

Impact of silicon and nitrogen on growth, lodging and yield of transplanted rice (*Oryza sativa* L.) under temperate Kashmir conditions

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(2013-478-D)



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Technology of Kashmir**

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2017



*Dedicated
To my Family*

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Faculty of Agriculture, Division of Agronomy

Certificate – I

This is to certify that the thesis entitled, “**Impact of silicon and nitrogen on growth, lodging and yield of transplanted rice (*Oryza sativa* L.) under temperate Kashmir conditions**” submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Agriculture (Agronomy)**, to the **Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** is a record of bonafide research work carried out by **Ms. Rukhsana Jan (Regd. No. 2013-478-D)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

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ABSTRACT

The field experiment entitled “Impact of silicon and nitrogen on growth, lodging and yield of transplanted rice (*Oryza Sativa* L.) under temperate Kashmir conditions was conducted at Agronomy Research Farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir during Kharif season 2014 and 2015. The soil of the experiment was silty clay loam in texture, neutral in reaction with medium available nitrogen (442.88kg ha⁻¹), phosphorus (9.3kg ha⁻¹), potassium (221.60kg ha⁻¹) and low available silicon (280.23kg ha⁻¹). The experiment was laid out in Factorial Randomized Completely Block Design assigning combinations of nitrogen levels and silicon applications with four replications. The results revealed that the growth characters viz. number of tillers m⁻², leaf area index, dry matter accumulation and relative growth rate were significantly highest with 180kgN ha⁻¹ from 30-45DAT. But from 60DAT upto at harvest, these growth parameters were significantly highest with 120kgN ha⁻¹ during 2014 and 2015. Culm thickness was significantly highest with 120kgN ha⁻¹ at all growth stages during both the years. Plant height and internodal length (except mid tillering) were significantly superior with 180kgN ha⁻¹ at all growth stages during both the years. Days taken to different phenological stages were

curtailed with 120kgN ha⁻¹ and prolonged with 180kgN ha⁻¹ during both the consecutive years. The lodging parameters viz. breaking resistance and bending moment were significantly highest with 120kgN ha⁻¹ while lodging index decreased with the same treatment during both the years. The yield attributes viz. number of panicles m⁻², panicle length, panicle weight, spikelets panicle⁻¹ and grains panicle⁻¹ were significantly higher with 120kgN ha⁻¹ resulting in highest grain yield (75.61q ha⁻¹ and 76.39q ha⁻¹), straw yield (93.38 q ha⁻¹ and 94.56q ha⁻¹) and harvest index (44.72% and 44.96 %) as well as nitrogen and silicon uptake by crops during both the years respectively. Nitrogen levels could not make any significant difference on nitrogen content and silicon content of grain and straw during both the years.

So far as application of silicon is concerned, 15%Si caused significant improvement in crop growth and yield attributing characters during 2014 and 2015. Similar trend was also observed for grain yield (76.41q ha⁻¹ and 77.11q ha⁻¹), straw yield (94.36q ha⁻¹ and 95.09q ha⁻¹), harvest index (44.69% and 44.92%) and nitrogen and silicon uptake by crops during both the years respectively. All silicon applications showed non significant effect on silicon content and nitrogen content of grain and straw and phenological stages during both the years. The lodging parameters viz. breaking resistance and bending moment were significantly highest with 15%Si while lodging index decreased with the same treatment during both the years. Interaction effect of nitrogen and silicon on grain yield were significantly highest at 120kgN ha⁻¹ with 15% Si was 80.05q ha⁻¹ and 80.62q ha⁻¹ during both the years which statistically remained at par with 150kgN ha⁻¹ and 15%Si was 78.76q ha⁻¹ and 79.53q ha⁻¹ during both the consecutive years. Relative economics revealed that 120kgN ha⁻¹ with 15%Si realized highest benefit cost ratio (Rs. 2.11 and Rs. 2.13) during 2014 and 2015.

Keywords: Growth, Lodging, Nitrogen, Rice, Silicon, Yield.

Signature of Student

Signature of Major Advisor

Dated:

Dated:

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Chapter 1

INTRODUCTION

Rice (*Oryza sativa* L.) belonging to family Graminae and sub family Poacea is a staple food for more than half of the world's population. Globally it is grown on an acreage of 158 million hectares with total production of 700 million tonnes and productivity 4.43 ton per hectare (FAO, 2014). In India, it is grown on an area of about 43.4 million hectare with the production of 157.2 million tonnes and productivity of 3.6 tonnes per hectare (FAO, 2014). Among the rice growing countries, India stands first in area and second in production next to china. In Jammu and Kashmir rice is grown on an area of 261.66 hectares with a production of 5456 quintals and productivity of 20.95 quintals per hectares (DES, 2012-2013).

The productivity of rice in Jammu and Kashmir is quite low as compared to national average. In India, at the present growth rate, the demand for rice by 2025 A.D is expected to be 136 million tonnes indicating requirement of 2.5 million tonnes of enhanced rice production every year.

Application of nitrogen fertilizer is an important practice for increasing rice yield. It is essential to the rice plant, with about 75 per cent of leaf nitrogen associated with chloroplasts, which are physiologically important in dry matter production (Dalling, 1995). Rice plants require nitrogen during the vegetative phase to promote tillering, which determines the potential number of panicles (Mae, 1997). Nitrogen contributes to spikelet production during the early panicle formation stage and contributes to sink size by decreasing the number of generated spikelets and increasing full size during the late panicle formation stage.

Nitrogen deficiency generally results in stunted growth and chlorotic leaves by poor assimilate formation that leads to premature flowering and shortening of the growth cycle. The presence of nitrogen in excess promotes development of the above ground organs with abundant dark green (high

chlorophyll) tissues of soft consistency and relatively poor root growth. This increases the risk of lodging and reduces the plant resistance to harsh climatic condition and foliar diseases (Mohammadin *et al.*, 2011).

Silicon is usually considered as one of the most important beneficial elements for rice production as rice requires large amounts of silica for its growth. The silicon content of soils can vary dramatically from <1 to 45 per cent by dry weight basis (Sommer *et al.*, 2006) and its uptake by plants takes place in the form of silicic acid [Si(OH)₄]. The essentiality of silicon as a nutrient for higher plants is very difficult to prove because of its ubiquitous presence in the biosphere. It is estimated that nearly 20 kg of silica is removed from the soil by rice plants for production of 100 kg brown rice (Dobermann and Fairhurst, 1997). Most beneficial effects from silicon are realized through the formation of silicon gel, which is deposited on the surface of leaves, stems and other organs of rice crops (Fallah, 2012).

Lodging may occur in vigorously growing rice plants after heading stage. It constitutes a major constraint to rice production, especially in high yielding environments. It causes direct loss in grain yield and quality and has some indirect effects such as hindering harvesting operations (Fallah, 2000). Although silica has not been considered important for vegetative growth but it aids the plant in healthy development under stresses in different grasses especially in rice. Plant tissue analysis has revealed the optimum amount of silica to be necessary for cell development and differentiation (Liang *et al.*, 2005). Silicon helps plants to overcome multiple stresses including biotic stresses such as insect-pests and diseases like blast, brown spot and sheath blight and also abiotic stresses such as metal toxicity, salinity, drought and temperature (Ma, 2004 and Liang *et al.*, 2007).

Many scientists working on role of silicon in plant growth have concluded that reduced amount of silicon in plant develops necrosis, disturbance in leaf photosynthetic efficiency, growth retardation and reduces grain yield in cereals

especially rice (Shashidhar *et al.*, 2008). Rice is considered to be a silicon accumulator plant and tends to actively accumulate Si to tissue concentrations of 5% or higher. Recently Si has been regarded as quasi-essential element for the growth of higher plants (Epstein, 2002). Some of the studies suggest that Si, enhances disease resistance in plants, imparts turgidity to the cell walls and has a putative role in mitigating the metal toxicities (Datnoff *et al.*, 1997). Keeping in view the above facts, the present study entitled” Impact of silicon and nitrogen on growth, lodging and yield of transplanted rice (*Oryza sativa* L.) under temperate conditions” was designed with following objectives:

- To study the impact of silicon and nitrogen on growth and yield of rice
- To study the effect of nitrogen and silicon on lodging
- To workout the relative economics

Chapter 2

REVIEW AND LITERATURE

The present investigation includes two factors viz. four silicon and three nitrogen levels. A brief resume of workdone on the effect of these factors on growth, lodging and yield of transplanted rice and abroad has been reviewed and presented in this chapter under appropriate heads.

2.1 Effect of nitrogen

2.1.1 Growth parameters

Salahuddin *et al.* (2009) revealed that the plant height increased significantly with the increasing rates of nitrogen upto 200 kg ha⁻¹.

Pramanik and Bera (2013) reported that the plant height and number of tillers per hill increased gradually due to successive increase in level of nitrogen fertilizer during both years. Tallest plant height and number of tillers per hill were increased in crop receiving N₂₀₀ kg ha⁻¹ as compared to N₀, N₅₀, N₁₀₀ and N₁₅₀ kg ha⁻¹.

Yoseftabar (2013) observed maximum tillers at 150N kg ha⁻¹ and minimum was obtained by applying nitrogen at the rate of 50 kg ha⁻¹.

Abou-Khalifa (2012) evaluated some rice varieties under different nitrogen levels and found maximum tillers m⁻² when nitrogen was applied at the rate of 220 kg ha⁻¹ while minimum was recorded at control having no nitrogen application.

The highest leaf area index value was observed from 100 kg N ha⁻¹ and the lowest leaf area index value was obtained from control (0 kg ha⁻¹) at all sampling dates (Rahman *et al.*, 2007). Leaf area index value at lower nitrogen levels is less than higher levels. Maximum LAI for all the treatments was obtained at flowering stage and then it was reduced.

Maximum total dry matter accumulation in each treatment was occurred at

grain filling stage (95 days after sowing) and in general it can be stated that the computed value of total dry matter accumulation was more at higher nitrogen levels than lower ones and the percentage of dry weight of 30, 60 and 90 rate kg ha⁻¹ nitrogen treatments was 19, 37 and 50% compared to the control treatment. Correlation between nitrogen content, leaf chlorophyll and net exchange of CO₂ in different rice cultivars emphasis that increase in nitrogen is necessary for dry matter production (Fageria and Baligar, 2001; Fageria and Baligar, 2005; Fageria 2007). It sounds that higher level of nitrogen through effect on yield components specially the number of panicle and the number of seeds per panicle and also effect on traits such as panicle length and increase in flag leaf area causes more increment in total dry matter accumulation (Ntanos and Koutroubas, 2002).

There are many reports on the increase of total dry matter due to increased nitrogen fertilizer application (Rahman *et al.*, 2007). Anzoua *et al.* (2010), Azarpour *et al.* (2011) and Shibu *et al.* (2010), reported that total dry matter production increased due to increased nitrogen application at active tillering stage and panicle initiation stage.

The highest dry matter was obtained when rice plants were fertilized with 100 kg N ha⁻¹ and the lowest dry matter was obtained in control treatment (Haque and Haque, 2016).

Haque *et al.* (2006) studied the effect of nitrogen on phenology, light interception and growth in aromatic rice and revealed that irrespective of cultivars the days required to flowering and maturity significantly increased with the increase in the amount of nitrogen applied.

Generally the slope of relative growth rate curve is indicative of dry matter accumulation rate which was sharper at higher nitrogen fertilizer contents than lower ones. It means that their dry matter accumulation had more rates. The percentage of increase in relative growth rate of 30, 60 and 90 kg ha⁻¹ nitrogen treatments were 11, 23 and 40% compared to the control treatment. Since nitrogen

increases photosynthetic tissues, higher nitrogen fertilizer has higher relative growth rate (Timothy and Joe, 2003) and maximum relative growth rate in the treatments was observed at early growth stage and over the time it is decreased linearly.

Singh *et al.* (2009) reported similar results about relative growth rate changes under nitrogen fertilizer content.

The pattern of relative growth rate changes at nitrogen fertilizer different contents was relatively similar but the computed relative growth rate at higher nitrogen content was more than lower one (Azarpour *et al.*, 2014).

Mehbub *et al.* (2006) reported that lower nitrogen content in internode reduced lodging tendency of variety. The results revealed that the length of internode increased significantly upto 60 N kg ha⁻¹ and no significant difference was found between 60 and 120 N kg ha⁻¹.

Yang *et al.* (2009) reported with the increase in nitrogen rate, the plant height and length of basal internode increased, the diameter of stem and the wall thickness of culm reduced.

Zhang *et al.* (2013) reported that higher levels of nitrogen fertilizer induced reduction of breaking strength of rice varieties due to low culm thickness.

Zhang *et al.* (2014) studied the effects of nitrogen application rate and ratio on lodging resistance of super rice with different genotypes recorded that culm diameter and culm wall thickness were reduced during increase of nitrogen fertilizer rate upto 300 kg ha⁻¹.

Wu-jun *et al.* (2015) reported that increase in nitrogen fertilizer rate, upto 270 kg ha⁻¹, culm thickness increases slightly. The average culm diameter and culm wall thickness of Wuyunjing 23 increased significantly from 17.5 to 21.5%. Similar reports were also revealed by Li *et al.* (2013).

2.1.2 Lodging parameters

Prook and Ennos (1995) found that breaking resistance decreased by 20% as nitrogen fertilizer rate increased from 160 to 240 kg ha⁻¹. Li *et al.* (2013) found that with the increase in nitrogen rate, the breaking resistance decreased with resulted in reduced lodging resistance.

Islam *et al.* (2005) revealed that application of lower amount of nitrogen at the early vegetative stage of rice crop slightly increased the lower internode, dry weight and subsequently internode breaking resistance.

Hwang *et al.* (2012) studied the effect of nitrogen and silicon nutrition on bioactive Gibberellins and growth of rice under field conditions and observed pronounced increase in lodging index at 180 Nkg ha⁻¹ treatment.

Salman (2012) studied the application of nitrogen and silicon rates on morphological and chemical lodging related characteristics in rice (*Oryza sativa* L.) at north of Iran reported that highest bending moment obtained for fourth internode and maximum grain yield (6063kg ha⁻¹) was observed in N₁₅₀.

Hui *et al.* (2013) observed the effect of nitrogen application on stem lodging resistance of rice and its morphological and mechanical mechanisms reported that as nitrogen input increased, basal internode length increased, breaking resistance and elastic modules decreased, lodging index increased.

Jafari *et al.* (2013) studied the effects of weeds control and nitrogen application on weeds and rice characteristics I Iranian paddy field reported that bending moment of third internode increased 28.32% with nitrogen application (92 kg ha⁻¹) compare to control (0 kg ha⁻¹). Bending moment of third internode 2528, 2669, 2807, 3017 and 3244 g cm was obtained by nitrogen application 0, 23, 46, 69 and 92 kg ha⁻¹ respectively.

Wu-jun *et al.* (2015) evaluated top dressing nitrogen fertilizer rate which contributes to reduce culm physical strength through decrease in structural carbohydrate contents in japonica rice varieties and revealed that increasing

nitrogen upto 270 kg ha⁻¹, increased the lodging index value significantly in both varieties.

2.1.3 Yield attributes

Krishnan *et al.* (1994) revealed a linear rice response with increasing nitrogen levels though the yield contributing characters continued to increase upto 240 kg N ha⁻¹.

Nine different nitrogen levels i.e., 0, 50, 75, 100, 125, 150, 175, 200 and 225 kg ha⁻¹ were evaluated by Manzoor *et al.* (2006) for observing the field effect of rice. Panicle length, no. of productive tillers hill⁻¹, No. of spikelets panicle⁻¹, no. of grains panicle⁻¹ and panicle weight showed increasing trend from 0 kg N ha⁻¹ upto 175 kg N ha⁻¹. These yield contributing characters started declining at 200 kg N ha⁻¹ level and above.

