growth degree days accumulated by the three rice varieties – Jhelum, SKUA-403 and SR-1 throughout their growth cycle is presented in Appendix II and Fig.11 for the years 2010 and 2011, respectively as per the phenological stages of the crop. In general aged seedlings accumulated more GDD as compared to young seedlings during all the growth stages. Thus, 40 day old seedlings of Jhelum, SKUA-403 and SR-1 had more GDD as compared to their 30 and 20 days counterparts. At mid-tillering stage during 2010, 40 days old SR-1 and SKUA-403 seedlings were observed to accumulate highest GDD as compared to Jhelum. Again in 2011, 40 days old seedlings of SKUA-403 accumulated more heat units at mid-tillering than other two varieties. At panicle initiation stage and flowering also more GDD was again observed in the same variety. At harvesting again same trend was found.



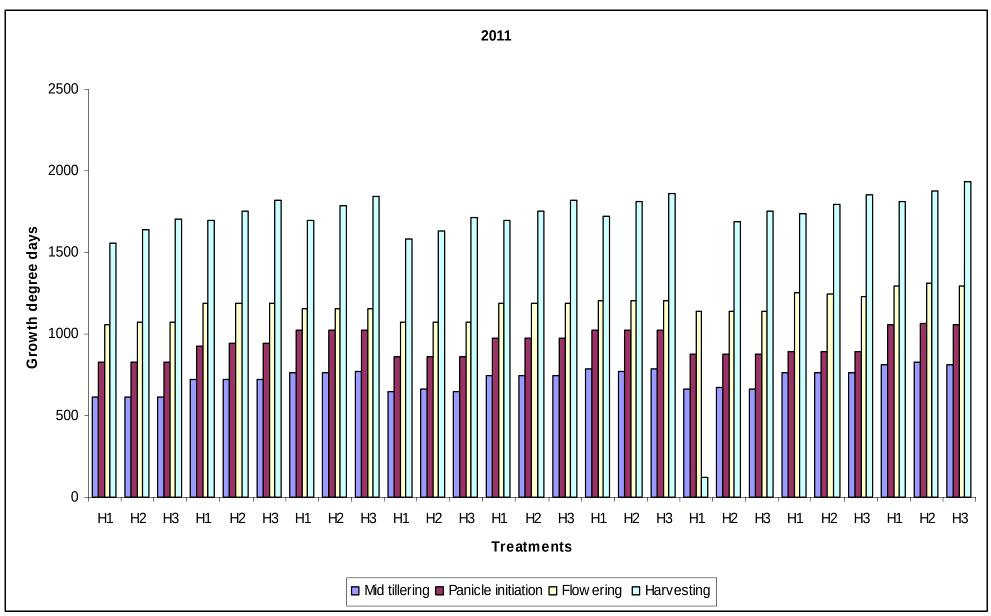


Fig.11: Growing degree days (GDD) at different growth stages as affected by rice cultivars, age of seedling and harvesting schedules (2010 and 2011)

Table 4.13: Interaction effect for age of seedling x harvesting schedule on grain yield

Treatment	2010			2011		
	Harvesting schedule (Days after flowering)					
	35	42	49	35	42	49
Age of seedling (days)						
20	46.23	43.71	40.87	48.47	46.11	42.43
30	65.89	63.34	60.50	68.77	66.41	62.73
40	78.34	75.78	72.95	79.62	44.26	73.58
CD ($p \leq 0.05$)	3.23			3.49		

4.6 Moisture content in grain

Results presented in Table-4.14 shows that varieties Jhelum and SR-1 recorded grain moisture content of 20.4 and 20.1 per cent during 2010 than SKUA-403 which had 23.3 per cent during 2010. The observed data indicated that grain moisture content which was at par with SR-1 but significantly higher than Jhelum. During 2011, again same trend was observed.

It was observed that the grains obtained from transplanting 40 days old seedling contained significantly lower moisture content viz. 19.2 and 19.1 per cent than 30 days old seedling viz. 21.7 and 21.4 per cent and 20 days old seedling viz. 24.7 and 24.3 per cent during 2010 and 2011, respectively. 30 days old seedling also recorded significantly lower grain moisture content than 20 days seedling during both the years of investigation.

Data also revealed that the crop harvested at 49 days after flowering contained significantly lower grain moisture content viz., 20.6 and 20.4 per cent than harvested at 42 DAF viz. 21.2 and 21.0 per cent and at 49 DAF viz. 23.80 and 23.40 per cent during 2010 and 2011, respectively. Crop harvested at 42 DAF also recorded significantly lower grain moisture content than harvested at 35 DAF.

In general, it was noticed that the grain moisture content decreased marginally during 2011 compared to 2010.

4.7 Head recovery

Data pertaining to head recovery (Table-4.14) indicated that variety Jhelum and SR-1 at par with one another had significantly higher head recovery than SKUA-403 during both years. The highest head recovery of 43.8 and 44.2 per cent was recorded with Jhelum variety during 2010 and 2011, respectively.

It was found that 40 days old seedling recorded significantly higher head recovery than both 30 and 20 days old seedling viz. 44.8 and 45.2 per cent during 2010 and 2011, respectively. However, 30 days old seedling remained significantly better than 20 days old seedling in this regard.

The crop harvested at 49 days after flowering (DAF) recorded significantly higher head recovery viz. 43.4 and 44.0 per cent during 2010 and 2011, respectively than harvested at 42 and 35 DAF viz. 31.61 and

Table 4.14: Moisture content (%) and head rice recovery (%) as influenced by rice cultivars, age of seedling and harvesting schedule

Treatment		Grain moisture content		Head rice recovery	
		2010	2011	2010	2011
Varieties					
Jhelum	(V_1)	20.4	20.1	43.8	44.2
SKUA-403	(V_2)	23.3	23.0	37.4	37.9
SR-1	(V_3)	21.9	21.7	42.2	42.8
SEm±		0.62	0.56	0.66	0.70
CD ($p \leq 0.05$)		1.87	1.68	1.97	2.10
Age of seedling (Days)					
20	(A_1)	24.7	24.3	37.6	38.1
30	(A_2)	21.7	21.4	41.0	41.6
40	(A_3)	19.2	19.1	44.8	45.2
SEm±		0.62	0.56	0.68	0.70
CD ($p \leq 0.05$)		1.87	1.68	1.97	2.10
Harvesting schedule (Days after flowering)					
35	(H_1)	23.8	23.4	38.2	39.2
42	(H_2)	21.2	21.0	40.8	41.7
49	(H_3)	20.6	20.4	43.4	44.0
SEm±		0.60	0.54	0.63	0.67
CD ($p \leq 0.05$)		1.79	1.61	1.88	2.01

31.24 per cent during 2010 and 2011, respectively. However, crop harvested at 42 DAF also recorded significantly higher head recovery than at 35 DAF during both years of investigation.

4.8 SIMULATION STUDIES

Validation of the model DSSAT-4.5 (CERES-Rice)

Observed crop growth parameter for validation of the model

The CERES-Rice model was validated for 03 rice varieties – Jhelum, SKUA-403 and SR-1 with three ages of seedlings - 20, 30 and 40 days during 2010 and 2011. The results of the experiment were validated in terms of grain yield, biological yield, straw yield and anthesis day and the data was plotted against observed. Results obtained were as:

4.8.1 Evaluation

The genetic coefficients of the three varieties were estimated using crop data of the three cultivars including phenological dates, yield and yield components (Table-4.15).

The genetic coefficients varied due to variation in their developmental rate at different phases. The genetic coefficients which are an important input parameter of the CERES-Rice model to simulate crop growth parameters which are presented in the Table-4.15. As can be depicted from the table, the time period (GDD) of basic vegetative phase P1 ranged from 440 in Jhelum to 510 in SR-1, critical photoperiod hour was same in the three varieties, single grain weight ranged from 0.024 to 0.025, tillering coefficient was 1.0 for Jhelum and SKUA-403 and it increased to 1.1 in Shalimar rice-1.

Table 4.15: Genetic coefficient of various varieties of rice

Genetic parameters	Description	Jhelum	Shalimar Rice-1	SKUA-403
P_1	Time period (GDD) of basic vegetative phase	440	510	500
P_2R	Extent phasic development (GDD)	10	10	8.9
P_5	Time period (GDD) of grain filling phase	400	405	392
P_2O	Critical photoperiod (hour)	12	12	12
G_1	Potential spikelet number	60	60	60
G_2	Single grain weight	0.024	0.025	0.024
G_3	Tillering coefficient	1.0	1.1	1.0
G_4	Temp. tolerance coefficient	1.0	1.0	1.0

4.8.2 **Grain yield**

Validation results revealed that the grain yield could be predicted well. The predicted yield was plotted against the observed yield as in Table-4.16 and Fig.12. Simulated grain yield was comparable with the observed grain yield with a variation ranging between 0.27 to 22 per cent. The yield equation thus obtained was Y = 0.9789 x -0.7101 with R^2 = 0.9381 and RMSE = 4.05 indicated that a similar trend was followed by both observed and simulated values. The observed yield of all the treatments ranged between 39.32 to 82.34 q ha^{-1} compared to simulated

Table 4.16: Validation results of rice varieties for Grain yield (q ha^{-1}) as affected by age of seedling and harvesting schedules

Treatments		2010			2011		
		Observed	Simulated	Deviation (%)	Observed	Simulated	Deviation (%)
V_1A_1	H_1	45.23	42.74	5.82	47.34	42.80	10.60
	H_2	42.67	41.72	2.27	44.26	41.80	5.88
	H_3	39.32	41.22	-4.60	41.13	41.27	-0.33
V_1A_2	H_1	69.23	63.86	8.40	72.31	63.89	13.17
	H_2	64.17	60.58	5.75	68.32	60.72	12.51
	H_3	59.31	58.34	1.66	60.14	58.38	3.01
V_1A_3	H_1	81.47	79.36	2.65	82.34	79.38	3.72
	H_2	78.32	79.10	-0.98	80.13	79.01	1.41
	H_3	76.41	75.61	1.05	78.46	75.59	3.79
V_2A_1	H_1	44.32	43.69	1.44	46.53	43.59	6.74
	H_2	46.67	42.76	9.14	47.31	42.82	10.48
	H_3	44.31	42.28	4.80	43.38	42.36	2.40
V_2A_2	H_1	67.72	66.91	1.21	72.13	66.88	7.84
	H_2	64.45	65.10	-0.99	70.34	65.09	8.06
	H_3	58.32	64.01	-8.88	62.12	63.98	-2.90
V_2A_3	H_1	78.42	76.41	2.63	80.16	76.48	4.81
	H_2	75.41	75.51	-0.13	78.23	75.59	3.49
	H_3	77.32	75.67	-4.42	74.15	75.67	-2.00
V_3A_1	H_1	44.31	41.63	6.43	46.12	41.69	10.62
	H_2	43.32	42.10	2.89	45.23	42.17	7.25
	H_3	42.35	41.76	4.41	44.32	41.84	5.92
V_3A_2	H_1	65.23	63.48	2.75	77.54	63.52	22.07
	H_2	61.23	61.15	0.27	72.13	61.15	17.95
	H_3	59.42	59.12	0.50	68.43	59.13	15.72
V_3A_3	H_1	75.56	75.35	0.27	76.12	75.28	1.11
	H_2	72.20	74.55	-3.15	73.43	74.45	-1.37
	H_3	71.18	74.54	-4.50	72.14	74.53	-3.20

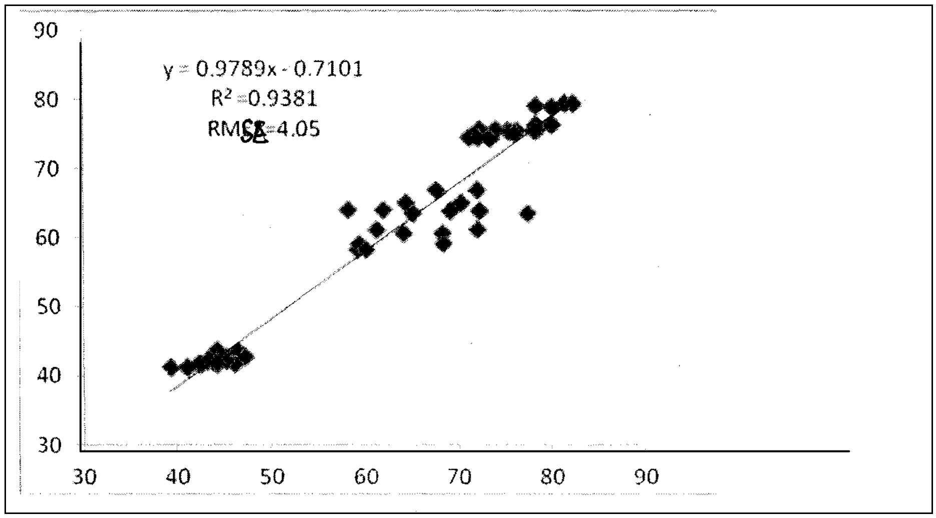


Fig.12: Validation results for grain yield (q ha^{-1}) as influenced by rice varieties, age of seedling and harvesting dates

yield ranging between 41.22 to 79.38 q ha^{-1}. 20 day old seedlings variety Jhelum harveste3d 49 DAF recorded lowest grain of 39.32 and 41.13 q ha^{-1} during 2010 and 2011 and 41.22 and 41.27 q ha^{-1} in predicted values while as the same variety when sown as 40 days old seedling and harvested 35 DAF recorded highest grain yield under both the values during both the years.

4.8.3 **Straw yield**

Like grain and biological yield, straw yield could also be predicted well. The predicted straw yield when plotted against the observed straw yield (Table-4.17 and Fig.13) indicated that the two followed a similar trend with yield equation Y = 0.7427 x +16.015 and R^2 and RMSE value = 0.7792 and 6.79, respectively. Simulated straw yield was comparable to observed straw yield with variation percentage ranging between 1.2 to 16.30. The observed straw yield ranged between 59.90 and 103.27 q ha^{-1} while as the simulated straw yield ranged between 59.55 to 94.32 q ha^{-1}. As observed from the data, 40 day old seedling of SKUA-403 harvested 49 days after flowering (DAF) gave the highest observed straw yield which varied from the simulated straw yield by 16.3 per cent while as 20 day old seedlings of SR-1 harvested 49 DAF recorded the lowest observed straw yield which varied from simulated straw yield by 1.44 per cent.

4.8.4 **Biological yield**

The simulated biological yield when compared with the observed biological yield showed a comparable variation percentage ranging between 0.99 to 11.23 only. The yield equation obtained was Y = 0.9533 x + 0.4126 with R^2 value equal to 0.9678 and RMSE = 7.5 indicating that

Table 4.17: Validation results of rice varieties for Straw yield (q ha^{-1}) as affected by age of seedling and harvesting schedules

Treatments		2010			2011		
		Observed	Simulated	Deviation (%)	Observed	Simulated	Deviation (%)
V_1A_1	H_1	65.20	59.55	9.48	61.31	59.65	2.78
	H_2	72.46	63.55	14.02	66.95	63.63	5.21
	H_3	74.99	63.03	18.97	74.99	63.13	18.78
V_1A_2	H_1	76.18	69.54	9.54	66.41	69.55	-4.51
	H_2	77.07	68.89	11.87	74.80	68.92	8.53
	H_3	80.93	70.09	15.46	80.96	70.13	15.44
V_1A_3	H_1	80.65	79.23	1.79	78.09	79.47	-1.73
	H_2	85.13	79.18	7.51	88.28	79.05	11.67
	H_3	91.71	81.06	13.13	91.27	81.11	13.14
V_2A_1	H_1	65.22	60.89	7.11	65.78	64.55	1.90
	H_2	61.64	61.81	-0.27	59.90	62.95	-4.84
	H_3	67.93	63.07	7.70	66.98	65.04	2.98
V_2A_2	H_1	80.49	76.06	5.82	79.52	82.96	-4.14
	H_2	80.86	71.09	13.74	79.07	78.94	0.16
	H_3	84.03	69.52	20.87	84.31	78.31	7.66
V_2A_3	H_1	86.79	82.48	5.22	90.16	84.46	6.74
	H_2	86.93	83.06	4.65	87.42	86.21	1.40
	H_3	87.33	81.03	7.77	90.17	86.60	4.12
V_3A_1	H_1	64.33	64.81	-2.24	61.20	63.04	-2.91
	H_2	64.19	63.51	1.07	63.09	62.57	0.83
	H_3	62.86	65.45	-3.95	63.06	63.77	-1.11
V_3A_2	H_1	83.28	87.03	-4.30	71.88	79.86	-9.97
	H_2	85.11	82.65	2.97	76.29	75.48	1.07
	H_3	80.90	83.15	-2.70	73.83	74.40	-0.76
V_3A_3	H_1	92.85	85.77	8.25	94.13	91.28	3.12
	H_2	95.15	87.38	8.89	98.92	94.32	4.87
	H_3	102.03	87.76	16.26	103.27	84.58	22.09

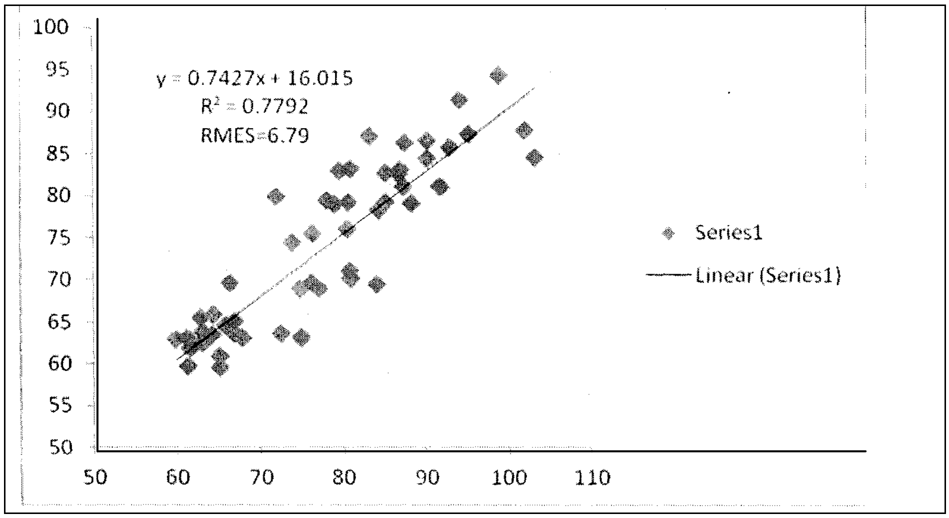


Fig.13: Validation results for straw yield (q ha⁻¹) as influenced by rice varieties, age of seedling and harvesting dates

the biological yield could be well predicted by the simulation method (Table-4.18). The observed biological yield ranged between 107.21 for 20 day old seedling of SR-1 harvested 42 DAF SKUA-403 in 2011 to 175.41 q ha^{-1} 40 day old seedling of harvested 49 DAF while as the simulated biological yield as depicted from the table ranged between 102.29 to 168.77 q ha^{-1} by treatments 20 day old seedlings of Jhelum harvested 35 DAF and 40 days old seedling of SKUA-403 harvested 42 DAF, respectively (Fig.14).