Manzoor *et al.* (2006) evaluated that the response of rice crop (Super Basmati) to different levels of nitrogen observed that the number of grains per panicle were more 9130.21) at a nitrogen level of 175 kg ha⁻¹ which remained statistically at par with that obtained by nitrogen application levels between 125 to 225 kg per hectare.

Manzoor *et al.* (2006) evaluated the response of rice crop (Super Basmati) to different nitrogen levels reported that rice plants produced more number of productive tillers per hill (23.42) where 225 kg Nitrogen per hectare was applied which remained statistically at between 125 to 200 kg per hectare.

Kumar *et al.* (2007) evaluated the study of relative response of high yielding variety and a hybrid of rice to levels and sources of nitrogen showed that the number of spikelets per panicle increased significantly with the application of 180 kg N ha⁻¹ as compared to other nitrogen levels.

An experiment was conducted by Salahuddin *et al.* (2009) at the Agronomy field lab, BAU, Mymensingh on the yield contributing characters of transplant Aman rice (var. BRRI Dhan 31). A gradual increase in panicle length

(24.50 cm) and grains panicle⁻¹ (110) were observed with the increase in nitrogen levels upto 150 kg ha⁻¹ and declined thereafter. Thousand grain weight was not significantly influenced by application of different levels of nitrogen.

Salahuddin *et al.* (2009) evaluated the response of nitrogen and plant spacing of transplanted Aman rice recorded that the number of panicles increased with the increasing rates of nitrogen upto 200 kg per hectare and it was found significant higher from other levels of nitrogen.

According to the findings of Kandil *et al.* (2010) maximum number of filled grains panicle⁻¹ were obtained at maximum number of filled grains panicle⁻¹ were obtained at maximum level of nitrogen i.e., 192 kg ha⁻¹ while minimum value was given by control having no nitrogen application.

Kaushal *et al.* (2010) counted more productive tillers m⁻² (48.34) when maximum level of nitrogen (150 kg ha⁻¹) was applied.

Metwally *et al.* (2011) checked the response of hybrid rice to different levels of nitrogen and found that number of filled grains panicle increased significantly with increase in nitrogen level upto certain limit and then starts declining with further increase

Abou-khalifa (2012) checked some rice varieties under different levels of nitrogen and found the significant effect of nitrogen on panicle length. Nitrogen fertilization at higher rate gave rise to increase panicle length (20.81) while control having no nitrogen application gained minimum panicle length (18.23 cm).

Two field experiments were conducted by Abou-khalifa (2012) to evaluate of five rice varieties under different nitrogen levels (0, 55, 111, 165 and 220 kg ha⁻¹). Main results induced that number of grains per panicle and panicle length were the highest value at 220 kg N ha⁻¹

Hasanuzzaman *et al.* (2012) observed more productive tillers hill⁻¹ (11.42) when 200 kg Nitrogen was used per hectare while minimum value (10.12) was

given by control having no nitrogen application.

Pramanik and Bera (2013) evaluated to study the effect of seedling age and nitrogen fertilizer on growth, chlorophyll content, yield and economics of hybrid rice (*Oryza sativa* L.) reported that the panicle length increased steadily upto the application of 200 kg N ha⁻¹.

Yoseftabar (2013) reported that number of grains panicle⁻¹ increased significantly with increase in nitrogen rate and maximum number of grains panicle⁻¹ (209.85) were recorded when nitrogen was applied @ 300 kg ha⁻¹ while minimum (190.31) was observed at 100 kg ha⁻¹.

In another field study Yoseftabar (2013) found more grains per panicle (96.51) when nitrogen was applied @ 150 kg ha⁻¹ while minimum (94.94) was obtained at 50 kg N ha⁻¹.

Yoseftabar (2013) noticed that panicle length increased with an increase in nitrogen fertilization, maximum panicle length (28.64) was obtained by applying 300 kg N ha⁻¹ while minimum was counted when nitrogen was applied @100 kg N ha⁻¹.

A field experiment was conducted by Pramanik and Bera (2013) where they found that the nitrogen levels 150 kg ha⁻¹ gave significant higher panicle weight and number of panicles as compared to other levels during both years.

Yoseftabar (2013) reported that panicle number and panicle weight increased significantly with nitrogen fertilizer @ 300 kg N ha⁻¹.

Siddique *et al.* (2014) evaluated the effect of nitrogen level on growth and yield of transplanted Aman rice CV.SURJOMONI recorded the maximum number of sterile spikelets panicle⁻¹ (39.82) was produced at 180 kg N ha⁻¹ and the minimum (29.16) at 0 kg N ha⁻¹. The results showed that number of sterile spikelets panicle gradually increased with level of nitrogen.

Rahman *et al.* (2007) evaluated the effect of number of seedlings hill⁻¹ and nitrogen levels on growth and yield of BRR1 dhan 32 reported that weight of 1000-grain weight were affected by different nitrogen levels.

Khorshida *et al.* (2011) reported that the effect of nitrogen fertilizer had no significant difference on 1000 seed weight.

Pramanik and Bera (2013) evaluated hybrid rice to three levels of seedling age and five levels of nitrogen. They observed that thousand grain weight increased gradually with increase in nitrogen rate from 0 to 150 kg ha⁻¹, maximum 1000-kernel weight (24.11g) was obtained with the application of 150 kg N ha⁻¹ and it decreased with further increase in nitrogen upto 200 kg ha⁻¹.

2.1.4 Post harvest observations

Nine different nitrogen levels i.e., 0, 50, 75, 100, 125, 150, 175, 200 and 225 kg ha⁻¹ were evaluated by Manzoor *et al.* (2006) for observing the field effect of rice and he also reported that maximum paddy yield (4.24 t ha⁻¹) was obtained from 175 kg ha⁻¹ nitrogen application treatment.

Metwally *et al.* (2011) studied to evaluate the response of egyptain hybrid rice 1 'H1' to nitrogen fertilizer. Nitrogen levels were 0, 50, 100, 150, 200, 250, 350 and 400 kg N ha⁻¹. Nitrogen fertilization significantly increased grain yield. The maximum grain yield was obtained with the application of 200 kg N ha⁻¹.

Abou-Khalifa (2012) evaluated rice varieties to different levels of nitrogen and found higher grain yield (10.64 t ha⁻¹) when nitrogen was applied at maximum level (220 kg ha⁻¹) where as minimum (7.11 t ha⁻¹) was recorded in case of no nitrogen application.

A field trail was carried out by Sharma *et al.* (2012) at HRC, Uttarakhand. The two years data revealed that the highest grain yield of 70.60 t ha⁻¹ was attained with the application of 180 kg N ha⁻¹. The lowest yield (44.12t ha⁻¹) was recorded in the control plot.

Yoseftabar 2013 tested hybrid rice using three levels of nitrogen and reported maximum yield (8611.0 kg ha⁻¹) by applying maximum level of nitrogen (300 kg ha⁻¹).

Kumar *et al.* (2007) reported that relative response of high yielding variety and a hybrid of rice to levels and sources of nitrogen recorded that straw yield were significantly higher @180 kg N ha⁻¹ during both years compared to other levels of nitrogen.

Awan *et al.* (2011) observed that straw yield increased significantly with increase in nitrogen level. Results revealed that maximum straw yield (9662.03 kg ha⁻¹) was obtained by applying nitrogen @ 156 kg ha⁻¹ while minimum (7867.27 kg ha⁻¹) was recorded with the application of 110 kg N ha⁻¹.

Pramanik and Bera (2013) evaluated the effect of seedling age and nitrogen fertilizer on growth, chlorophyll content, yield and economics of hybrid rice (*Oryza sativa* L.) recorded highest straw yield (74.61 and 77.39 kg ha⁻¹) was produced in crop receiving 200 kg N ha⁻¹ and was closely followed by the crop (7243 and 7460 kg ha⁻¹) at the 150 kg N ha⁻¹ during two consecutive years. Both the nitrogen levels recorded significantly higher straw yield than those obtained at the lower nitrogen levels.

Siddique *et al.* (2014) evaluated that the effect of nitrogen level on growth and yield of T. aman rice CV. SURJOMONI reported that the application of nitrogen fertilizer increased straw yield upto 180 kg N ha⁻¹.

Awan *et al.* (2011) found that harvest index was not significantly affected by nitrogen rates where as Pramanik and Bera (2013) reported significant effect of nitrogen on harvest index, maximum harvest index (47.07%) was observed when nitrogen was applied @ 150 kg ha⁻¹ while minimum (42.60%) was obtained in case of control having no nitrogen application.

Hasanuzzaman *et al.* (2012) evaluated the response of hybrid rice to different levels of nitrogen and phosphorus recorded that harvest index was the

highest (51.75%) in 160 kg ha⁻¹ followed by 120 kg ha⁻¹.

Jahan *et al.* (2014) evaluated that the effect of different nitrogen levels on yield performance of aromatic rice varieties reported that highest harvest index (25.57%) was obtained from 60 kg N ha⁻¹ which was statistically identical with 30 kg N ha⁻¹ and control treatment. The lowest harvest index (20.27%) was recorded from 120 kg N ha⁻¹. This result indicated that increasing rate of nitrogen application was increased biological yield and decreased harvest index.

Siddique *et al.* (2014) evaluated that the effect of nitrogen level on growth and yield of T. aman rice CV. SURJOMONI observed that the highest harvest index (39.60%) was recorded with the application of 90 kg N ha⁻¹ which was statistically similar to 45 kg N ha⁻¹ (39.49%) and the lowest harvest index (36.00%) with 180 kg N ha⁻¹.

Gerami *et al.* (2012) observed to study of silicon and nitrogen on yield components and shoot ions nutrient composition in rice recorded that shoot silicon was statistically affected by nitrogen levels.

Prakash *et al.* (2013) proposed the effect of N and P levels on growth parameters, yield parameters, yield, nutrient uptake and economics of rice observed that the highest total nitrogen uptake by rice was recorded with application of 240 kg N ha⁻¹ and lowest was with application of 160 kg N ha⁻¹ in grain and straw.

2.1.5 Relative economics

Malik *et al.* (2014) evaluated the effect of different levels of nitrogen on growth and yield attributes of different varieties of Basmati rice (*Oryza sativa* L.) described from the data that N level 120 kg ha⁻¹ gave the maximum profit of Rs 30914 with the benefit cost ratio of 3.5.

Murthy *et al.* (2015) evaluated that the effect of nitrogen, phosphorus and potassium on performance of rice revealed that the economic analysis of three years pooled data showed that the highest gross returns, net returns and rupee per

rupee invested were higher with application of NPK @ 210-60-40 kg ha⁻¹. Though the gross returns, net returns and rupee per rupee invested were increased progressively with incremental doses of nitrogen.

2.2 Effect of Silicon

2.2.1 Growth parameters

Ahmad *et al.* (2012) showed that the effect of silicon and boron foliar application on yield and quality of rice revealed that the maximum plant height (104.69cm) was recorded with the application of 1% Si solution.

Ahmad *et al.* (2013) studied the effect of foliar application of silicon on yield and quality of rice reported that plant height was non-significant with the application of all silicon treatments.

Malav *et al.* (2015) studied the effect of silicon levels on growth, yield attributes and yield of rice in typic ustochrepts soils recorded that silicon fertilizers significantly increased plant height.

Fallah (2000) concluded, by increasing the amount of silicon in nutrient solution feeding, the tillering of rice has increased.

Pereira *et al.* (2004) reported that increase in applied silicon amount enhanced the total number of tillers m⁻².

With the increase of silicon levels, the dry weight of the plant will increase together with its height and number of tillers (Gerami *et al.*, 2012).

Jafari *et al.* (2013) evaluated nitrogen and silicon application facts on rice growth parameters at Alborz Mountain range found that Si₆₀₀ kg ha⁻¹ had the highest significant no. of tillers per hill as compared to control.

Pati *et al.* (2015) evaluated the effect of silicon fertilization on growth, yield and nutrient uptake of rice recorded that greatest increase in number of tillers (325.5 m⁻²) of rice occurred with the application of silicon at 600 kg DE ha⁻¹.

Pereira *et al.* (2004) studied silicon sources for rice crop and they found that with respect to dry matter yield, Wollastonite showed linear increase with increasing silicon doses.

Singh *et al.* (2006) evaluated the effect of level and time of silicon application on growth, yield and its uptake by rice (*Oryza sativa* L.) concluded that increasing level of silicon upto 120kg/ha significantly increased leaf area index and dry matter.

Ahmad *et al.* (2011) found that the increase in silicon leads to increase in leaf area index, chlorophyll content, leaf dry weight, total dry weight and remarkable decrease in leaf water potential and shoot to root ratio in rice cultivars as compared to control treatment

Fallah (2012) studied silicon effect on lodging parameters of rice plants under hydroponic culture revealed that total dry weight was increased upto 100 ppm as compared to the control.

Yadi *et al.* (2011) reported that number of nodes, length of first, second and fourth internode diameter increased with increase in silicon fertilizer application @600 kg ha⁻¹.

Fallah (2012) observed silicon effect on lodging parameters of rice plants under hydroponic culture found that internode length and culm thickness was affected by silicon and show a significant increase with increasing silicon level upto 100 ppm. Silicon improved internode length in rice (Fallah, 2008).

2.2.2 Lodging parameters

Silicon improved bending moment, breaking resistance, lodging index and increase tolerance of lodging in rice (Fallah, 2008).

Yadi *et al.* (2011) reported that bending moment increased with increase in silicon fertilizer application @ 600 kg ha⁻¹.

Fallah (2012) observed silicon effect on lodging parameters of rice plants

under hydroponics culture found that bending moment was affected by silicon and records show a significant increase with increasing silicon level upto 100 ppm and showed that breaking resistance increased with increasing silicon concentration in the culture solution while the lodging index decreased.

Kim *et al.* (2013) studies silicon treatment to rice (*Oryza sativa* L. cv 'Gopumbyco') plants during different growth periods and its effects on growth and grain yield recorded that the lodging index of silicon treated rice plants significantly decreased(13.7% on liquid silicon 25%) as compared to control.

2.2.3 Yield attributes

Pereira *et al.* (2004) reported that increase in applied silicon amount enhanced the number of productive tillers.

Kim *et al.* (2012) studied silicon treatment to rice (*Oryza sativa* cv. 'GOPUMBYEO') plants during different growth periods and its effects on growth and grain yield reported that best silicon concentration (LS-36%) increased the number of panicles per plant and other yield attributing characters as compared to control.

Ahmad *et al.* (2013) evaluated the effect of foliar application of silicon on yield and quality of rice (*Oryza sativa* L.) reported that spike panicle and 1000-grain weight were significantly highest with the treatment of Si₃ (1.0% silicon) as compared to control.

Pati *et al.* (2015) studied the effect of silicon fertilization on growth, yield and nutrient uptake of rice showed that application of silicon @ 600 kg DEha⁻¹ significantly increased yield attributing parameters such as number of panicles m⁻² and 1000-grain weight.

2.2.4 Post harvest observations

Agarie *et al.* (1993) showed that silicate fertilizers increased dry matters by effect on vegetation growth. Consequently increases straw yield.

Chaoming *et al.* (1999) stated that silicon application increased grain yield by increase of spikelet number, filled spikelet percentage and 1000-seed weight.

Muad *et al.* (2003); Ma and Takashi (1990); Mobasser *et al.* (2008) reported that grain yield increased by silicon application.

The studies found that the addition of silicon in nutrient solution increased the silicon in leaves as well as in straw (Kaya *et al.*, 2006).

Malidareh (2011) studied silicon application and nitrogen on yield and yield components in rice (*Oryza sativa* L.) in two irrigation systems reported that silicon application increased grain yield but decreased harvest index.

Fallah (2012) studied silicon effect on lodging parameters of rice plants under hydroponic culture reported that silicon concentration in roots, stems, green leaves and panicles increased under application of silicon. Silicon content in plant parts decreased under increased nitrogen concentration in the cultural solution.

Kim *et al.* (2012) observed silicon treatment of rice (*Oryza sativa* L. cv' GOPUMBYEO') plants during different growth periods and its effects on growth and grain yield reported that best silicon application concentration (LS-36%) increased grain yield per 10 acre as compared to control.