4.8.5 **Anthesis day**

As far as the anthesis day is concerned, the simulation studies in most of the treatments revealed that lesser days were taken to anthesis than the observed days expect for treatment 20 days old seedlings of SR-1 harvested 42 DAF and 49 DAF and same variety when sown as 30 day old seedling and harvested 35 DAF in which lesser days were taken to anthesis on field than were revealed by the simulation studies ranged between 4.08 to 24 per cent. The obtained equation was Y = 1.0122 x - 4.0511 with R^2 = 0.8891 and RMSE = 3.95. From observed data, it could be concluded that 20 day old SR-1 seedlings harvested 35 DAF took least number of days to anthesis during both the years i.e. 48 and 51 days on field while as simulation studies revealed that 40 day old Jhelum seedlings harvested 49 DAF, 20 day old SR-1 seedlings harvested 35 DAF and 20 day old seedlings of SR-1 harvested 42 DAF took lowest number of days to anthesis during 1st year 2nd year and 20 day old seedlings of SKUA-403 harvested 42 DAF and 20 day old seedlings of SR-1 harvested 49 DAF gave highest observed straw yield during 1st year while as 20 day old seedlings of SKUA-403 harvested 49 DAF gave highest simulated straw yield in 2nd year (Table-4.19 and Fig.15).

Table 4.18: Validation results of rice varieties for Biological yield (q ha^{-1}) as affected by age of seedling and harvesting schedules

Treatments		2010			2011		
		Observed	Simulated	Deviation (%)	Observed	Simulated	Deviation (%)
V_1A_1	H_1	110.43	102.29	7.96	108.65	102.45	6.05
	H_2	115.13	105.27	9.37	111.21	105.43	5.48
	H_3	114.31	104.25	9.65	116.12	104.40	11.23
V_1A_2	H_1	145.41	133.40	9.00	138.72	133.44	3.96
	H_2	141.24	129.57	9.01	143.12	129.64	10.40
	H_3	140.24	128.43	9.20	141.10	128.51	9.80
V_1A_3	H_1	162.12	158.59	2.23	160.43	158.85	0.99
	H_2	163.45	158.28	3.27	168.41	158.06	6.55
	H_3	168.12	156.67	7.31	170.23	156.70	8.63
V_2A_1	H_1	109.54	104.58	4.74	112.31	108.14	3.86
	H_2	108.31	104.57	3.58	107.21	105.77	1.36
	H_3	112.24	105.35	6.54	110.36	107.40	2.76
V_2A_2	H_1	148.21	142.97	3.67	151.65	149.84	1.21
	H_2	145.31	136.19	6.70	149.41	144.03	3.74
	H_3	142.35	133.53	6.61	146.43	142.29	2.91
V_2A_3	H_1	165.21	158.89	3.98	170.32	160.94	5.83
	H_2	162.34	158.57	2.38	165.65	161.80	2.38
	H_3	159.65	156.70	1.88	164.32	162.27	1.26
V_3A_1	H_1	108.64	107.44	1.12	107.32	104.73	2.47
	H_2	107.51	105.61	1.80	108.32	104.74	3.42
	H_3	105.21	107.21	-1.87	107.38	105.61	1.68
V_3A_2	H_1	148.51	150.51	-1.33	149.43	143.38	4.22
	H_2	146.43	143.80	1.83	148.42	136.63	8.63
	H_3	140.32	142.27	-1.37	142.26	133.53	6.54
V_3A_3	H_1	168.41	161.12	4.52	170.25	166.56	2.22
	H_2	167.35	161.93	3.35	172.35	168.77	2.12
	H_3	173.21	162.30	6.72	175.41	159.11	10.24

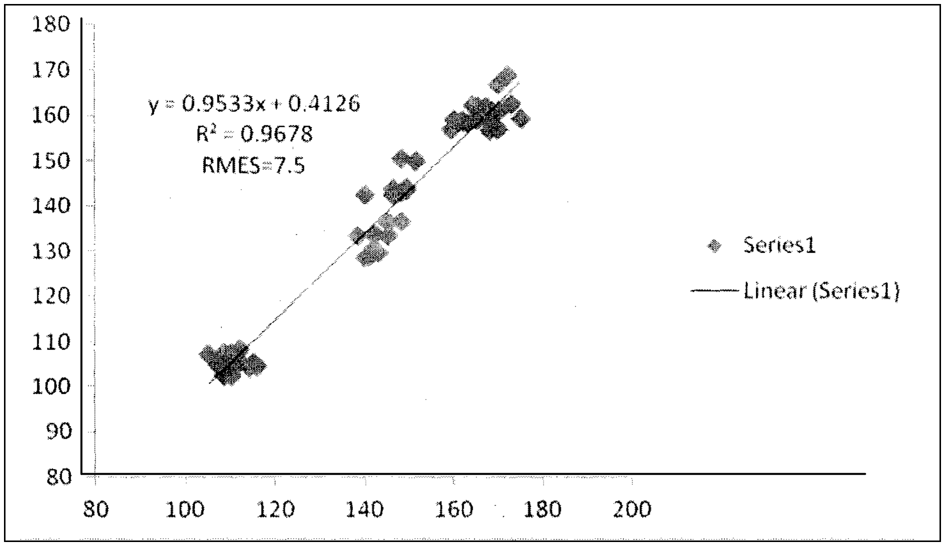


Fig.14: **Validation results for biological yield (q ha^{-1}) as influenced by rice varieties, age of seedling and harvesting dates**

Table 4.19: Validation results of rice varieties for Anthesis day as affected by age of seedling and harvesting schedules

Treatments		2010			2011		
		Observed	Simulated	Deviation (%)	Observed	Simulated	Deviation (%)
V_1A_1	H_1	60	59	1.69	66	59	11.86
	H_2	61	59	3.38	66	59	11.86
	H_3	62	59	5.08	65	59	10.16
V_1A_2	H_1	64	47	36.17	61	47	29.78
	H_2	64	48	33.33	61	48	27.08
	H_3	65	49	32.65	61	49	24.48
V_1A_3	H_1	54	46	17.39	60	46	30.43
	H_2	54	46	17.39	60	46	30.43
	H_3	55	46	19.56	60	46	30.43
V_2A_1	H_1	62	63	-1.58	68	63	7.93
	H_2	61	64	-4.68	68	64	6.25
	H_3	63	65	-3.07	68	65	4.61
V_2A_2	H_1	65	53	22.64	64	53	20.75
	H_2	65	54	20.37	64	54	18.51
	H_3	64	54	18.51	64	54	18.51
V_2A_3	H_1	58	49	18.36	63	49	28.57
	H_2	56	50	12.00	63	50	26.00
	H_3	58	50	16.00	63	50	26.00
V_3A_1	H_1	68	62	9.67	67	62	8.06
	H_2	66	63	4.76	67	63	6.34
	H_3	66	64	3.12	67	64	61.68
V_3A_2	H_1	65	52	25.00	64	52	23.07
	H_2	64	53	20.75	64	53	20.75
	H_3	64	53	20.75	64	53	20.75
V_3A_3	H_1	62	48	29.16	63	48	31.25
	H_2	63	49	28.57	63	49	28.57
	H_3	61	50	22.00	62	50	24.00

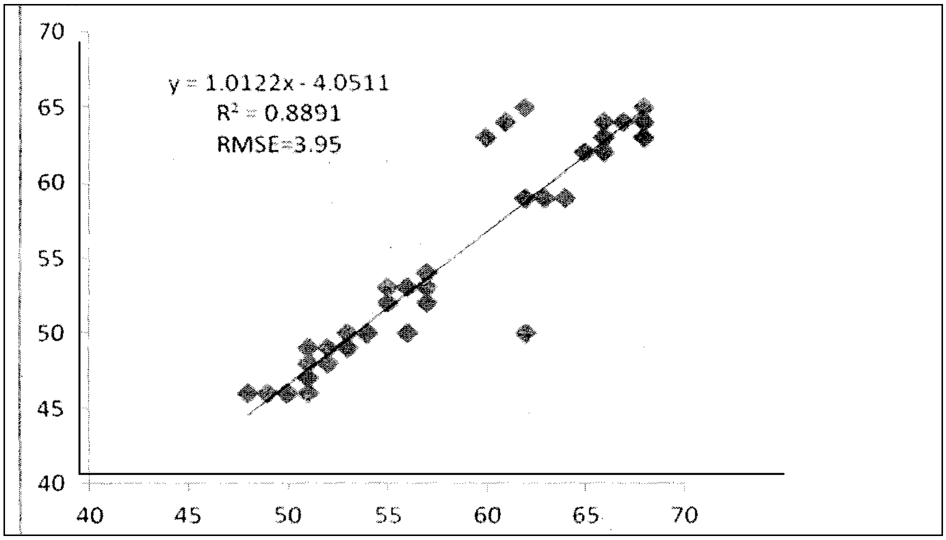


Fig.15: Validation results for days to Anthesis after transplanting as influenced by rice varieties, age of seedling and harvesting dates

4.9 SIMULATION STUDIES

4.9.1 Growth patter

CERES-Rice model was used to simulate the growth and yield of rice varieties under different ages of seedlings and harvesting dates. The response of three rice varieties viz. Jhelum, SKUA-403 and SR-1 in terms of growth and yield parameters to extrapolated dates of sowing from 20th April to 1st June was simulated using weather data of years 2010 and 2011.