Ahmad *et al.* (2013) found that foliar application of 1% silicon solution produced highest paddy yield (4.88 t ha⁻¹) but all three silicon applications are statistically similar while differing from control and also maximum straw yield (12.61 t ha⁻¹) was produced when 1% silicon was applied followed by 0.5% silicon and 0.25% respectively while minimum (10.49 t ha⁻¹) was found in control (Si₀). Similar were reported by Ahmad *et al.* (2007).

Ahmad *et al.* (2013) also evaluated the effect of foliar application of silicon on yield and quality of rice (*Oryza sativa* L.) found that silicon showed no significant effect on harvest index among all treatments.

Prakash *et al.* (2011) evaluated the effect of foliar spray of soluble silicic

acid on growth and yield parameters of wetland rice in hilly and coastal zone soils of Karnataka. South India reported that foliar spray of silicon at 2 and 4 ml L⁻¹ alone increased the silicon percent and uptake in both grain as well as straw of both the locations.

Malav *et al.* (2015) studied the effect of silicon levels on growth, yield attributes and yield of rice in typic ustochrepts soils reported that silicon application upto 200 mgSi kg ha⁻¹ soil significantly increased straw yield over control.

Pati *et al.* (2015) studied the effect of silicon fertilization on growth, yield and nutrient uptake of rice reported that silicon application caused a significant increase in harvest index of rice over the control.

Pati *et al.* (2015) also studied the effect of silicon fertilization on growth, yield and nutrient uptake of rice found that concentration and uptake of nitrogen in grain and straw were greater @ 600 kgDE Si ha⁻¹ compared to others.

2.2.5 Relative economics

Alvarez and Datnoff (2001) analyzed the economic potential of silicon for integrated management and sustainable rice production. They reported that the average extra net revenue per year amounts to dollar 73.54 per hectare while applying silicon @ 2.5 ton ha⁻¹.

Jawahar and Vaiyapuri (2010) evaluated the effect of silicon fertilization on economics of rice and they inferred that among the different treatment combinations imposed on rice, silicon at 120 kg ha⁻¹ resulted in more net return invested in rice crop. The next best treatment was 80 kg ha⁻¹.

2.2.6 Interaction effect of silicon and nitrogen levels on grain yield of rice

Singh *et al.* (2005) evaluated the effect of nitrogen and silicon levels on growth, yield attributes and yield of rice in Alfisols observed that yield increased with increasing level nitrogen upto 180 kg ha⁻¹ followed by 150 kg ha⁻¹. Similarly

yield increased with increasing silicon levels, the highest yield being obtained at 150 kg Si ha⁻¹. Rani *et al.* (1997) reported similar findings. Gerami *et al.* (2012) evaluated to study of silicon and nitrogen effects on yield components and shoot ions nutrient composition in rice reported that significant interaction effect of silicon and nitrogen mean square was detected for grain yield. However, due to increase of most yield components at high levels of silicon and nitrogen applications, grain yield was subsequently increased. Rajamani *et al.* (2013) studied that the effect of silicon and nitrogen nutrition on pest and disease intensity in rice reported that among different silica and nitrogen levels, N₁₆₀ + Si₆₀₀ recorded highest grain yield of 7180 kg ha⁻¹ and was at par with other treatments which received N @ 120 and 160 kg ha⁻¹ along with silica gels.

Chapter 3

MATERIAL AND METHODS

The methods employed and materials used for conducting study entitled “Impact of silicon and nitrogen on growth, lodging and yield of transplanted rice (*Oryza sativa* L.) under temperate Kashmir conditions” are detailed in this chapter.

3.1 Location

The field experiment was carried out at Research Farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar during Kharif 2014 and 2015. The site is about 16 km from Srinagar city situated at 34°05' N latitude and 74°-89' E longitude with an altitude of 1587 meters above mean sea level.

3.2 Climatic characteristics

Climatically, the experimental site is located in mid to high altitude temperate zone characterized by hot summers and very cold winters. The average annual precipitation is 944.6mm (average of past 25 years) most of which was received from December to April in the form of snow and rain. Mean weekly meteorological data of cropping season was recorded from meteorological observatory, Division of Agronomy, Shalimar and presented in appendix-I, illustrated in Fig.1. It is evident from the data that mean maximum and mean minimum temperatures for the entire cropping season during 2014 and 2015 were 27.50°C and 12.60°C and 27.30°C and 13.20°C, respectively whereas mean maximum and minimum relative humidities were 82.50 and 55.30 per cent and 82.80 and 56.20 per cent during 2014 and 2015, respectively. The total rainfall received during the experimentation period was 33.3mm during 2014 and 29.5mm during 2015.

3.3 Physico-chemical characteristics of soil

The soil samples taken from 0-15 cm depth from randomly selected spots prior to transplanting of rice crop and it was made composite, then analysed to know the initial fertility status of soil. The results of the analysis are presented in Table 1.

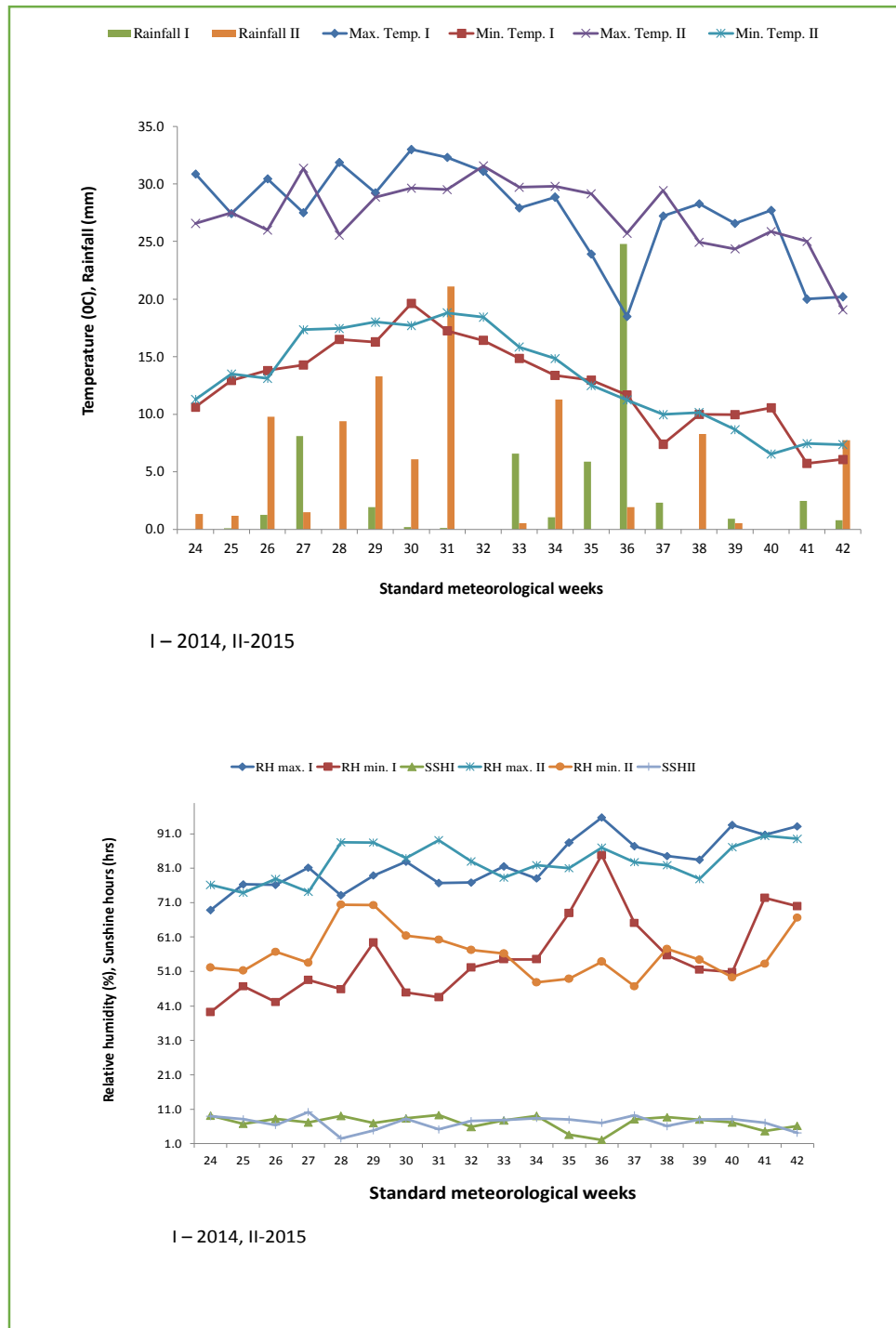


Fig. 1: Average weekly weather data during two cropping seasons

Table 1: Physico-chemical characteristics of soil of experimental field before the start of experiment

Particulars	Rating	Methods employed
A) Mechanical characteristics		
Coarse sand (%)	1.8	International pipette method (Piper, 1966)
Fine sand (%)	17.8	-
Silt (%)	44.5	-
Clay (%)	37.2	-
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°C	0.66	Solubridge conductivity meter (Jackson, 1973)
Organic carbon (%)	0.76	Chromic acid titration method (Walkley and Black, 1939)
Available nitrogen (kg ha ⁻¹)	442.88	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
Available phosphorus (kg ha ⁻¹)	9.3	Extraction with 0.5 N NaHCO ₃ (Olsen <i>et al.</i> , 1954)
Available potassium (kg ha ⁻¹)	221.60	Extraction with neutral normal ammonium acetate (Jackson, 1973)
Available silicon (kg ha ⁻¹)	280.23	Extraction with 20% acetic acid and ammonium molybdate (Yoshida 1976)

3.4 Cropping history of the experimental field

The cropping history of the experimental field in table 2. The crop was followed by brown sarson for two consecutive years.

Table 2: Cropping history of experimental field

Year	Kharif	Rabi
2010	Rice	Brown sarson
2011	Rice	Brown sarson
2012	Rice	Brown sarson
2013	Rice	Brown sarson
2014	Rice (Experimental)	
2015	Rice (Experimental)	

3.5 Experimental details

The experiment comprising two factors (four silicon and three nitrogen levels) was laid out in a randomized completely block design with four replications as per layout plan shown in Fig. 2. The details are given below:

3.5.1 Treatments

A) Silicon application (Source: Calcium silicate as foliar spray)

Treatments	Treatment code
0%	S ₀
5%	S ₁
10%	S ₂
15%	S ₃

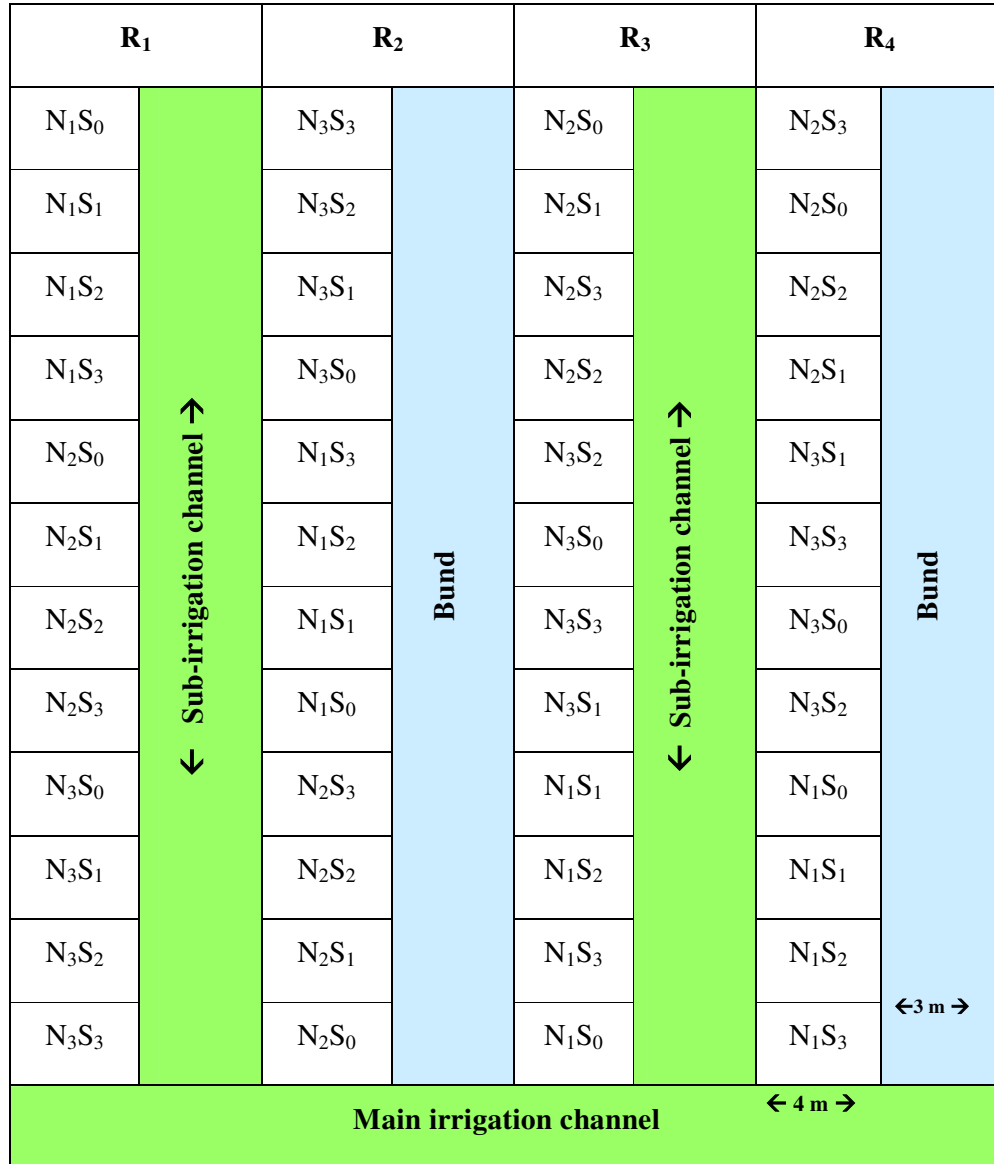
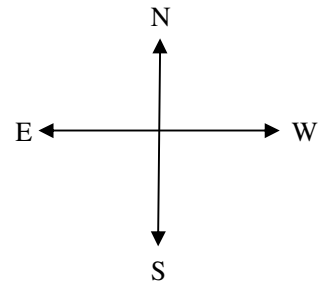


Fig. 2: Layout plan of the experimental field

B) Nitrogen application (Source: urea as soil application)

Treatments	Treatment code
120 kg/ha	N ₁
150 kg/ha	N ₂
180 kg/ha	N ₃

Design	Factorial (RCBD)
Number of replications	4
Number of treatment combinations	12
Total number of plots	48
Spacing	20cm×15cm
Gross plot size	4m×3m=12m ²
Net plot size	3m×2.4m=7.4m ²
Variety	SR-1

3.6 Description of variety (SR-1)

It is low altitude rice variety recommended for cultivation in areas above 1650m amsl. It is derived from a cross between ch-1087×IET-1444 released in 2004. The variety matures in 130-135 days and possesses high yielding capacity of 7.0-7.8 t ha⁻¹. It is moderately resistant to blast. Average height of plant is 120cm. Grains are short and slender. It is very sensitive to lodging.

3.7 Details of field operations

The details of field operations are given in Table 3.

3.7.1 Land preparation

The field was disc ploughed after the harvest of brown Sarson. Subsequently two ploughings were given with tiller followed by one ploughing

Table 3: Details of field operations

Operations	2014	2015
Nursery sowing	11 th May	11 th May
Tractor discing	5 th June	5 th June
Tractorization with tiller and rotavator (3 tuns)	7 th June	7 th June
Layout	8 th June	8 th June
Puddling	9 th June	9 th June
Making of bunds and irrigation channels	10 th June	10 th June
Uprooting of seedlings	11 th June	11 th June
Fertilization (application of basal dose of nitrogen, phosphorus and potassium)	11 th June	11 th June
Transplanting of seedlings	11 th June	11 th june
Application of herbicide (Butachlor)	13 th June	13 th June
First hand weeding	2 nd July	2 nd July
First top dressing of nitrogen	2 nd July	2 nd July
Second top dressing of nitrogen	20 th July	20 th July
Application of silicon	22 th July	22 th July
Irrigation and drainage	18 th Aug	18 th Aug
Harvesting	20 th Oct	20 th Oct
Threshing	23 th Oct	24 th Oct

with rotavator to obtain desirable tilth. However, during 2015 previous year 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 into the soil. Water was let in the plots for puddling operation. Proper leveling of plots were done before transplanting of seedlings. Field was laid out into treatment beds as per the layout plan (fig.2) making four replications, borders, paths and irrigation channels as per requirement.

3.7.2 Fertilizer application

Full dose of phosphorus, potassium and zinc @ 60 kg ha⁻¹, 40 kg ha⁻¹ and 20 kg ha⁻¹ of P₂O₅, K₂O, Zn and half dose of nitrogen with three levels @ 120,150,180 kg N ha⁻¹ respectively through diammonium phosphate, murate of potash, zinc sulphate and urea, respectively was applied to each plot as basal dose 1-2 hours before transplanting of seedlings and mixed well into the soil. Remaining half dose of nitrogen through urea was top dressed into two equal splits, one at tillering and second dose at panicle initiation stage.

3.7.3 Transplanting

Three seedlings per hill were transplanted at a spacing of 20×15cm as per the package of practices.

3.7.4 Application of herbicide

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

3.7.5 Application of silicon

Silicon @ 5%, 10% and 15% were applied in different plots through calcium silicate as foliar spray without control.

3.7.6 Irrigation and Drainage

A water level of 5 cm±2 was maintained in the beds throughout the

vegetative phase except at tillering and panicle initiation stage when fertilizer was applied. After flowering, alternate wetting and drying was followed till dough stage.

3.7.7 Harvesting and threshing

Harvesting was done at physiological maturity i.e. at about 20% moisture content of grain, after excluding border and penultimate rows from all sides of each plot. The harvested crop after sun-drying in the field for 72 hours was piled into bundles and biological weight of each bundle was taken with spring balance in kg per plot and then convert into $q\ ha^{-1}$. Threshing was done with the help of paddy thresher. Rice yield was recorded in $kg\ plot^{-1}$ and then expressed in $q\ ha^{-1}$.

3.8 Experimental observations

Two penultimate rows from both sides of each plot were used for dry matter studies, observations on various plant characteristics were taken from plants falling in randomly selected one metre row length in third penultimate row from sides of each plot. The following observations were recorded during the experiment.

3.8.1 Growth parameters

3.8.1.1 Plant height

Plant height of seven hills tagged in the marked row length from each plot was measured at 15 days interval after transplanting till harvest. The height was measured from ground level to the apex of last fully opened leaf during vegetative period and upto the tip of the panicle after flowering. It was averaged and expressed in centimetres.

3.8.1.2 Tiller count

Number of tillers was counted at 15 days interval after transplanting till harvest from one metre marked row of each plot and expressed as tillers m^{-2}

3.8.1.3 Leaf area index

The leaf area index was recorded at 15 days interval after transplanting using canopy analyser Accupan L-80.

$$\text{Leaf area index} = \frac{\text{Total leaf area}}{\text{Ground area}}$$

3.8.1.4 Dry matter accumulation

Samples of six randomly selected hills from penultimate rows in each plot were collected at 15 days interval after transplanting till harvest. After sun-drying for one day, the samples were oven dried at 60-65 °C till constant weight was obtained. The dry weight was recorded in grams with the help of electronic balance and then converted into qha⁻¹

3.8.1.5 Number of days taken to reach phenological stages

Number of days taken by the crop to reach various phenological stages was recorded from each treatment. This was determined when more than 50% of the plants in the plot attained the stage viz. mid tillering, panicle initiation, anthesis and physiological maturity.

3.8.1.5 Relative growth rate

Relative growth rate was recorded at 15 days interval after transplanting till harvest using the formula,

$$\text{RGR} = \frac{\text{Loge } W_2 - \text{Loge } W_1}{t_2 - t_1}$$

Where, W_1 and W_2 are dry matter at times t_1 and t_2 respectively

3.8.1.7 Internode length (cm)

Number of internode lengths were counted at four stages viz. mid-tillering, panicle initiation, anthesis and maturity from five randomly tagged hills of each plot and expressed as cm.

3.8.1.8 Culm thickness (mm)

Culm thickness was recorded at 15 days interval after transplanting till harvest using vernier clipper.

3.8.2 Lodging parameters

3.8.2.1 Breaking resistance (g.cm)

The rice plant was tied to the hook of a weighing balance with the help of rope. The rope was then pulled and the weight (in grams) at which the rice plant got lodged was recorded and the length of that whole plant was measured expressed in cm.

3.8.2.2 Bending moment (g.cm)

Bending moment (g.cm) using the formula,

$$\text{BMN}_3 = \text{Length from the lowest node of N}_3 \text{ to the top of panicle} \times (W_1 + W_2)$$

Where w_1 is the fresh weight of whole plant and w_2 is the fresh weight of third internode with leaf sheath.

3.8.2.3 Lodging index (%)

$$\text{Lodging index (\%)} = \text{Bending moment/Breaking resistance} \times 100$$

3.8.3 Observations on yield attributes

3.8.3.1 Number of panicles

The number of panicles from ten randomly tagged hills of each plot was counted and the number was converted into panicles m^{-2}

3.8.3.2 Panicle length

Panicle length of ten randomly selected panicles from each plot was measured from neck node to the tip of panicle and then averaged and expressed in cm.

3.8.3.3 Panicle weight

Ten randomly selected panicles from each plot were weighed and average weight was calculated and expressed in grams.

3.8.3.4 Number of spikelets per panicle

Number of spikelets of 10 randomly selected panicles from each plot were counted and then averaged as spikelets panicle⁻¹

3.8.3.5 Number of grains per panicle

Total number of grains from 10 randomly selected panicles were counted from each plot and expressed as grains panicle⁻¹

3.8.3.7 1000-grain weight

Samples of grain collected separately at the time of threshing from each plot were dried properly. 1000-grains from each of these samples were taken and their weights were recorded and expressed in grams.

3.8.4 Post harvest observations

3.8.4.1 Grain yield

After two days of sun drying of bundles, each net plot was separately threshed. Grain yield of each plot was recorded separately as kg plot⁻¹ and then converted into q ha⁻¹.

3.8.4.2 Straw yield

First, sun dried bundles of net plot were weighted for biological yield then straw yield of each plot was computed by deducting the grain yield from biological yield and expressed as q ha⁻¹.

3.8.4.3 Harvest index (%)

It was calculated by the following formula :

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

3.8.5 Plant analysis

Plant samples collected at harvest were sun dried for 24-48 hours in the field and then oven dried at 60 to 65 °C to a constant weight. Grain and straw samples were separately grinded and subsequently used for chemical analysis as under:

3.8.5.1 Nitrogen content (%)

Nitrogen content was estimated by modified Kjeldhal method (Jackson, 1973) after digesting 0.5g of plant sample (grain and straw) with 10 ml concentrated sulphuric acid and digestion mixture. Nitrogen content was expressed in per cent.

3.8.5.2 Silicon content (%)

Silicon content was estimated by Vanado-molybdo phosphoric yellow method using spectrophotometer after digestion of the samples and expressed in per cent.

3.8.5.3 Nitrogen and silicon uptake by crops

Nitrogen and silicon uptake was calculated by multiplying grain and straw yield with respective percentages of nitrogen and silicon content and expressed in kg ha^{-1}

3.8.8 Relative economics

Economics of different treatments was worked out on the basis of grain and straw yield per hectare. The cost of input and output was estimated as per prevailing market rates. The benefit : cost ratio (returns per rupee invested) was determined as:

$$\text{Benefit cost ratio} = \frac{\text{Net returns}}{\text{Total cost of cultivation}}$$

3.9 Statistical analysis

The data obtained in respect of various observations were statistically analysed by the method described by Cochran and Cox (1963). The significance of 'F' and 'T' was tested at 5% level of significance. The critical difference value was determined wherever 'F' test was found to be significant.

Chapter 4

EXPERIMENTAL FINDINGS

The data obtained in the study entitled “Impact of silicon and nitrogen on growth, lodging and yield of transplanted rice (*Oryza sativa* L.) under temperate Kashmir conditions were tabulated and statistically analyzed. The results of investigation and its analysis were summarized and presented in this chapter in tabulated form along with the description on the experimental findings and necessary figures.

4.1 Growth parameters

4.1.1 Plant height (cm)

Plant height is the primary growth determining character. It is apparent from the Fig. 3 and 4 that the growth curve followed a typical sigmoid pattern with the highest rate of increase between 45 to 75 DAT during both the years of 2014 and 2015. The plant height as affected by different treatments is presented in Table 4. A perusal of the data revealed that plant height increased consistently upto 90 DAT thereafter a gradual increase upto at harvest was recorded with respect to both factors viz. nitrogen levels and silicon applications. At 15 DAT, non-significant difference was recorded with respect to nitrogen levels viz. 120 kg N ha⁻¹, 150 kg N ha⁻¹ and 180 kg N ha⁻¹ during 2014 and 2015. But from 30 DAT upto at harvest, significantly taller plants were recorded with 180 kg N ha⁻¹ followed by 150 kg N ha⁻¹ and significantly lowest plant height was observed with 120 kg N ha⁻¹ during both the years of 2014 and 2015.

There was a non-significant difference with silicon treatments at all levels upto 30 DAT during both the years. Significantly highest plant height was recorded with 15%Si followed by 10%Si which remained statistically at par with 5%Si from 45 DAT upto at harvest and significantly lowest plant height was observed with control from 45 DAT upto at harvest during both the years. While comparing control versus rest of treatments, there was a significant difference among the treatments during both the years.

Table 4: Impact of nitrogen and silicon on plant height (cm) of transplanted rice

↓Treatments Year→		Days after transplanting									
		15		30		45		60		75	
		2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Nitrogen levels (kg ha⁻¹)											
N ₁	120	23.89	24.04	46.66	48.29	58.15	60.02	80.69	82.27	103.08	105.34
N ₂	150	24.35	24.36	47.64	49.20	59.91	61.16	84.15	86.55	104.03	106.81
N ₃	180	24.54	24.65	48.43	50.21	61.81	62.46	87.66	90.73	105.24	107.94
SEm±		0.23	0.27	0.26	0.29	0.38	0.39	1.13	1.16	0.30	0.38
LSD (p≤0.05)		NS	NS	0.78	0.86	1.11	1.14	3.33	3.40	0.89	1.12
Silicon applications (%)											
Si ₀	Control	23.79	24.34	47.16	48.60	56.38	59.15	78.10	80.53	102.41	104.45
Si ₁	5	24.18	24.08	47.27	48.94	59.91	61.23	83.95	85.68	103.93	106.76
Si ₂	10	24.44	24.30	47.59	49.66	60.76	61.52	85.11	87.90	104.24	106.85
Si ₃	15	24.62	24.66	48.29	49.77	62.77	62.96	89.51	91.94	105.90	108.72
SEm±		0.27	0.32	0.31	0.34	0.43	0.45	1.31	1.34	0.35	0.44
LSD(p≤0.05)		NS	NS	NS	NS	1.28	1.32	3.84	3.93	1.03	1.29

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Table 4 contd...

↓Treatments Year→	Days after transplanting						At harvest	
	90		105		120		2014	2015
	2014	2015	2014	2015	2014	2015		
Nitrogen levels (kg ha⁻¹)								
N ₁ 120	113.29	114.35	115.27	115.49	115.91	116.14	116.08	116.42
N ₂ 150	114.62	115.84	116.01	117.49	117.25	118.61	117.50	118.73
N ₃ 180	115.84	117.33	117.95	118.79	119.16	119.98	119.46	120.18
SEm±	0.37	0.44	0.33	0.35	0.40	0.42	0.42	0.48
LSD (p≤0.05)	1.08	1.31	0.98	1.04	1.19	1.25	1.24	1.40
Silicon applications (%)								
Si ₀ Control	112.10	112.86	114.08	114.93	115.03	115.60	115.21	115.89
Si ₁ 5	114.88	116.00	116.45	117.46	117.63	117.91	117.89	118.13
Si ₂ 10	115.01	116.22	116.64	117.61	117.85	118.77	118.08	119.05
Si ₃ 15	116.34	118.29	118.47	119.03	119.25	120.69	119.53	120.71
SEm±	0.42	0.51	0.38	0.41	0.46	0.49	0.48	0.55
LSD (p≤0.05)	1.25	1.51	1.13	1.20	1.37	1.44	1.43	1.62