4.9.2 Grain yield

The grain yield of rice under temperate conditions of Kashmir decreases by delayed sowings. In general, the decrease in the yield is irrespective of the varietal variations. Yield obtained from aged seedlings is more when sown earlier as compared to the yield obtained when younger seedlings are grown late in the season. The grain yield of three cultivars viz. Jhelum, SKUA-403 and SR-1 with different ages of seedling and harvesting dates was simulated for two years viz. 2010 and 2011. A decreasing trend was obtained in grain yield when simulated for different ages of seedlings sown on different dates (Fig. 16). Highest predicted grain yield was obtained from 40 days old seedling sown on 20th April indicating that longer growth duration in the field gives more yield. Although under existing agro-climatic conditions, it is not possible to achieve 40 days old seedling during early spring. Same 40 days old seedling of same varieties when sown on 1st June gave lowest yield. Subsequent decrease in age of seedling with 5 days variation showed a decreasing trend in yield in all the three varieties so that 15 days old seedling sown on 20th April gave a grain yield of around 50-55 q ha^{-1}

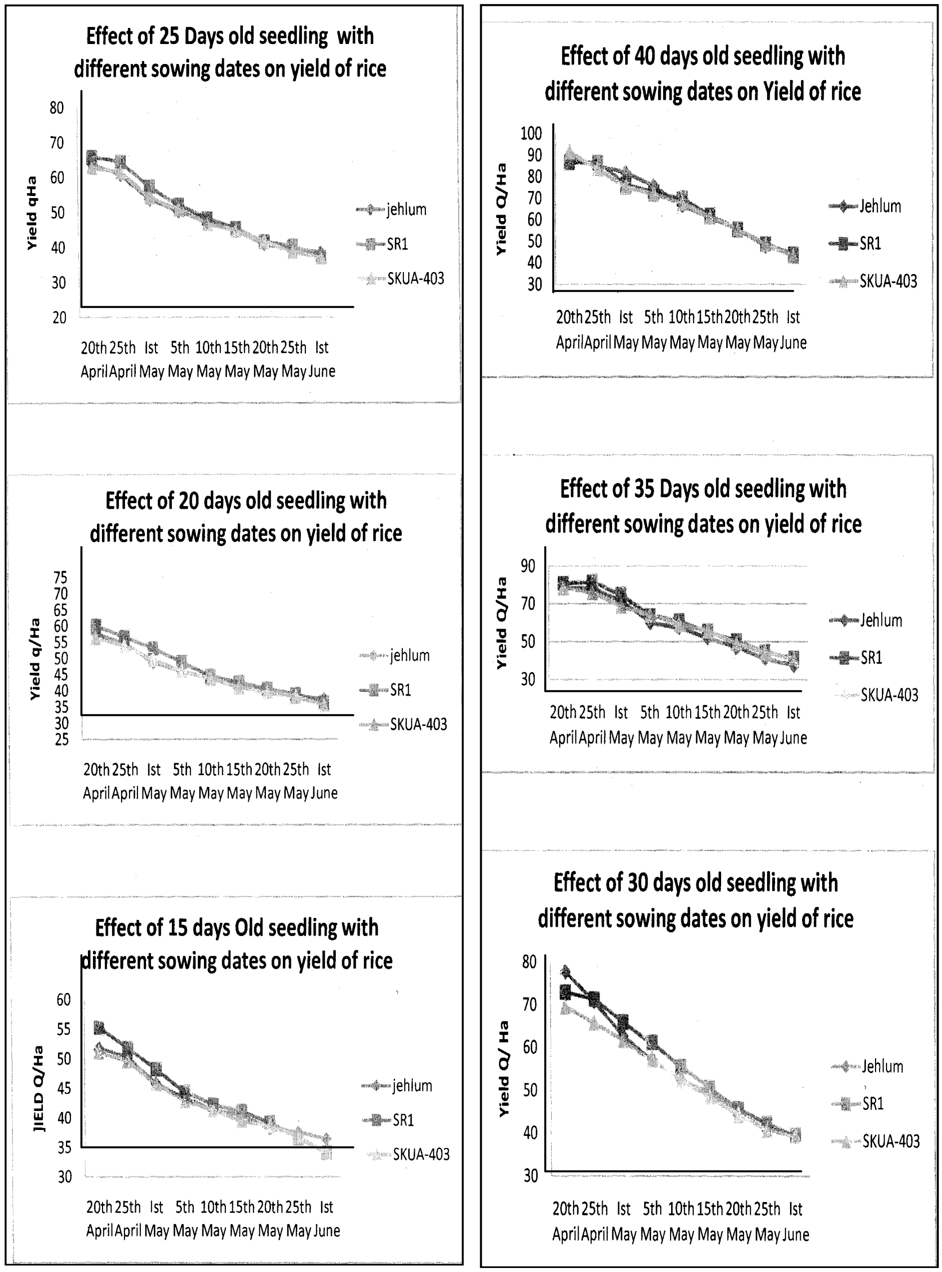


Fig.16: Simulation results of rice varieties for grain yield (q ha^{-1}) under different age of seedling

while as the same aged seedlings gave a yield of 35-37 q ha^{-1} only when sown on 1st June which indicates that the younger seedlings when sown late are subjected to restricted growth duration and consequently the yield (Fig. 16).

As far as the varietal behaviour is concerned, simulation studies of the three varieties taking ages of seedlings into consideration revealed that all the three varieties followed almost a similar trend as far as yield is considered. However, in case of Jhelum, yield was highest (78 q ha^{-1}) when 30 days old seedling were obtained from 20th April sowing, followed by SR-1 30 days old. SKUA-403 seedlings gave only 70 q ha^{-1} yield when sown on 20th April. Similarly, variation in yield was observed in 15 days old seedlings. Simulation studies revealed that younger seedlings of SR-1 i.e. 15 days old seedlings gave highest yield (55 q ha^{-1}) compared to Jhelum and SKUA-403 (50 q ha^{-1} each) when sown earlier in the season i.e. on 20th April. Yield of all the varieties decreased when sowing was delayed so that 15 days old seedlings sown on 1st June gave lowest yield of 35 q ha^{-1} only. In that case, however, Jhelum gave more yield than the other two varieties.

Two extrapolated dates viz. 25th April and 1st June were considered to study the simulation effects on growth parameters like LAI, root weight.

The top weight of varieties also showed an increasing trend. 40 days old seedlings planted earlier in the season accumulated more top weight as compared to 20 days old seedling (Fig. 17).

As far as LAI was considered, varieties showed no variation and a similar trend was followed by all the three varieties. It can be depicted

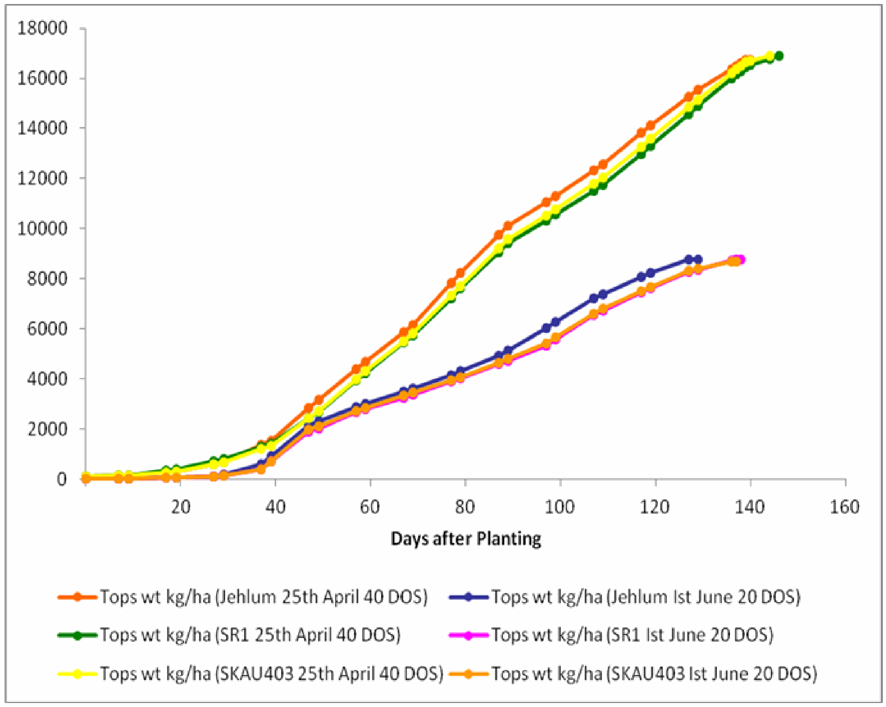


Fig.17: Simulation results of rice varieties for tops weight as affected by age of seedling and date of sowing

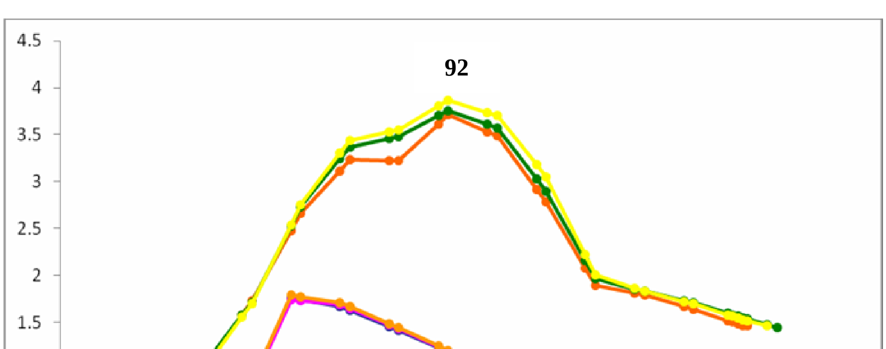
from the Fig.18 that 40 days old seedling of all the three varieties had a higher LAI as compared to 20 days old seedling. Also the duration of increase in leaf area index was more (up to 80 days) in order seedlings than in younger ones (up to 45 days only) after which LAI decreased in both the cases.

There was an increase in root weight in all the three varieties throughout the growing period. No variation as regards the varieties could be depicted form the Fig.19. However, the age of seedlings had a pronounced effect on root weight. Older the seedlings, irrespective of the variety, more was the root weight as compared to the younger seedlings.

As regards number of tillers, all the three varieties showed a highest number of tillers during 40 to 60 days after planting. However, the number of tillers was more for aged seedlings planted earlier as compared to younger ones (Fig.20).

Figure-21 depicts that there was a greater increase in ear weight of the older varieties sown earlier than the same varieties of lesser age when sown later in the season. However, all the three varieties followed a same trend for older and the younger seedlings.