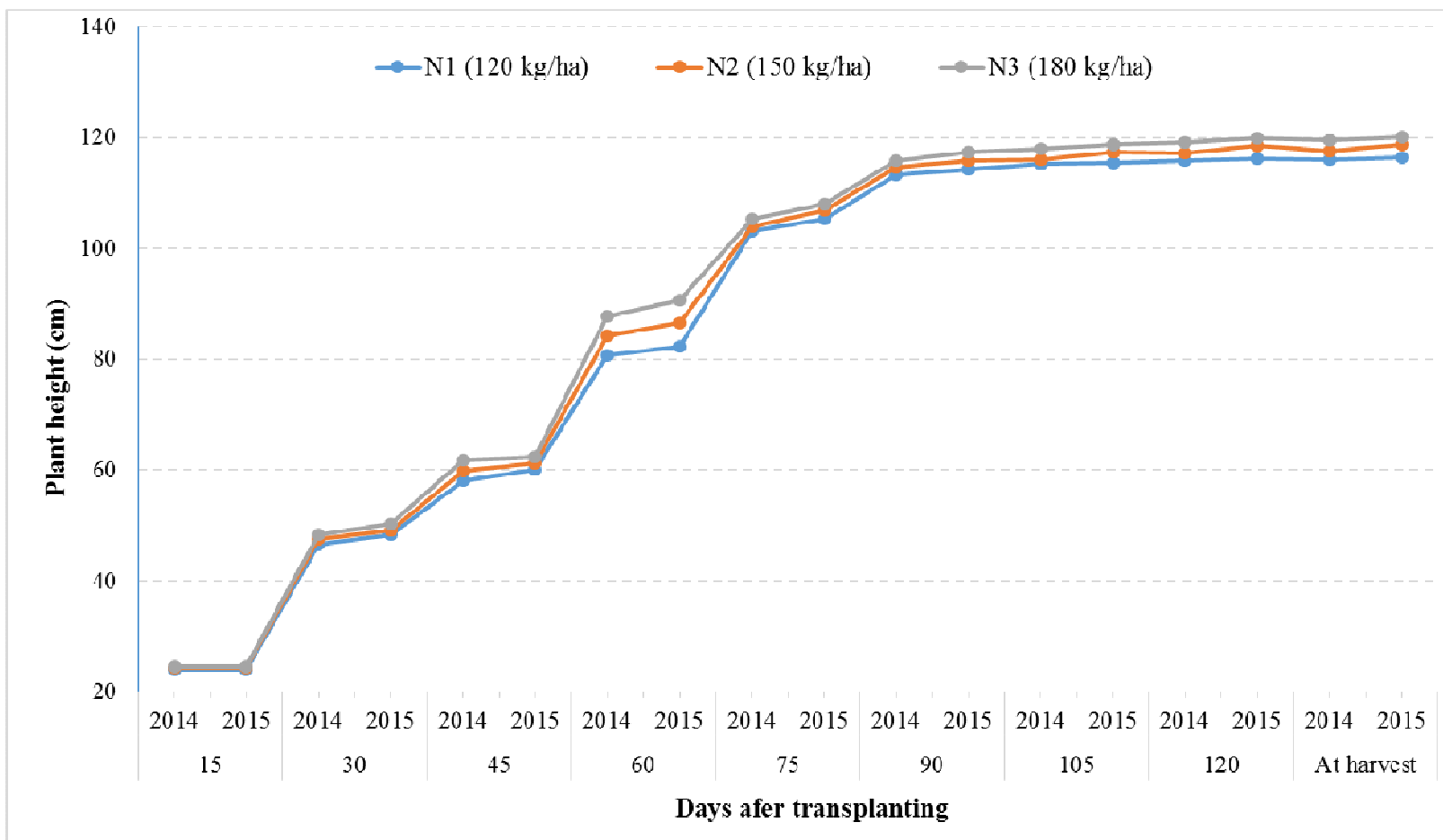


Fig. 3 : Impact of nitrogen on plant height (cm) of transplanted rice

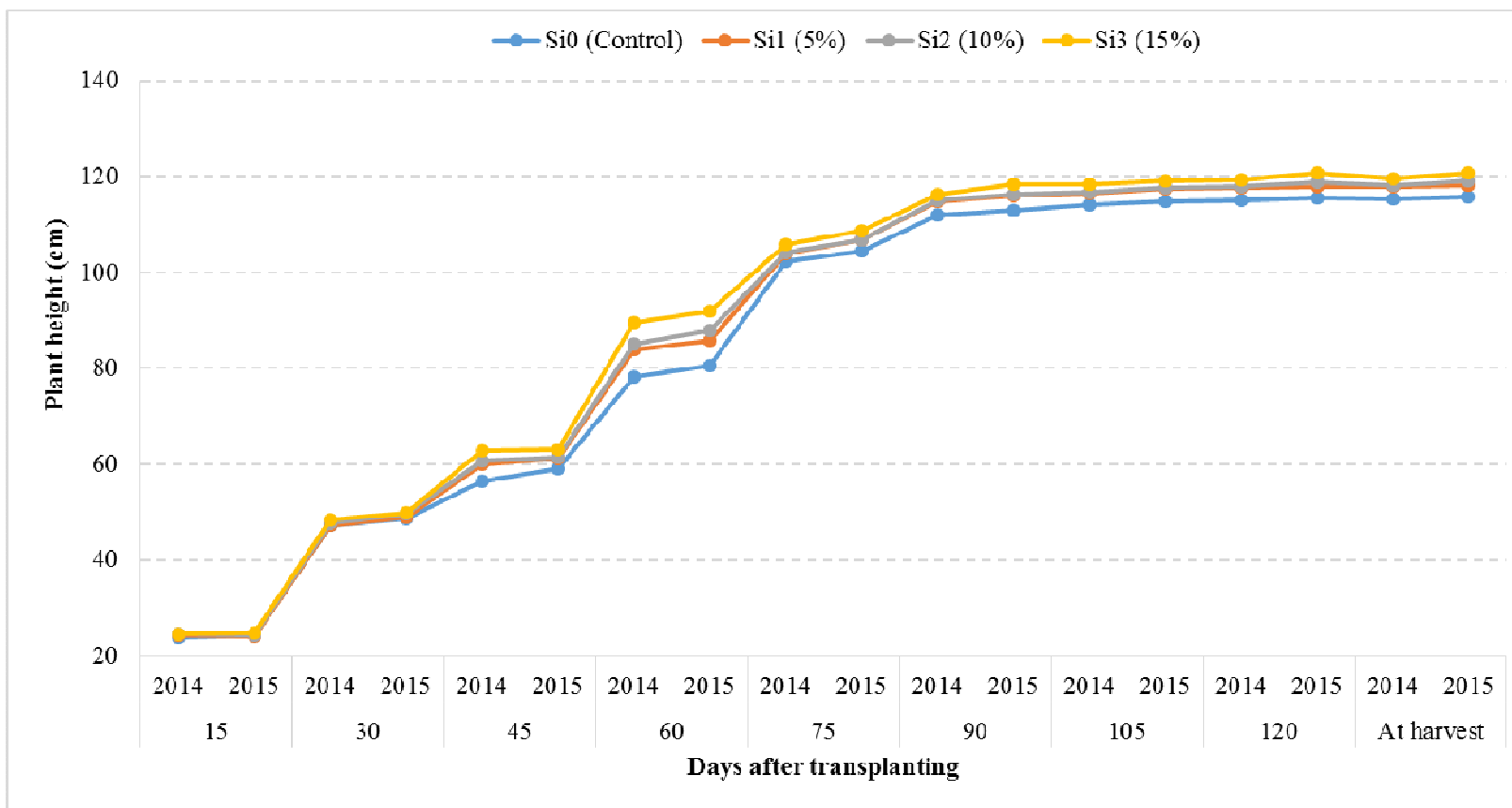


Fig. 4: Impact of silicon on plant height (cm) of transplanted rice

4.1.2 Number of tillers m⁻²

Data presented in Table 5 (Fig. 5 and 6) showed that different nitrogen levels induce significant variation in tillers m⁻². Tiller number increased rapidly from 15 DAT to 45 DAT, thereafter showed a gradual decrease upto at harvest with respect to both factors viz. nitrogen levels and silicon applications during both the years.

Data revealed that all nitrogen levels have shown non-significant differences at 15DAT during both the years. Significantly highest number of tillers m⁻² were recorded with 180 kg N ha⁻¹ followed by 150 kg N ha⁻¹ from 30 DAT upto 45 DAT and significantly lowest number of tillers m⁻² were observed with 120 kg N ha⁻¹ from 30 DAT upto 45 DAT. But from 60 DAT upto at harvest, significantly highest number of tillers m⁻² were recorded with 120 kg N ha⁻¹ followed by 150 kg N ha⁻¹ and lowest tillers were observed with 180 kg N ha⁻¹ during both years.

The data further revealed that non-significant difference was recorded at 15 DAT and 30 DAT with respect to all silicon applications during 2014 and 2015. Significantly lowest tiller count in control compared to rest of treatments at 45 DAT, 60 DAT, 75 DAT, 90 DAT, 105 DAT, 120 DAT and at harvest respectively. However, 15%Si showed significantly highest number of tillers from 45 DAT upto at harvest followed by 10%Si treatment which were at par with 5%Si during both years.

4.1.3 Leaf area index

Leaf area index is an important parameter which influences the growth and yield of a crop and is mainly responsible for photosynthetic activity of the plant.

Data presented in Table 6 (Fig. 7 and 8) indicated that leaf area index increased gradually from 15 DAT upto 60 DAT followed by a sharp decline upto at harvest during both the consecutive years. Among nitrogen levels, non-significant was observed at 15 DAT with respect to all nitrogen levels. At 30 DAT

Table 5: Impact of nitrogen and silicon on number of tillers (m⁻²) of transplanted rice

↓Treatments Year→		Days after transplanting									
		15		30		45		60		75	
		2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Nitrogen levels (kg ha⁻¹)											
N ₁	120	255.17	259.34	331.39	333.67	494.78	498.99	476.28	480.02	441.63	445.48
N ₂	150	259.64	263.73	347.06	352.05	511.73	515.60	470.88	474.48	432.86	437.02
N ₃	180	261.80	266.18	368.74	373.10	527.69	531.78	461.67	466.14	423.71	426.88
SEm±		4.52	5.16	4.92	5.87	5.20	5.27	1.80	1.84	2.95	2.85
LSD (p≤0.05)		NS	NS	14.43	17.23	15.25	15.46	5.28	5.41	8.65	8.36
Silicon applications (%)											
Si ₀	Control	248.53	252.65	345.23	348.77	482.76	486.22	455.82	459.41	418.93	420.22
Si ₁	5	254.84	258.63	346.01	352.35	509.44	514.91	470.25	474.17	431.70	435.70
Si ₂	10	263.30	267.44	348.06	353.58	517.48	520.58	472.13	475.94	434.46	439.51
Si ₃	15	268.81	273.62	356.96	357.07	535.93	540.11	480.24	484.67	445.86	450.42
SEm±		5.22	5.96	5.68	6.78	6.00	6.08	2.08	2.13	3.40	3.29
LSD (p≤0.05)		NS	NS	NS	NS	17.61	17.85	6.10	6.24	9.99	9.65

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Table 5 contd...

↓Treatments Year→	Days after transplanting						At harvest	
	90		105		120		2014	2015
	2014	2015	2014	2015	2014	2015		
Nitrogen levels (kg ha⁻¹)								
N ₁ 120	420.20	424.11	409.43	413.63	404.31	408.05	401.89	405.84
N ₂ 150	410.20	415.39	401.11	405.21	395.76	399.21	392.38	397.30
N ₃ 180	400.65	404.45	389.52	393.50	384.12	385.95	380.48	383.68
SEm±	2.84	2.81	2.78	2.74	2.76	2.80	2.73	2.77
LSD (p≤0.05)	8.35	8.26	8.17	8.06	8.07	8.20	7.83	8.11
Silicon applications (%)								
Si ₀ Control	392.95	396.00	382.98	386.06	377.46	378.20	373.68	375.54
Si ₁ 5	409.34	413.79	398.56	404.10	392.40	395.86	388.93	392.48
Si ₂ 10	414.50	419.61	403.62	407.72	398.73	403.42	395.92	397.80
Si ₃ 15	424.62	429.20	414.92	418.58	410.33	413.46	407.82	409.94
SEm±	3.28	3.25	3.22	3.19	3.21	3.24	3.18	3.20
LSD (p≤0.05)	9.64	9.53	9.44	9.41	9.37	9.49	9.35	9.33

Table 6: Impact of nitrogen and silicon on leaf area index of transplanted rice

↓Treatments	Year→	Days after transplanting									
		15		30		45		60		75	
		2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Nitrogen levels (kg ha⁻¹)											
N ₁	120	0.53	0.51	1.45	1.53	3.00	3.18	5.55	5.89	4.77	5.07
N ₂	150	0.54	0.52	1.54	1.62	3.30	3.50	5.09	5.31	4.32	4.63
N ₃	180	0.55	0.55	1.63	1.77	3.61	3.84	4.63	4.86	3.94	4.27
SEm±		0.007	0.01	0.02	0.03	0.09	0.10	0.14	0.13	0.11	0.12
LSD (p≤0.05)		NS	NS	0.08	0.09	0.28	0.30	0.41	0.40	0.32	0.36
Silicon applications (%)											
Si ₀	Control	0.53	0.51	1.49	1.62	2.88	3.01	4.36	4.67	3.64	3.92
Si ₁	5	0.54	0.52	1.53	1.58	3.30	3.47	4.91	5.28	4.30	4.64
Si ₂	10	0.55	0.54	1.55	1.67	3.36	3.60	5.30	5.50	4.49	4.80
Si ₃	15	0.55	0.53	1.59	1.70	3.69	3.96	5.77	5.96	4.87	5.26
SEm±		0.009	0.01	0.03	0.03	0.11	0.12	0.16	0.15	0.12	0.14
LSD (p≤0.05)		NS	NS	NS	NS	0.33	0.35	0.47	0.46	0.37	0.41

Contd...

Table 6 contd...

↓Treatments Year→	Days after transplanting						At harvest	
	90		105		120		2014	2015
	2014	2015	2014	2015	2014	2015		
Nitrogen levels (kg ha⁻¹)								
N ₁ 120	4.11	4.34	3.94	4.10	3.75	3.88	3.70	3.83
N ₂ 150	3.86	4.09	3.69	3.81	3.54	3.70	3.46	3.61
N ₃ 180	3.68	3.80	3.50	3.65	3.36	3.43	3.20	3.37
SEm±	0.04	0.08	0.06	0.05	0.04	0.04	0.08	0.06
LSD (p≤0.05)	0.14	0.23	0.18	0.15	0.12	0.13	0.24	0.19
Silicon applications (%)								
Si ₀ Control	3.38	3.49	3.02	3.19	2.97	3.10	2.88	2.96
Si ₁ 5	3.90	4.08	3.79	3.91	3.58	3.69	3.45	3.64
Si ₂ 10	4.00	4.21	3.88	4.06	3.66	3.83	3.59	3.76
Si ₃ 15	4.30	4.52	4.15	4.27	3.99	4.08	3.88	4.04
SEm±	0.05	0.09	0.07	0.06	0.04	0.05	0.09	0.09
LSD (p≤0.05)	0.16	0.27	0.21	0.17	0.14	0.15	0.28	0.28

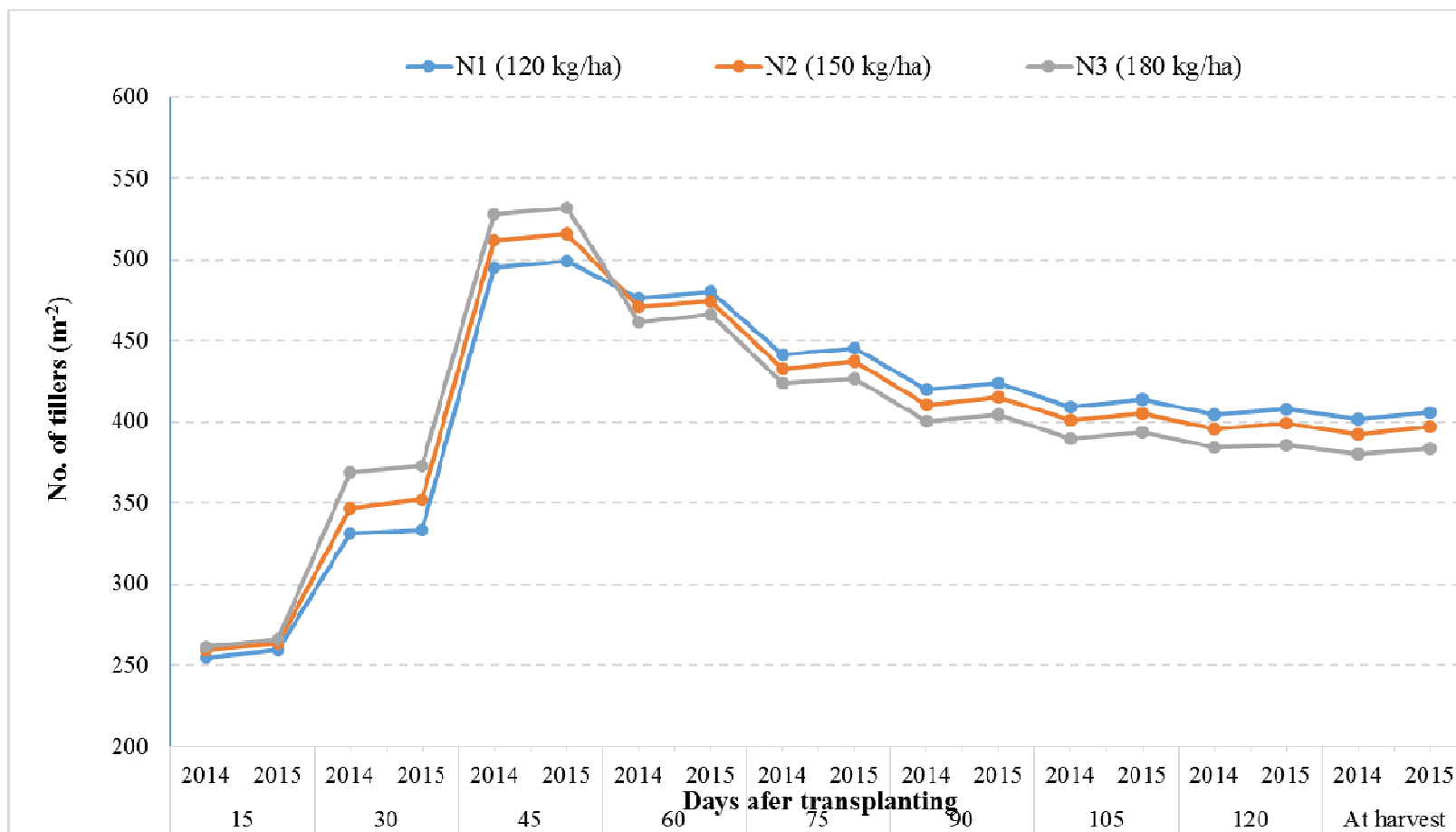


Fig. 5: Impact of nitrogen on tillers (m^{-2}) of transplanted rice

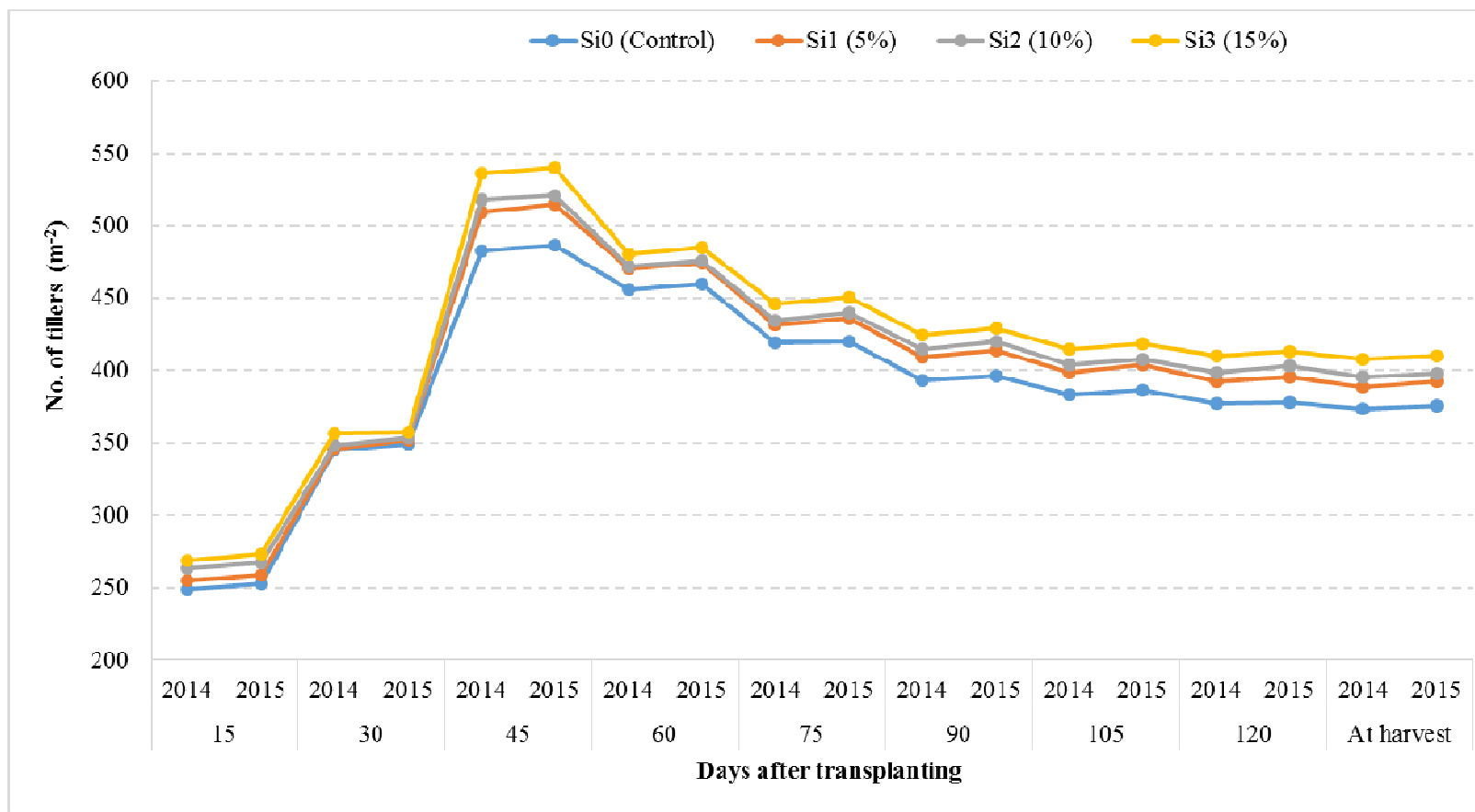


Fig. 6: Impact of silicon on tillers (m⁻²) of transplanted rice

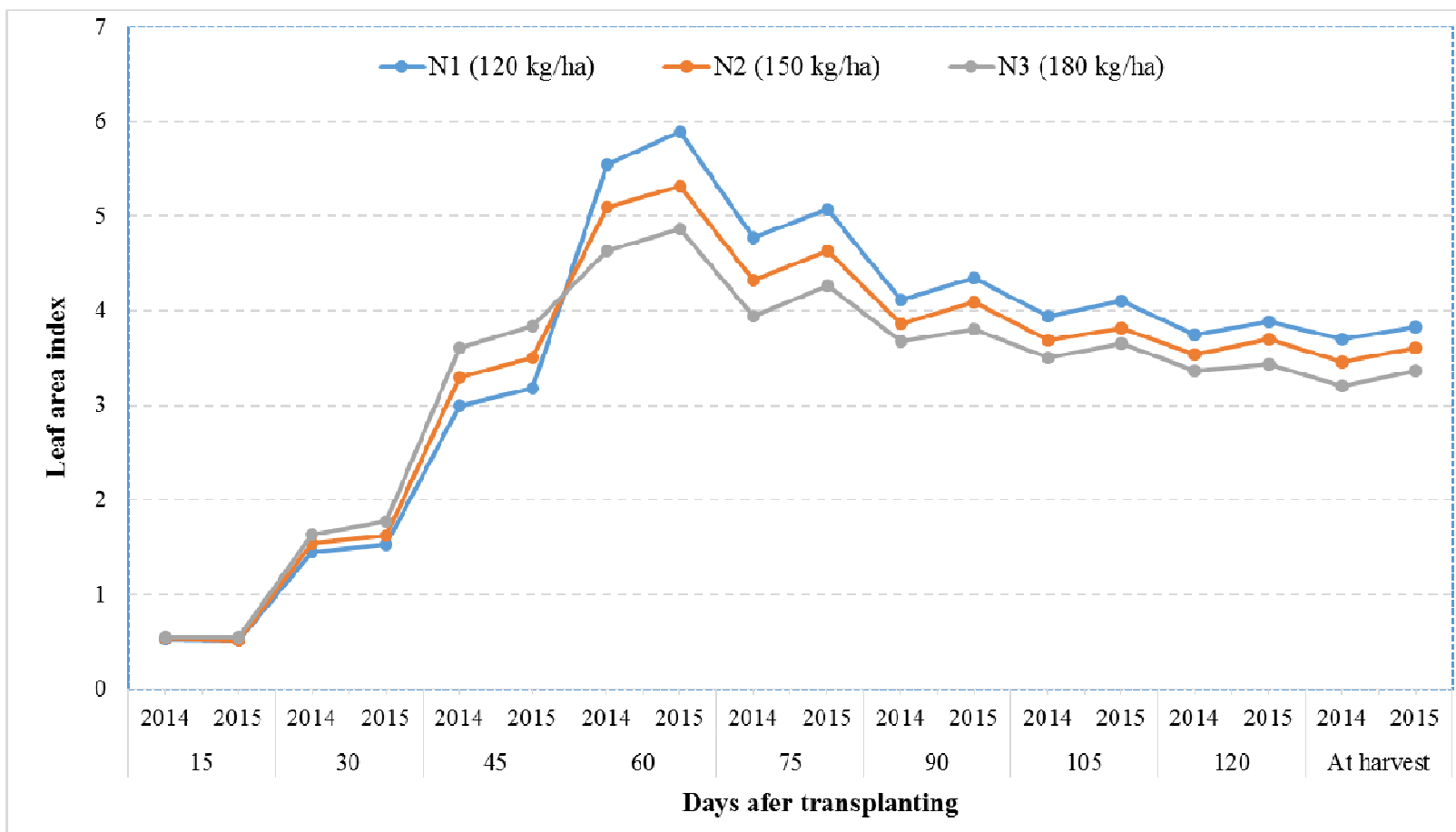


Fig. 7: Impact of nitrogen on leaf area index of transplanted rice

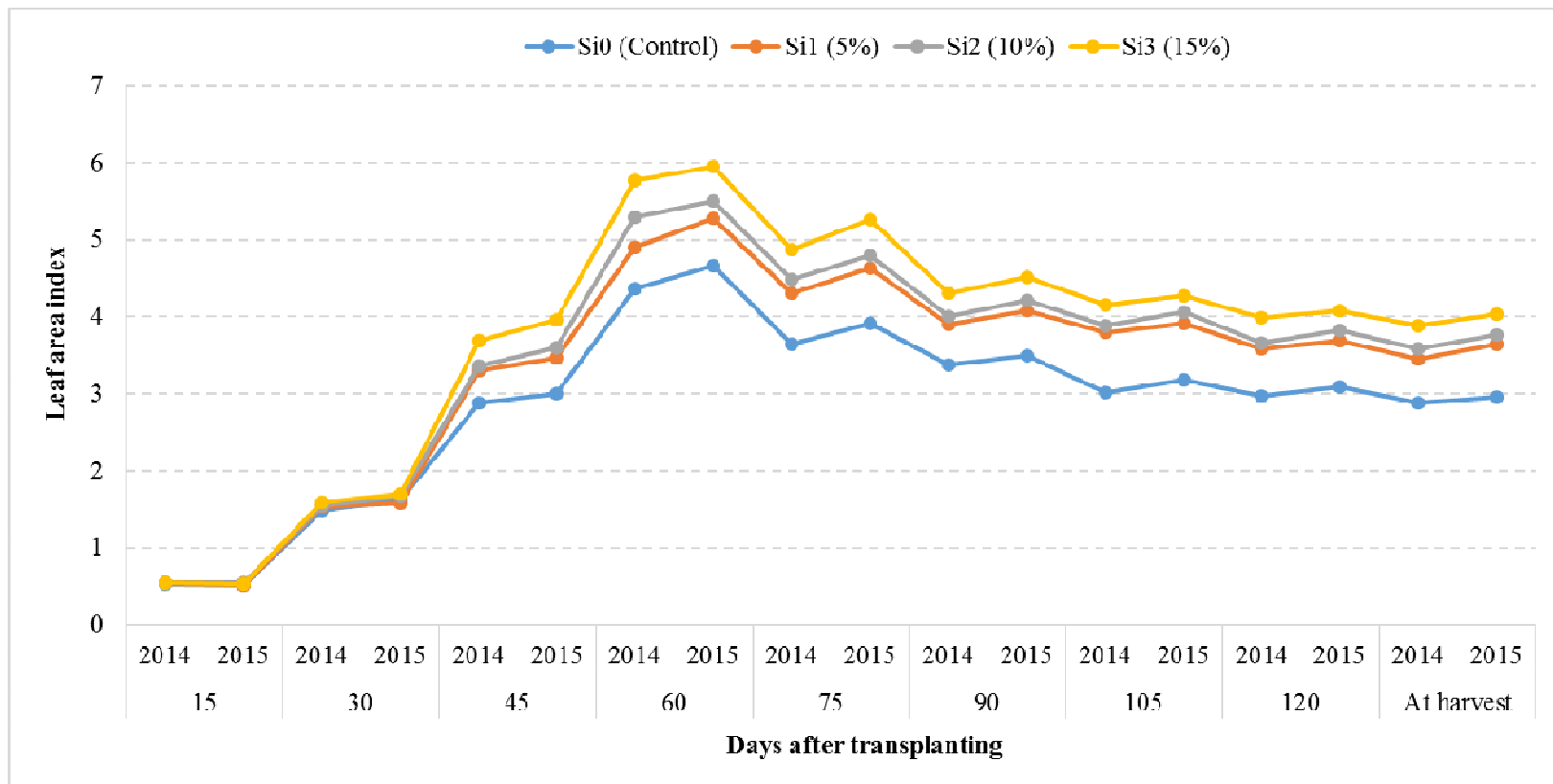


Fig. 8: Impact of silicon on leaf area index of transplanted rice

to 45 DAT, significantly highest leaf area index was recorded with 180 kg N ha⁻¹ followed by 150 kg N ha⁻¹ and lowest was observed with 120 kg N ha⁻¹ during both the years of 2014 and 2015. But from 60 DAT upto at harvest, significantly highest leaf area index was observed with 120 kg N ha⁻¹ followed by 150 kg N ha⁻¹ while lowest was observed with 180 kg N ha⁻¹ during 2014 and 2015.

The data further revealed that among silicon applications, non-significant difference was observed at 15DAT and 30 DAT during both years. At 45 DAT upto at harvest, 15%Si caused highly significant improvement in leaf area index followed by 10%Si which remained at par with 5%Si and significantly lowest leaf area index was recorded in control during 2014 and 2015.

4.1.4 Dry matter accumulation (q ha⁻¹)

Dry matter accumulation is another important character to express the growth and metabolic efficiency of the plant, which ultimately influences the economic yield.

Perusal of data from Table 7 shows an increase in dry matter accumulation with the advancement of crop. Non-significant difference was recorded with respect to all nitrogen levels at 15DAT. 180 kg N ha⁻¹ recorded significantly highest crop dry matter accumulation and significantly lowest was observed with 120 kg N ha⁻¹ from 30 DAT to 45 DAT during 2014 and 2015. But from 60 DAT upto at harvest, 120 kg N ha⁻¹ recorded significantly highest crop dry matter accumulation followed by 150 kg N ha⁻¹ and lowest was recorded with 180 kg N ha⁻¹ during both the consecutive years of 2014 and 2015.

With regards to the effect of silicon applications, non-significant difference was recorded with respect to all silicon applications at 15DAT and 30 DAT during both years. 15%Si recorded significantly highest dry matter accumulation followed by 10%Si which remained statistically at par with 5%Si and lowest dry matter accumulation were observed with control.

Table 7: Impact of nitrogen and silicon on dry matter accumulation ($q\ ha^{-1}$) of transplanted rice

↓Treatments Year→		Days after transplanting									
		15		30		45		60		75	
		2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Nitrogen levels ($kg\ ha^{-1}$)											
N ₁	120	3.91	4.05	12.98	13.84	35.28	37.16	60.86	63.05	96.97	98.63
N ₂	150	4.06	4.20	13.26	14.23	35.64	37.97	58.92	61.36	94.55	96.26
N ₃	180	4.06	4.30	13.53	14.62	36.00	38.52	57.24	58.83	92.39	94.01
SEm±		0.12	0.13	0.08	0.11	0.09	0.12	0.52	0.53	0.65	0.75
LSD ($p\leq 0.05$)		NS	NS	0.24	0.34	0.28	0.37	1.53	1.57	1.92	2.21
Silicon applications (%)											
Si ₀	Control	3.79	3.96	13.11	14.05	34.20	37.01	55.27	56.70	91.39	92.42
Si ₁	5	3.97	4.14	13.20	14.17	35.93	37.91	58.48	61.03	94.09	95.65
Si ₂	10	4.10	4.27	13.31	14.27	36.03	38.06	59.83	62.38	95.38	97.04
Si ₃	15	4.18	4.35	13.41	14.43	36.40	38.55	62.44	64.20	97.69	100.09
SEm±		0.14	0.15	0.09	0.13	0.11	0.14	0.60	0.61	0.76	0.87
LSD ($p\leq 0.05$)		0.42	NS	NS	NS	0.32	0.42	1.76	1.81	2.23	2.55

Contd...

Table 7 contd...