All the three varieties followed a similar trend for leaf weight throughout the growing season. However, leaf weight of 40 days old seedling was far more than 20 days old seedling of the three varieties. Also, after 45 days of planting leaf weight of 20 days old seedlings increased slightly as compared to 40 days old seedling in which leaf weight increased up to later stages (Fig.22).



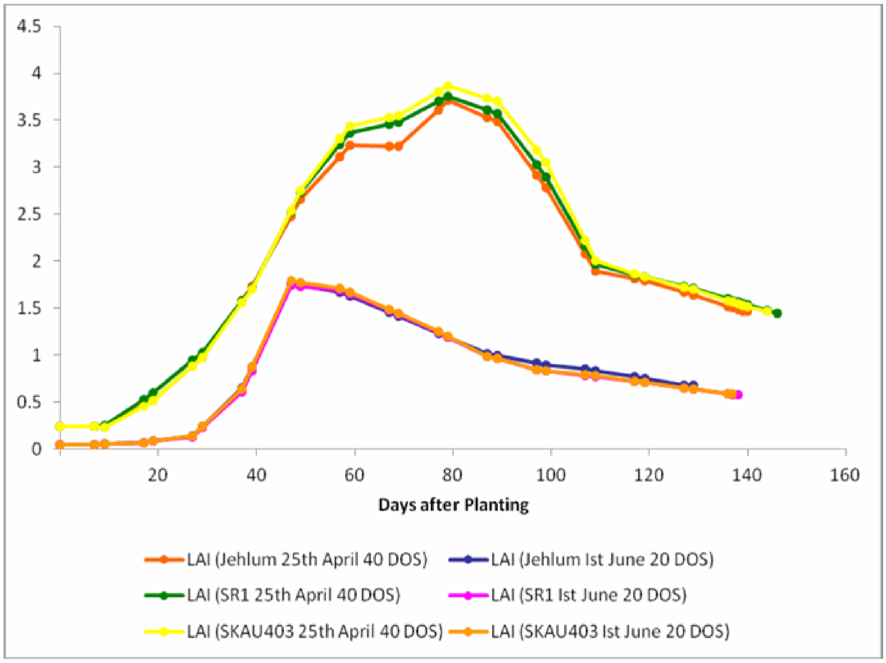


Fig.18: **Simulation results of rice varieties for Leaf Area Index as affected by age of seedling and date of sowing**

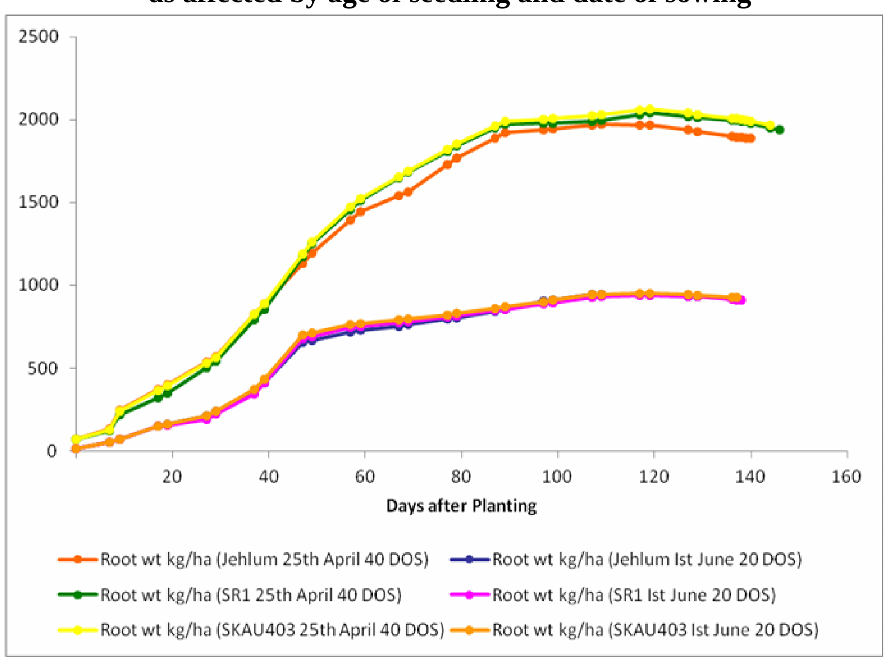


Fig.19: **Simulation results of rice varieties for root weight as affected by age of seedling and date of sowing**

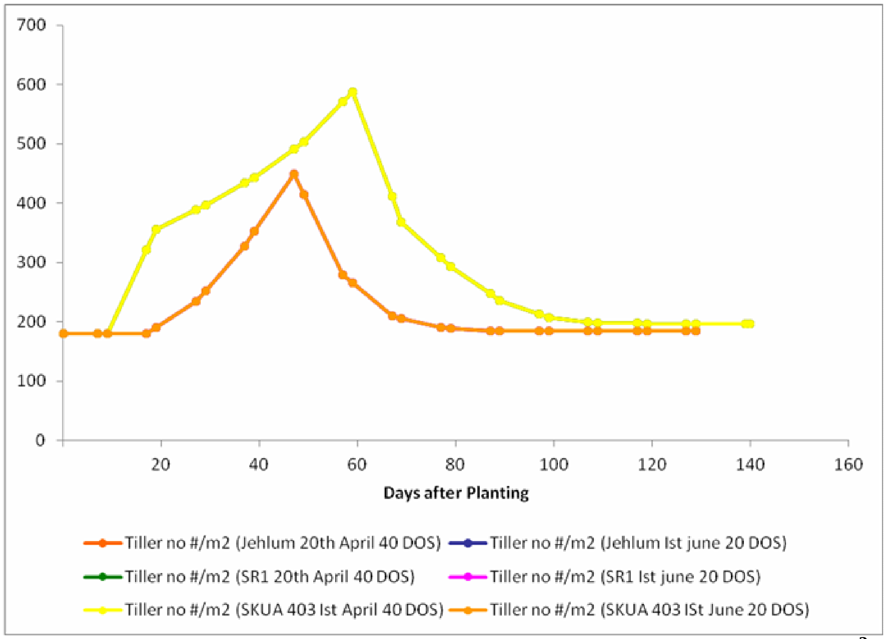


Fig.20: **Simulation results of rice varieties for tiller number m^2 as affected by age of seedling and date of sowing**

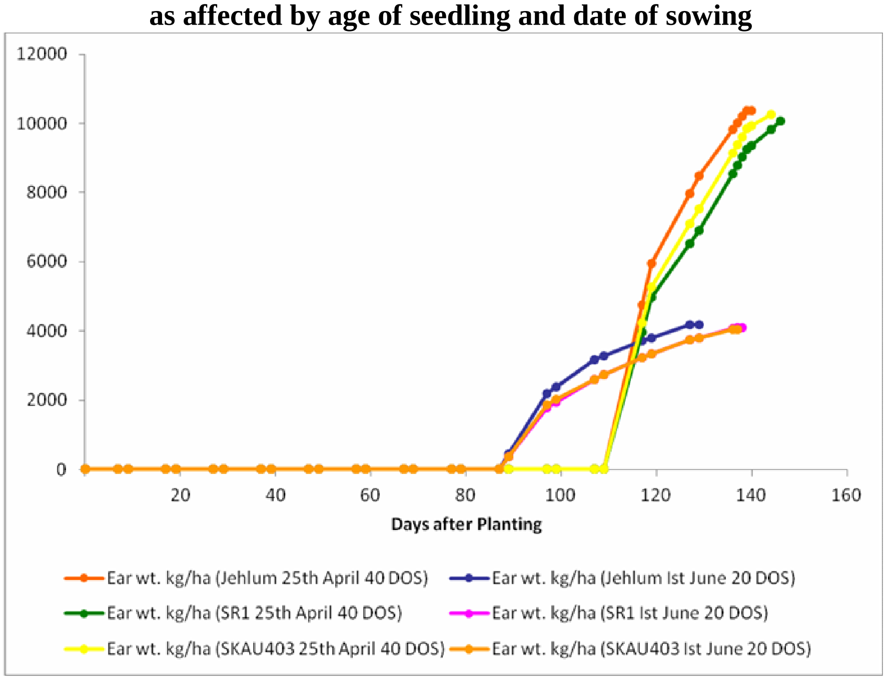


Fig.21: **Simulation results of rice varieties for ear weight as affected by age of seedling and date of sowing**

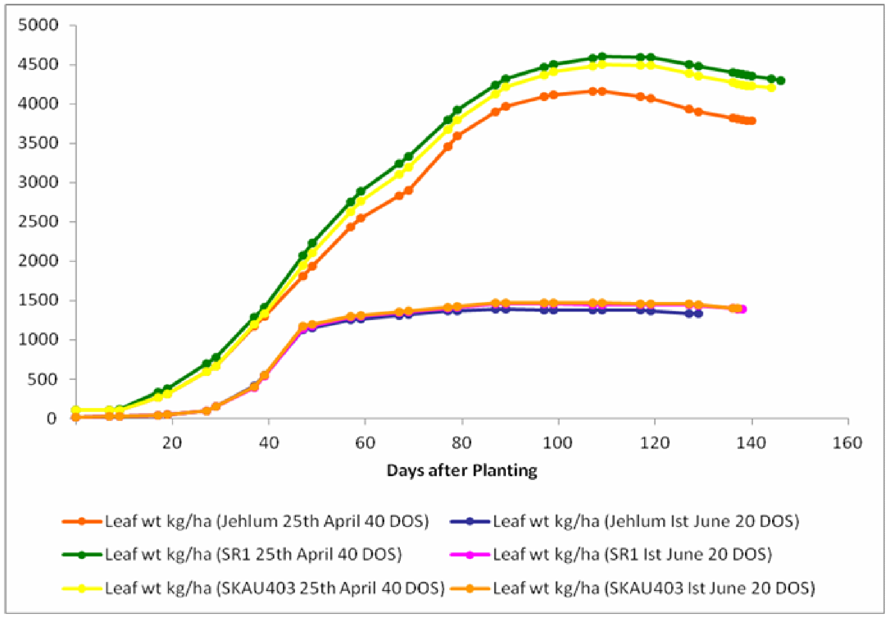


Fig.22: Simulation results of rice varieties for leaf weight as affected by age of seedling and date of sowing

Chapter 5

DISCUSSION

The results obtained during two years of investigation ‘Simulation of growth and yield of various rice varieties (*Oryza sativa* L.) as influenced by seedling age and harvesting schedules’ are discussed in this chapter under appropriate heads showing cause and effect in light of available scientific evidences.