↓Treatments	Year→	Days after transplanting						At harvest	
		90		105		120		2014	2015
		2014	2015	2014	2015	2014	2015		
Nitrogen levels (kg ha⁻¹)									
N ₁	120	149.50	152.45	159.81	162.62	164.60	167.13	168.37	170.65
N ₂	150	147.04	149.84	157.06	159.82	161.68	164.00	164.40	166.29
N ₃	180	144.86	145.60	150.55	153.48	153.94	156.54	156.60	157.97
SEm±		0.71	0.74	0.93	0.95	0.97	0.99	1.19	1.06
LSD (p≤0.05)		2.08	2.17	2.72	2.79	2.86	2.92	3.49	3.13
Silicon applications (%)									
Si ₀	Control	140.32	142.27	148.41	151.15	150.76	153.44	151.27	154.05
Si ₁	5	147.39	149.61	155.18	158.81	160.89	162.45	164.06	165.41
Si ₂	10	148.93	151.05	157.54	160.23	162.25	164.90	166.43	168.11
Si ₃	15	151.90	154.25	162.10	164.38	166.39	169.44	170.74	172.32
SEm±		0.82	0.85	1.07	1.09	1.12	1.15	1.37	1.23
LSD (p≤0.05)		2.41	2.51	3.15	3.22	3.30	3.38	4.04	3.61

4.1.5 Culm thickness (mm)

Culm thickness is important character to express the lodging index of the plant, which ultimately influences the economic yield.

Data pertaining to culm thickness (Table 8) indicated that the influence of nitrogen levels on culm thickness showed that non-significant difference was recorded at 15 DAT during 2014 and 2015. Significantly highest culm thickness was recorded with 120 kg N ha⁻¹ followed by 150 kg N ha⁻¹ and lowest was recorded with 180 kg N ha⁻¹ from 30 DAT upto at harvest during both the years.

The data further revealed that among silicon applications, non-significant difference was observed at 15 DAT and 30 DAT. But from 45 DAT upto at harvest, 15%Si recorded significantly higher culm thickness followed by 10%Si remained at par with 5%Si and lowest was observed with control during both the consecutive years.

4.1.6 Relative growth rate (g g⁻¹ day⁻¹)

The data pertaining to the effect of different treatments on relative growth rate from 15 DAT upto at harvest has been presented in Table 9. The same has been represented graphically in Fig. 9 & 10. At 15DAT, non-significant difference was recorded with respect to all nitrogen levels during both the years. From 30 DAT upto at 45 DAT, relative growth rate were significantly highest with 180 kg N ha⁻¹ followed by 150 kg N ha⁻¹ and lowest was observed with 120 kg N ha⁻¹ during both the years. But from 60 DAT upto at harvest, relative growth rate were significantly highest with 120 kg N ha⁻¹ followed by 150 kg N ha⁻¹ and lowest relative growth rate was recorded with 180 kg N ha⁻¹ during 2014 and 2015.

Among silicon applications, non-significant difference was observed at 15 DAT and 30 DAT with respect to all silicon applications, but 15%Si recorded significantly higher relative growth rate followed by 10%Si which remained at par with 5%Si and significantly lowest was recorded with control from 45 DAT upto at harvest during both the years.

Table 8: Impact of nitrogen and silicon on culm thickness (mm) of transplanted rice

↓Treatments Year→		Days after transplanting									
		15		30		45		60		75	
		2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Nitrogen levels (kg ha⁻¹)											
N ₁	120	0.35	0.37	1.74	1.80	10.61	11.86	17.19	18.35	19.80	20.91
N ₂	150	0.35	0.35	1.61	1.66	10.24	11.48	17.00	18.15	19.52	20.64
N ₃	180	0.33	0.35	1.45	1.52	9.88	11.06	16.72	17.85	19.17	20.27
SEm±		0.01	0.02	0.04	0.05	0.09	0.10	0.05	0.06	0.08	0.08
LSD (p≤0.05)		NS	NS	0.13	0.14	0.26	0.30	0.17	0.19	0.24	0.26
Silicon applications (%)											
Si ₀	Control	0.31	0.32	1.56	1.54	9.41	10.57	16.43	17.54	18.72	19.82
Si ₁	5	0.33	0.35	1.57	1.65	10.15	11.42	16.92	18.09	19.44	20.56
Si ₂	10	0.35	0.36	1.62	1.70	10.39	11.62	17.03	18.23	19.63	20.75
Si ₃	15	0.37	0.39	1.65	1.74	11.02	12.26	17.49	18.61	20.19	21.31
SEm±		0.02	0.02	0.05	0.05	0.10	0.11	0.06	0.07	0.09	0.10
LSD (p≤0.05)		NS	NS	NS	NS	0.30	0.34	0.19	0.22	0.28	0.30

Contd...

Table 8 contd...

↓Treatments Year→		Days after transplanting						At harvest	
		90		105		120		2014	2015
		2014	2015	2014	2015	2014	2015		
Nitrogen levels (kg ha⁻¹)									
N ₁	120	20.85	21.64	21.78	22.89	21.90	23.13	22.14	23.23
N ₂	150	20.48	21.24	21.30	22.48	21.43	22.63	21.68	22.79
N ₃	180	20.01	20.77	20.90	22.01	21.02	22.15	21.13	22.23
SEm±		0.12	0.13	0.13	0.14	0.14	0.16	0.15	0.14
LSD (p≤0.05)		0.37	0.39	0.39	0.41	0.41	0.48	0.44	0.42
Silicon applications (%)									
Si ₀	Control	19.36	20.12	20.26	21.38	20.37	21.52	20.44	21.52
Si ₁	5	20.44	21.21	21.38	22.53	21.50	22.72	21.80	22.88
Si ₂	10	20.68	21.44	21.53	22.66	21.65	22.84	21.92	23.00
Si ₃	15	21.30	22.09	22.15	23.29	22.27	23.46	22.45	23.59
SEm±		0.14	0.15	0.15	0.16	0.16	0.19	0.17	0.18
LSD (p≤0.05)		0.43	0.45	0.46	0.48	0.48	0.58	0.51	0.54

Table 9: Impact of nitrogen and silicon on relative growth rate ($\text{g g}^{-1} \text{ day}^{-1}$) of transplanted rice

↓Treatments Year→		Days after transplanting									
		15		30		45		60		75	
		2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Nitrogen levels (kg ha^{-1})											
N ₁	120	1.29	1.32	2.46	2.52	3.39	3.47	3.85	3.88	4.30	4.31
N ₂	150	1.31	1.34	2.49	2.55	3.40	3.46	3.82	3.85	4.27	4.28
N ₃	180	1.31	1.36	2.51	2.58	3.41	3.43	3.79	3.81	4.24	4.25
SEm±		0.03	0.03	0.007	0.008	0.002	0.003	0.01	0.01	0.009	0.008
LSD ($p \leq 0.05$)		NS	NS	0.022	0.023	0.008	0.009	0.03	0.03	0.027	0.024
Silicon applications (%)											
Si ₀	Control	1.25	1.29	2.48	2.55	3.36	3.43	3.76	3.78	4.23	4.24
Si ₁	5	1.29	1.33	2.48	2.54	3.40	3.45	3.81	3.85	4.27	4.28
Si ₂	10	1.33	1.36	2.49	2.55	3.41	3.46	3.84	3.87	4.28	4.29
Si ₃	15	1.34	1.38	2.49	2.56	3.42	3.48	3.88	3.90	4.31	4.32
SEm±		0.03	0.03	0.008	0.009	0.003	0.003	0.01	0.01	0.01	0.009
LSD ($p \leq 0.05$)		NS	NS	NS	NS	0.009	0.011	0.03	0.03	0.03	0.028

Contd...

Table 4 contd...

↓Treatments	Year→	Days after transplanting						At harvest	
		90		105		120		2014	2015
		2014	2015	2014	2015	2014	2015		
Nitrogen levels (kg ha⁻¹)									
N ₁	120	4.70	4.72	4.74	4.75	4.76	4.77	4.78	4.79
N ₂	150	4.68	4.70	4.72	4.73	4.74	4.75	4.75	4.77
N ₃	180	4.66	4.67	4.67	4.69	4.69	4.71	4.71	4.72
SEm±		0.004	0.004	0.005	0.006	0.005	0.005	0.007	0.006
LSD (p≤0.05)		0.012	0.013	0.016	0.017	0.016	0.015	0.022	0.017
Silicon applications (%)									
Si ₀	Control	4.64	4.65	4.66	4.68	4.67	4.69	4.68	4.70
Si ₁	5	4.68	4.70	4.71	4.73	4.74	4.75	4.76	4.77
Si ₂	10	4.69	4.71	4.72	4.74	4.75	4.76	4.76	4.78
Si ₃	15	4.71	4.73	4.74	4.76	4.77	4.78	4.79	4.80
SEm±		0.004	0.005	0.006	0.006	0.006	0.006	0.008	0.007
LSD (p≤0.05)		0.014	0.015	0.019	0.020	0.018	0.018	0.025	0.020

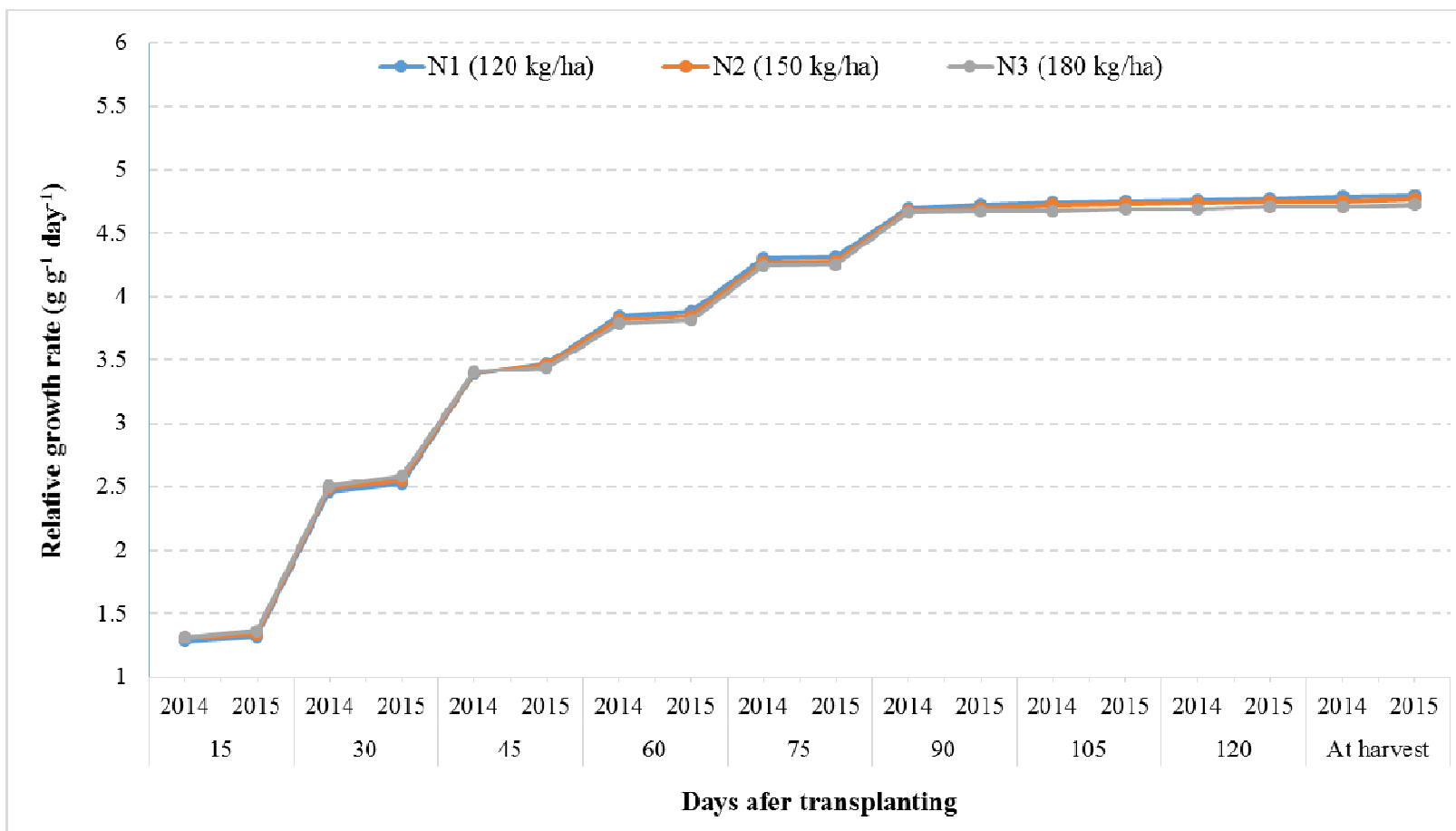


Fig. 9: Impact of nitrogen on relative growth rate ($\text{g g}^{-1} \text{day}^{-1}$) of transplanted rice

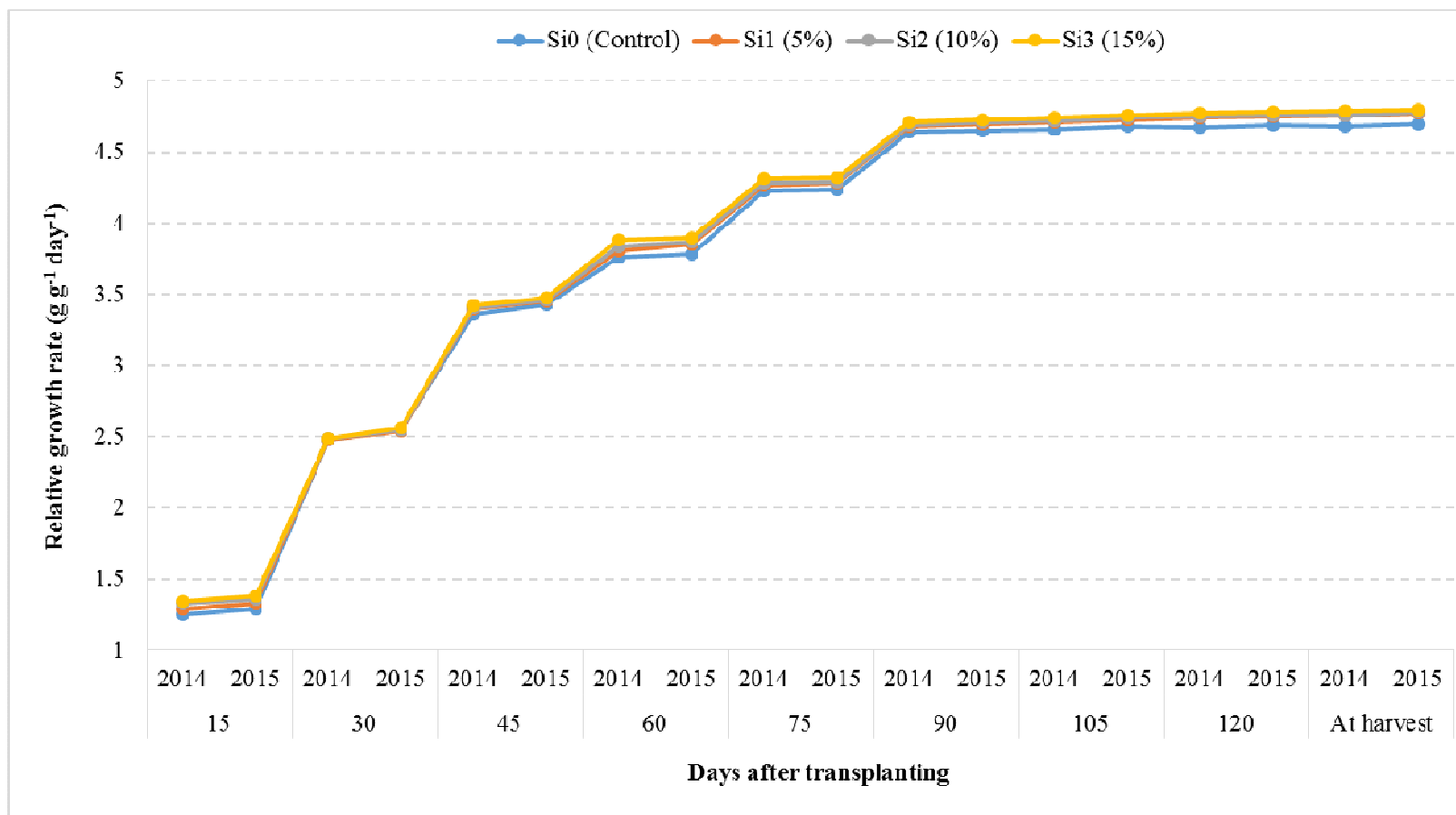


Fig. 10: Impact of silicon on relative growth rate ($\text{g g}^{-1} \text{day}^{-1}$) of transplanted rice

4.1.7 Phenological stages

The various phenological stages viz. mid tillering, panicle initiation, anthesis and maturity were affected due to different nitrogen levels. Fig. 11 and 12 revealed that 180 kg N ha⁻¹ took more number of days to reach different phenological stages than 150 kg N ha⁻¹ and 120 kg N ha⁻¹ during 2014 and 2015.