Salient features of weather conditions during the course of investigation e.g. cropping seasons explain that the precipitation received during the crop growth period from June to September were 34.4 and 27.06 mm during 2010 and 2011, respectively. The mean maximum and mean minimum temperatures for the entire cropping season during 2010 and 2011 were 27.89^{O}C and 14.80^{O}C and 29.86^{O}C and 15.88^{O}C, respectively (Appendix-I). Sunshine hours were 847.70 and 917.20 hours, whereas mean maximum and minimum relative humidities were 84.05 and 59.49 per cent and 83.59 and 57.41 per cent during 2010 and 2011, respectively. Thus comparatively higher temperatures and sunshine hours available to the crop at early growth stages might be the reason for higher growth characters and grain yield during 2011 than 2010.

5.1 **Effect of rice cultivars, age of seedling and harvesting schedule**

Growth characters

5.1.1 **Plant height**

Plant height varied significantly due to the effect of rice cultivars and seedling age but was not significantly influenced by harvesting schedule (Table-4.1, 4.2). Rice varieties showed significant variation in the plant height from 21 DAT to harvesting. SR-1 at par with SKUA-403 produced significantly taller plants than Jhelum. This might be due to genetic make up of the varieties. The variation in the plant height of rice varieties under varied agro-climatic conditions was also reported by various workers (Peng and Khush, 2003; Laza *et al.*, 2004 and Singh *et al.*, 2004).

40 days old seedling recorded significantly highest plant height from 7 DAT to harvesting as compared to 20 and 30 day old seedlings. The increment in the plant height was prominent between 28 to 56 DAT. This might be due to transplanting of seedling at most appropriate time when it had gained height in the nursery for 40 days as against transplanting seedling of lesser age with lower height attained at nursery stage.

Harvesting of crop at 35, 42 or 49 days after flowering did not cause any significant variation in the plant height at any crop growth period.

5.1.2 **Leaf area index**

The leaves of a plant are normally its main organ of photosynthesis and the total area of leaves per unit ground area called leaf area index, has, therefore, been proposed by Watson (1947) as the best measure of the capacity of crop producing dry matter and called it as productive capital. The study showed that leaf area index increased from 14 DAT to 63 DAT, period coinciding flowering, thereafter decreased gradually up to harvest (Table-4.3, 4.4). The decrease in LAI after flowering might be attributed to senescence of lower leaves due to shading. Similar findings were reported earlier by Shukla *et al.* (1995) and Sitaramiah *et al.* (1998). Rice variety SR-1 at par with SKUA-403 recorded significantly higher LAI than Jhelum at all crop growth periods. Variation in LAI trend of different varieties has also been reported by Bali *et al.* (1995) and Choudhary (1999).

The study revealed that 40 days old seedling recorded significantly higher LAI at all crop growth periods. Comparatively taller and more robust 40 days seedling transplanted at appropriate time might have produced better vegetative growth in terms of length and breadth of leaves as well as number of leaves plant^{-1} than the late transplanted seedlings which could not exploit their potential fully. However, it was nearing maturity that 20 days old seedling possessed more LAI than 40 days old seedling.

Harvesting of the crop at 35, 42 or 49 days after flowering did not cause any significant variation in LAI.

5.1.3 **Tiller production**

Substantial differences were observed in the number of tiller/m^2 among the rice cultivars and seedling age, however, harvesting time did not affect the tiller production (Table-4.5, 4.6). The results revealed that the tiller/m^2 increased up to 42 DAT, thereafter declined gradually up to maturity. The increment in average number of tillers/m^2 was remarkably high in the period between 28 DAT to 42 DAT. It was observed that rice variety Jhelum produced significantly higher number of tillers from 21 DAT to maturity than SR-1 and SKUA-403. The decrease in the number of tillers after 49 DAT might be due to shading of lower tillers causing their death. The results are in accordance with the findings of Calitha

(2000). Laza *et al.* (2001) and Suresh *et al.* (2001) also reported variation in the tiller production of rice varieties.

40 days old seedling transplanted recorded significantly higher number of tillers/m^2 from 21 DAT to harvesting than other seedling ages. 40 days seedling transplanted at appropriate sowing date after attaining robust height in the nursery was able to tiller profusely compared to thin seedlings planted late. Molla (2001) reported that 28 days old seedling produced more tillers than 21 days old seedling.

The harvesting schedule did not significantly affect the tiller production of the crop at any growth period whether the crop was harvested at 35, 42 or 49 days after flowering.

5.1.4 **Dry matter production**

The first pre-requisite for higher yield is higher production of total dry matter per unit area. The amount of dry matter production depends on the effectiveness of photosynthesis of crop and furthermore, on plants whose vital activities are functioning effectively. The total yield of dry matter is the total amount of dry matter produced minus the photosynthates used for respiration. Finally, the manner in which dry matter produced is distributed among different parts of plant determines magnitude of the economic yield (Arnon, 1972). The present results show that response of dry matter production on rice cultivars and seedling ages were significant but remained non-significant among harvesting dates (Table-4.7, 4.8). Rice variety Jhelum accumulated significantly higher biomass than other varieties at different growth periods. Significantly higher production of tillers by variety Jhelum might have significantly increased dry matter accumulation even when having lower plant height and leaf area index. The differential behaviour of rice cultivars in the production of dry matter was also reported by Zhia *et al.* (2002), Yang *et al.* (2002b) and Nazki (2005).

40 days old seedling produced significantly highest dry matter at all growth periods. Significantly higher plant height, more tiller production and LAI recorded with 40 days old seedling might have increased the dry matter.

Harvesting of crop at 35, 42 or 49 days after flowering did not cause any significant variation in the dry matter. This may be the reflection of the effect of harvesting schedule on the plant height, tiller production and leaf area index of crop.

5.1.5 **Phenology**

The investigation revealed that Jhelum variety at par with SR-1 took significantly lower number of days to reach mid tillering, panicle initiation, flowering, milking, dough and maturity stages than SKUA-403 during both years (Table-4.9). Further, the number of days to reach these stages varied by less than 7 days among the varieties. This variation might be due to genetic make up of varieties. Earlier Slaton (2001), Dixit *et al.* (2004) and Nazki (2005) have also reported variation in the growth period of different rice cultivars.

It was found that 20 days old seedling took significantly highest number of days to reach different phenological stages from date of transplanting whereas 40 days seedling took significantly lowest number of days to reach different stages. Since 20 days old seedling was transplanted 20 days later than 40 day old seedling, it could not quickly jump its growth to come parallel to other varieties in reaching different phenological stages.

Harvesting schedule did not affect the phenology of the crop at any stage.

5.1.6 **Yield contributing characters**

Substantial differences were observed in the effective tillers/m^2, grains per panicle and 1000-grain weight among rice cultivars and age of seedling (Table-4.10). Variety Jhelum recorded significantly higher number of panicles/m^2 and grains panicle^{-1} than SKUA-403 though remaining at par with SR-1, whereas 1000-grain weight was significantly higher in SKUA-403 compared to Jhelum and SR-1 during 2010 but in 2011, SKUA-403 being at par with SR-1 recorded significantly higher 1000-grain weight than Jhelum. Significant variation among varieties with regard to yield attributes might be due to their genetic make up. Earlier Bhowmick and Nayak (2000), Yang *et al.* (2001) and Laza *et al.* (2004) also reported variation in yield contributing characters of different rice cultivars.

The study also revealed that yield contributing characters viz. panicles/m^2, grains panicle^{-1} and 1000-grain weight were significantly higher in 40 days old seedling and transplanted at appropriate time. Delayed transplanted seedlings were subjected to comparatively lower right from their transplanting time and sunshine hours which hindered them to exploit their potential. Earlier, Joseph (1991) reported that five rice cultivars with seedling ages of 25, 32, 39, 46 and 53 days and transplanted on 20th July, 27th July, 3rd August, 10th August and 17th August, respectively produced grain yield of 1.80, 2.25, 2.56, 3.05 and

2.04 t ha^{-1}, respectively with corresponding 1000 grain weight of 2.21, 2.15, 2.14, 2.16 and 2.20 g, respectively. Pattar *et al.* (2001) also found that 35 or 45 days old seedling produced significantly higher grain weight and number of filled grains per panicle than 25 days old seedling.

5.1.7 **Yield**

In general, the grain yield remained comparatively higher during 2011 than 2010 irrespective of treatments. This variation in the yield might be attributed to better environmental conditions in terms of temperature and sunshine hours (Appendix-I). Rice varieties differed significantly in respect of grain yield. Jhelum produced 3.97 and 4.93 per cent higher grain yield than SKUA-403 and SR-1, respectively during 2010 and 2011 (Table-4.12). In fact, rice yield is dependent on the number of panicles per unit area and grains per panicle. Both panicles/m^2 and grains $panicle^{-1}$ were significantly higher in Jhelum and hence the higher grain yield Jhelum also produced significantly higher dry matter than other varieties. Despite the fact that LAI was significantly higher in SKUA-403 and SR-1 particularly at panicle initiation and flowering stages but due to higher production of tillers/m^2, Jhelum recorded higher dry matter thereby contributing to comparatively higher yield. Bali *et al.* (1995), Dhiman *et al.* (1999) and Ganajaxi *et al.* (2001) have also reported variation in the grain yield of different rice cultivars.

Transplanting 40 days seedling earlier by 10 and 20 days than 30 and 20 days seedling recorded grain yield superiority of 19.68 and 73.56 per cent over 30 and 20 days seedling, respectively (Table-4.12). In fact, the higher growth and yield contributing characters in terms of dry matter production, panicles/m^2, grains $panicle^{-1}$ and 1000-grain weight recorded in 40 days seedling might have contributed to the higher grain yield. Paul (1994) reported that transplanting 50 days old seedling on 20th July instead of 19th August or 2nd September gave the highest grain yield. This also indicated that old aged seedling if transplanted earlier compared to transplanting lower aged seedling late produces higher grain yields. Ali *et al.* (1995) found that rice yield decreased with delay in planting date but was higher in 60 or 70 days old seedling than 30 or 45 days old seedling. Channabasappa *et al.* (1998) reported that rice yield increased with increasing age of seedling from 25, 35 to 45 days.

Significantly higher rice yields of 63.49 and 65.62 q ha^{-1} during 2010 and 2011, respectively were obtained when the crop was harvested at 35 days after flowering which was higher by 4.18 and 9.27 per cent and 3.73 and 10.13 per cent over the crop harvested at 42 and 49 days after flowering during 2010 and 2011, respectively. Delay in harvesting beyond 35 days after flowering might have increased shattering percentage thereby, reducing the grain yield. Earlier Jayawardena (1973) has also reported that delayed harvesting gave reduced yields in tall and shattering susceptible varieties than resistant medium height varieties.

The straw yield varied significantly due to the effect of rice varieties, seedling age and harvesting schedule. Variety SKUA-403 recorded significantly higher straw yield compared to Jhelum and SR-1 (Table-4.12). Nazki (2005) also recorded higher straw yield in SR-1 rice variety compared to Jhelum and Chenab.

The investigation showed that 40 days old seedling produced significantly higher straw yield than 20 days old seedling. Higher straw yield might be attributed to higher plant height, tiller production and higher dry matter accumulation. Earlier Bali *et al.* (1995) also reported significantly higher straw yield in the rice seedling transplanted earlier.

Harvesting the crop at different days after flowering did not cause any significant variation in the straw yield.

Harvest index denotes the translocation of photosynthates from source to the sink. Higher is the harvest index, the more would be the translocation of photosynthates from leaves and other photosynthetic organs to the economic part i.e. the grain. During the present study, it was found that the variety Jhelum recorded higher values of harvest index than other cultivars viz. SKUA-403 and SR-1. Ganajaxi *et al.* (2001) and Nazki (2005) have also reported significant variation in the harvest index among rice cultivars.

40 days old seedling recorded higher harvest index than 30 and 20 days seedling. This could be attributed to higher grain to straw ratio as harvest index is the per cent ratio of economic yield to the biological yield.

The crop harvested at 35 days after flowering recorded higher harvest index than harvested later. In fact, delay in harvesting might have increased shattering of grains and thus higher ratio of grain yield to straw yield led to the higher harvest index values.

5.1.8 **Moisture content in grain**

The moisture content of the grain can be used as a reliable criterion to decide the optimum time of harvest. The study revealed a significant variation in the moisture content of grain due to the effect of various treatments (Table-4.14). Rice variety Jhelum recorded significantly lowest grain moisture content of 20.4 and 20.1 per cent during 2010 and 2011, respectively, whereas the variety SKUA-403 recorded the highest grain moisture content at harvest. Bhol Rao (1969) and Kuiper (1971) reported that the optimum moisture content in paddy should range between 19-23 per cent at harvest to obtain high yields. The variation in the grain moisture content of the varieties at harvest was also reported earlier by Malik *et al.* (1981).

40 days old seedling transplanted 20 days earlier than 20 days seedling recorded significantly lowest grain moisture content at harvest than 20 days old seedling. Significantly highest grain moisture content at harvest in 20 days old seedling was due to very high percentage of un-matured grains because the crop was subjected to less than required photoperiod and the temperatures.

Time of harvesting greatly affected the grain moisture content of the crop. The crop harvested at 35 days after flowering recorded significantly higher moisture content. Moisture content decreased with advancement in harvesting. The results are in agreement with the findings of Malik *et al.* (1981).

5.1.9 **Head recovery**

The crop harvested at higher moisture level and after sun drying loses moisture at a rapid rate causing sun cracks in the grains which enhances breakage in milling. Late harvested crops which had been left in the field to over mature and dry to moisture level below 18 per cent tend to absorb moisture from the air, dew etc. This process of intermittent wetting and drying causes sun cracks in grain, a phenomenon reported to be the primary cause for breakages in milling. The development of sun cracks begins at the centre of the kernel and progresses towards the circumference and that the dew induces cracking. It is reported that the highest head rice yield is obtained when the lowest air drying temperature is used to dry paddy. Uneven expansion of the kernel due to intermittent drying and wetting cause cracks in the grain resulting in breakages at milling.

During the present investigation, it was observed that the grains of variety SKUA-403 had the highest breakage at milling (Table-4.14). The susceptibility to breakage in rice varieties is dependent on grain characteristics such as grain length, hardness and chalkiness. The grains of Jhelum having small type grain were less susceptible to breakage in milling. Jayawardena (1973) also reported variation in the grain breakage of different varieties at milling.

It was found that 40 days seedling recorded the highest head recovery than 20 and 30 days seedling transplanted 20 and 10 days later, respectively (Table-4.14). Significantly lowest head recovery recorded in 20 days seedling could be associated to higher grain moisture content. The best time to harvest the crop is the stage when 19-23 moisture content is present in the grain and above this limit the breakage percentage at milling increases. Earlier Jayawardena (1973) also reported similar findings.

The crop harvested at 49 days after flowering recorded significantly higher percentage of head recovery whereas the lowest head recovery was found in the crop harvested at 35 days after flowering thereby showing that the crop harvested at 20-21 per cent moisture level recorded the highest head recovery. Earlier Malik *et al.* (1981) working in Pakistan reported that head rice recovery in case of sun drying increased gradually from 30.16 to 53.50 per cent when harvesting was done 18 and 40 days after flowering, respectively, thereby clearly suggesting that with advancement in the harvesting, the head rice recovery increases.

5.2 Growing degree days

The GDD of rice varieties was more in 2011 as compared to 2010. Among varieties, SKUA-403 accumulated more GDD as compared to Jhelum and SR-1. This may be due to longer duration of SKUA-403 on field to complete its growth as compared to Jhelum and SR-1. Varietal variation for accumulation of GDD to complete different phenophases has also been reported by Singh (2003). 40 days old seedlings accumulated more heat units as compared to 30 and 20 days old seedling. This may be as a result of prolonged early growth phases of older seedlings sown early in the season as compared to younger seedlings sown late in the season. Similar results were given by Chopra and Chopra (2004) attributing accumulation of more heat units to prolonged growth phases.

5.3 Simulation studies

The three rice varieties Jhelum, SKUA-403 and SR-1 were subjected to the simulation studies taking into consideration various growth and yield parameters. Validation of CERES-Rice model when done suggested that the phenology of all the three rice varieties could be predicted well.

The predicted grain, straw and biological yield were in agreement with the observed values as indicated in Fig.14, 15 and 18. Simulated grain yield was comparable with the observed values with a variation ranging between 0.27 to 22.0 per cent. R^2 value obtained was 0.9381 with RMSE = 4.05. As far as the straw yield was concerned, the R^2 value obtained was 0.7792 and the RMSE = 6.79 indicating that a similar trend was followed by both observed and simulated values. There was only a variation percentage ranging between 1.2 to 16.30. The observed straw yield ranged between 59.90 and 103.27 q ha^{-1} while as the simulated straw yield ranged between 59.55 and 94.32 q ha^{-1}. Same was the case with biological yield in which R^2 value was 0.9678 and RMSE was 7.5 (Fig.16). Validation of different rice varieties under temperate conditions of Kashmir was also done by Singh and Singh (2006) at Shalimar.

As far as the anthesis day is concerned, the simulation studies in most of the treatments revealed that lesser days were taken to anthesis than observed days except for 20 day old SR-1 seedlings harvested at 42 and 49 days after flowering and 30 day old seedlings of same variety harvested 35 days after flowering in which lesser days were taken to anthesis on field than revealed by the simulation studies. The deviation between observed and simulated data ranged from 4.08 to 24.0 per cent and the R^2 and RMSE values obtained were 0.8891 and 3.95, respectively, indicating that the model was well fitted.

Simulation studies on the basis of extrapolated dates from 20th April to 1st June taking into consideration growth and yield parameters revealed that the seedlings planted early in the season performed better than the young seedlings planted late in the season under temperate conditions of Kashmir.

All the three varieties followed a similar trend for growth parameters like LAI, root weight, top weight, leaf weight, number of tillers and ear weight when extrapolated dates were taken into consideration (Fig.17, 18, 19, 20, 21, 22). Similarly, a similar trend was obtained for yield by all the three varieties when age of seedling was taken into consideration. Highest predicted grain yield was obtained when 40 day old seedlings was obtained from 20^{th} April sowing.

Chapter 6

SUMMARY AND CONCLUSION

Field trial was conducted at the Experimental Farm of the Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir, Shalimar Campus during *kharif* 2010 and 2011. The experiment was laid out in a split-plot design with three rice varieties (Jhelum-VI, SKUA-403 and SR-1), three seedling ages (20, 30 and 40 days) and three harvesting schedules (35, 42 and 49 DAF). The soil of the experimental field was silty clay loam in texture, low in available nitrogen and medium in available phosphorus and potassium with neutral pH. The treatment effects in various characters under study have been described and discussed in detail in preceding chapters. The important findings are summarized hereunder:

Effect of varieties

- The variety SR-1 recorded significantly highest plant height and leaf area index at various growth period, whereas number of tillers/m^2 and dry matter production at different growth periods was significantly highest in variety Jhelum.
- The variety Jhelum took significantly lesser days to reach phenological stages viz. tillering, panicle initiation, flowering milk, dough and maturity compared to other varieties.
- The yield contributing characters viz. number of effective tiller m^{-2} and grains panicle were significantly highest in variety Jhelum whereas 1000-seed weight was significantly higher in SKUA-403

and number of spikelets were higher in SR-1. SKUA-403 recorded significantly highest sterility percentage.

- Jhelum variety recorded significantly higher grain yield and harvest index compared to other cultivars whereas straw yield remained higher in SKUA-403.
- Rice cultivar Jhelum recorded significantly lowest grain moisture content and highest head recovery.

Effect of age of seedling

- 40 days old seedling recorded significantly taller plants, higher leaf area index, tiller production and dry matter accumulation than other seedling ages.
- 40 days old seedling took significantly lowest number of days to reach phenological stages viz. tillering, panicle initiation, flowering, milking, dough and maturity.
- All the yield contributing characters viz. number of effective tillers, spikelets and grains panicle^{-1} and 1000-grain weight remained significantly higher in 40 days old seedling compared to 30 and 20 days seedlings, whereas sterility percentage was significantly highest in 20 days old seedling.
- Both grain and straw yield, harvest index and biological yield remained significantly higher in 40 day seedling compared to other seedling ages.

- The grain moisture content was significantly lowest in and head recovery highest in 40 days old seedling compared to other seedling ages.

Effect of harvesting schedule

- Harvesting schedule did not cause any significant variation in the periodic plant height, leaf area index, tiller production and dry matter accumulation.
- Various phenological stages viz. tillering, panicle initiation, flowering, milking and dough remained unaffected with harvesting schedule. However, days taken to reach maturity were significantly lowest under harvesting at 35 days after flowering.
- Except for number of effective tillers m^{-2}, all yield contributing characters remained unaffected by harvesting schedule. Harvesting crop at 35 DAF recorded significantly highest number of panicle m^{-2}.
- Crop harvest at 35 DAF recorded significantly highest grain yield and harvest index whereas straw yield remained significantly highest at 49 DAF.
- Grain moisture content remained significantly highest and head recovery lowest in the crop harvested at 35 DAF, whereas significantly lowest moisture content and highest head recovery was recorded in the crop harvested at 49 DAF.
- The interaction effect between seedling age and harvesting schedule for grain yield was found significant.

CONCLUSION

The two year study revealed that transplanting 40 days old seedling of Jhelum variety and harvested at 35 days after flowering (DAF) improved both growth and yield contributing characters of rice. The said treatment combination also realized significantly higher grain yield and fitted well in the CERES-Rice model. Thus, the study leads to the conclusion that for realizing optimum rice yields, 40 days old seedling of rice cultivar Jhelum should be transplanted in the rice field by 10-11 June and harvested at 35 days after flowering. However, the study needs further testing at other suitable locations before arriving at final recommendations.

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Appendix-I

Standard weekly meteorological data for 2010 of SKUAST-K, Shalimar

Standard week	Mean temperature (^{O}C)		Sunshine	Rainfall (mm)
	Max.	Min.		
1	22.36	9.36	5.76	1.57
2	23.50	9.44	6.9	1.14
3	26.30	11.29	8.00	1.46
4	28.29	12.86	9.64	9.93
5	27.21	12.69	8.00	0.00
6	29.8	15.84	10.38	0.28
7	32.46	16.91	10.69	0.00
8	25.67	17.09	3.57	7.46
9	27.79	18.87	4.86	1.53
10	26.50	19.63	0.87	9.69
11	29.21	18.57	4.54	2.63
12	31.71	18.93	8.60	0.23
13	25.50	13.60	6.34	7.86
14	31.00	15.83	8.49	0.40
15	27.92	15.58	7.78	0.30
16	24.18	9.92	8.08	0.00
17	26.43	10.06	7.67	0.37
18	27.36	6.87	8.71	0.00
19	26.43	7.44	8.10	0.14

Source: Meteorological Observatory, Division of Agronomy, SKUAST-K, Shalimar

Appendix-I

Standard weekly meteorological data for 2011 of SKUAST-K, Shalimar

Standard week	Mean temperature (^{O}C)		Sunshine	Rainfall (mm)
	Max.	Min.		
22	27.57	11.27	9.33	0.14
23	30.36	13.50	10.49	5.50
24	31.43	15.14	9.33	0.00
25	33.16	17.86	9.57	0.49
26	29.43	15.71	8.60	1.03
27	28.64	15.56	6.00	0.71
28	28.86	16.77	6.63	1.29
29	32.07	19.19	7.11	0.00
30	31.64	16.47	8.63	1.40
31	31.73	17.63	7.53	1.03
32	27.66	16.80	5.59	2.26
33	32.30	16.09	9.61	0.00
34	29.50	17.60	5.41	3.17
35	29.79	15.97	6.86	1.77
36	30.30	17.14	7.19	1.94
37	23.44	13.17	4.33	4.83
38	27.64	8.71	8.60	0.00
39	28.57	8.69	8.66	0.00
40	22.29	7.96	5.16	1.50

Source: Meteorological Observatory, Division of Agronomy, SKUAST-K, Shalimar

Appendix-II

Growing degree days (GDD) at different growth stages of rice varieties as affected by age of seedling and harvesting dates (2010)

Treatments		Mid tillering	Panicle initiation	Flowering	Harvesting
V_1A_1	H_1	450.25	646.70	876.75	1306.20
	H_2	453.78	646.70	893.23	1366.20
	H_3	450.25	646.70	908.65	1425.70
V_1A_2	H_1	506.00	735.55	1003.25	1393.00
	H_2	506.00	735.55	1003.25	1440.00
	H_3	506.00	735.55	1018.00	1494.00
V_1A_3	H_1	564.50	770.00	943.40	1417.00
	H_2	564.50	770.00	943.40	1464.25
	H_3	568.70	770.00	956.43	1517.70
V_2A_1	H_1	477.60	687.50	907.70	1324.70
	H_2	480.90	687.50	907.70	1354.70
	H_3	477.60	687.50	921.95	1433.20
V_2A_2	H_1	518.55	730.05	1018.00	1423.00
	H_2	532.35	730.05	1018.00	1486.00
	H_3	518.55	730.05	1013.25	1526.80
V_2A_3	H_1	577.25	770.00	985.00	1455.25
	H_2	577.25	785.00	956.40	1485.05
	H_3	555.50	770.00	985.00	1557.25
V_3A_1	H_1	499.65	687.20	982.45	1370.20
	H_2	514.70	687.50	965.45	1417.70
	H_3	499.65	687.50	982.45	1485.80
V_3A_2	H_1	532.35	743.55	1018.00	1423.00
	H_2	545.90	743.55	1018.00	1486.00
	H_3	532.35	743.55	1018.00	1544.35
V_3A_3	H_1	577.25	785.21	1061.50	1494.25
	H_2	577.25	801.30	1074.50	1565.25
	H_3	577.25	801.30	1047.50	1606.55

Appendix-II

Growing degree days (GDD) at different growth stages of rice varieties as affected by age of seedling and harvesting dates (2011)

Treatments		Mid tillering	Panicle initiation	Flowering	Harvesting
V_1A_1	H_1	617.60	828.15	1060.00	1557.70
	H_2	617.60	828.15	1076.60	1641.30
	H_3	617.60	828.15	1076.60	1706.20
V_1A_2	H_1	718.80	924.90	1190.80	1695.40
	H_2	718.80	942.35	1190.80	1755.50
	H_3	718.80	942.35	1190.80	1820.40
V_1A_3	H_1	762.15	1021.65	1159.40	1692.70
	H_2	762.15	1021.65	1159.40	1790.70
	H_3	774.10	1021.65	1159.40	1843.30
V_2A_1	H_1	648.20	860.80	1076.60	1581.20
	H_2	661.95	860.80	1076.60	1632.30
	H_3	648.20	860.80	1076.60	1715.90
V_2A_2	H_1	745.90	975.00	1190.80	1695.40
	H_2	745.90	975.00	1190.80	1755.50
	H_3	745.90	975.00	1190.80	1820.40
V_2A_3	H_1	786.35	1021.70	1209.00	1721.40
	H_2	774.10	1021.70	1209.00	1807.80
	H_3	786.35	1021.70	1209.00	1861.80
V_3A_1	H_1	661.95	875.75	1140.60	122.80
	H_2	676.20	875.75	1140.60	1687.00
	H_3	661.95	875.75	1140.60	1754.40
V_3A_2	H_1	762.40	889.95	1254.80	1737.00
	H_2	762.40	889.95	1242.80	1792.00
	H_3	762.40	889.95	1230.10	1848.90
V_3A_3	H_1	811.30	1054.30	1296.85	1807.80
	H_2	825.20	1069.25	1309.60	1880.50
	H_3	811.30	1054.30	1296.85	1938.20

Sher-e-Kashmir
University of Agricultural Sciences and Technology of Kashmir
Division of Agronomy, Shalimar Campus Srinagar 191121

Certificate

Certified that all the corrections/ amendments as suggested by External Examiner **Dr. D. S. Rana**, Principal Scientist, Division of Agronomy, IARI, New Delhi during viva-voce examination held on **7th September 2012** have been incorporated in the manuscript entitled "**Simulation of growth and yield of various rice varieties (*Oryza sativa* L.) as influenced by seedling age and harvesting schedules**" submitted by **Ms. Sameera Qayoom (Registration No. 208-D-2008)**.

(Prof. B. A. Khanday)
Chairman
Advisory Committee