So far as silicon application is concerned, there was no significant difference with respect to all growth stages during both years.

4.1.8 Internode length (cm)

Data presented in Table 10 indicated that internode length was significantly highest with 180 kg N ha⁻¹ followed by 150 kg N ha⁻¹ at all growth stages and lowest was recorded with 120 kg N ha⁻¹ during both the years.

Among silicon applications, 15%Si observed significantly highest internode length followed by 10%Si being remained at par with 5%Si and significantly lowest internode length was recorded with control at all growth stages except mid tillering during both the years.

4.2 Lodging parameters

4.2.1 Breaking resistance (g.cm)

Data presented in Table 11 (Fig. 13 and 14) indicated that breaking resistance were significantly highest with 120 kg N ha⁻¹ (1659.93 and 1718.92 g.cm) followed by 150 kg N ha⁻¹ (1574.46 g.cm and 1644.83 g.cm) and lowest were recorded with 180 kg N ha⁻¹ (1485.84 and 1569.48 g.cm) during 2014 and 2015. It was further observed that among different silicon applications, 15%Si recorded highest breaking resistance (1689.87 g.cm and 1753.60 g.cm) followed by 10%Si (1600.19 and 1668.03 g.cm) which was statistically at par with 5%Si (1544.55 and 1624.75 g.cm) and lowest was recorded with control (1459.04 and 1531.27 g.cm) during both the consecutive years.

Table 10: Impact of nitrogen and silicon on internode length (cm) of transplanted rice

↓Treatments	Year→	Mid tillering		Panicle initiation		Anthesis		Maturity	
		2014	2015	2014	2015	2014	2015	2014	2015
Nitrogen levels (kg ha⁻¹)									
N ₁	120	1.74	1.75	13.95	15.02	24.78	25.58	26.35	26.85
N ₂	150	1.76	1.78	14.56	15.62	25.80	27.19	27.39	28.66
N ₃	180	1.79	1.82	14.78	15.84	26.75	28.20	28.45	29.74
SEm±		0.008	0.01	0.04	0.06	0.30	0.33	0.32	0.35
LSD (p≤0.05)		0.02	0.03	0.13	0.18	0.89	0.97	0.94	1.03
Silicon applications (%)									
Si ₀	Control	1.74	1.76	14.04	15.02	24.01	24.88	25.17	26.19
Si ₁	5	1.77	1.78	14.48	15.51	25.74	27.18	27.59	28.63
Si ₂	10	1.77	1.79	14.51	15.60	26.12	27.37	27.85	28.81
Si ₃	15	1.78	1.79	14.70	15.83	27.23	28.53	28.98	30.04
SEm±		0.009	0.01	0.05	0.07	0.35	0.38	0.37	0.40
LSD (p≤0.05)		NS	NS	0.15	0.21	1.03	1.12	1.08	1.19

Table 11: Impact of nitrogen and silicon on lodging parameters of transplanted rice

↓Treatments	Year→	Breaking resistance (g.cm)		Bending moment (g.cm)		Lodging index (%)	
		2014	2015	2014	2015	2014	2015
Nitrogen levels (kg ha⁻¹)							
N ₁	120	1659.93	1718.92	1589.98	1658.08	94.86	95.09
N ₂	150	1574.46	1644.83	1511.87	1586.34	95.89	96.06
N ₃	180	1485.84	1569.48	1438.26	1514.35	96.93	97.05
SEm±		24.17	24.97	22.43	23.65	0.33	0.32
LSD (p≤0.05)		70.92	73.23	65.80	69.38	1.01	0.97
Silicon applications (%)							
Si ₀	Control	1459.04	1531.27	1406.83	1476.71	97.80	97.92
Si ₁	5	1544.55	1624.75	1490.16	1561.83	96.63	96.83
Si ₂	10	1600.19	1668.03	1536.50	1611.32	96.28	96.62
Si ₃	15	1689.87	1753.60	1619.99	1695.17	95.13	95.46
SEm±		27.92	28.83	25.90	27.31	0.37	0.35
LSD (p≤0.05)		81.90	84.56	75.98	80.11	1.13	1.07

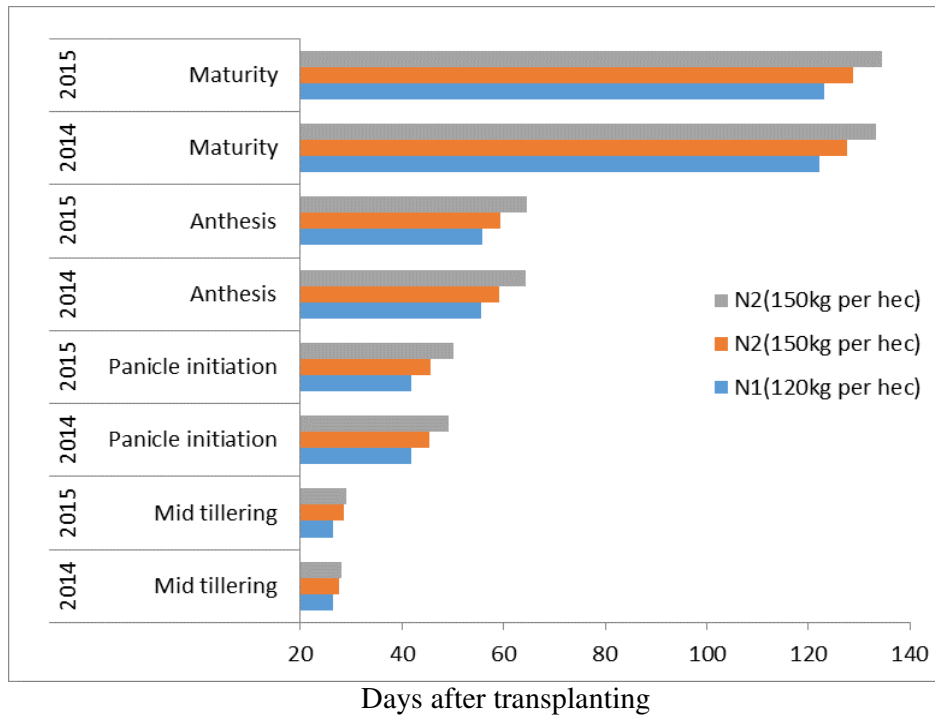


Fig. 11: Impact of nitrogen on phenological stages of transplanted rice

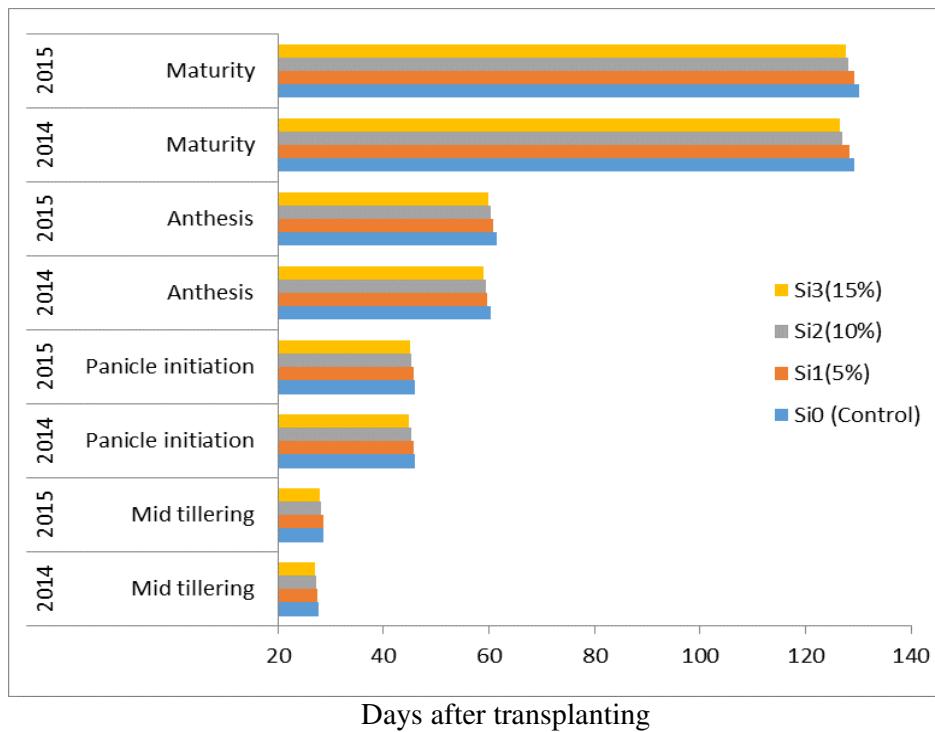


Fig. 12: Impact of silicon on phenological stages of transplanted rice

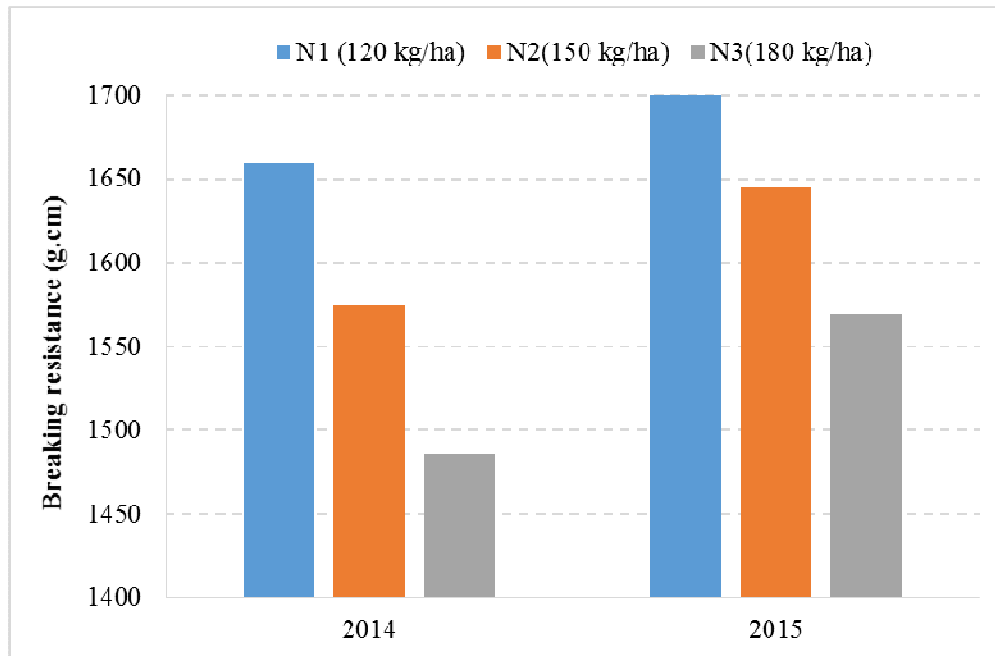


Fig. 13: Impact of nitrogen on breaking resistance (g.cm) of transplanted rice

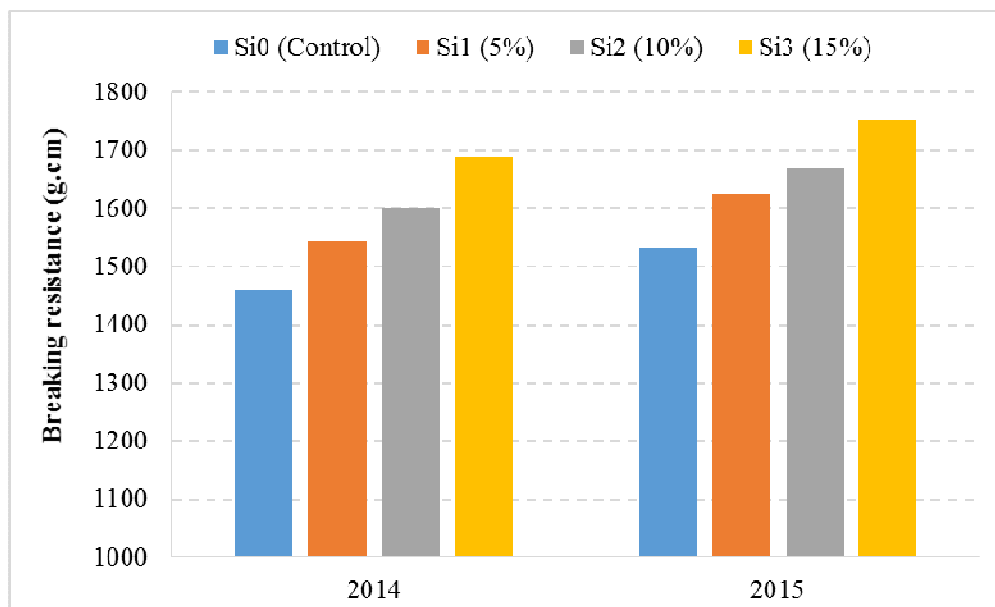


Fig. 14: Impact of silicon on breaking resistance (g.cm) of transplanted rice

4.2.2 Bending moment (g.cm)

The periodic data pertaining to bending moment have been presented in Table 11 (Fig. 15 and 16) which showed that bending moment were significantly highest with 120 kg N ha⁻¹ (1589.98 and 1658.08 g.cm) followed by 150 kg N ha⁻¹ (1511.87 and 1586.34 g.cm) and significantly lowest were recorded with 180 kg N ha⁻¹ (1438.26 g.cm and 1514.35 g.cm) during both the years.

Among different silicon applications, 15%Si observed highest bending moment (1619.99 and 1695.17 g.cm) followed by 10%Si (1536.50 and 1611.32 g.cm) being at par with 5%Si (1490.16 and 1561.83 g.cm) and lowest was recorded with control (1406.83 and 1476.71 g.cm) during 2014 and 2015.

4.2.3 Lodging index (%)

Out of the three nitrogen levels, 120 kg N ha⁻¹ proved significantly efficient in controlling lodging (94.86 and 95.09%) followed by 150 kg N ha⁻¹ (95.89 and 96.06%) during both the years. Significantly highest lodging index was recorded with 180 kg N ha⁻¹ (96.93 and 97.05%) during both the years as in Table 11 (Fig. 17 and 18).

The perusal of the data on different silicon applications, 15%Si proved significantly better measure (95.13 and 95.46%) for recording lodging index as compared to 10%Si (96.28 and 96.62%) and 5%Si (96.63 and 96.83%) and significantly higher lodging index was recorded with control (97.80 and 97.92%) during both the years.

4.3 Yield attributing characters

4.3.1 Number of panicles m⁻²

Number of panicles is the most important parameter directly influencing the ultimate yield of crop. The data pertaining to panicles m⁻² are presented in Table 12 revealed that 120 kg N ha⁻¹ caused highly significant improvement in the number of panicles m⁻² (362.74 and 366.80) followed by 150 kg N ha⁻¹ (358.17

Table 12: Impact of nitrogen and silicon on yield attributes of transplanted rice

↓Treatments	No. of panicles m ⁻²		Panicle length (cm)		Panicle weight (g)		No. of spikelets panicle ⁻¹		No. of grains panicle ⁻¹		1000-grain weight (g)		
	Year→	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Nitrogen levels (kg ha⁻¹)													
N ₁ 120	362.74	366.80	23.68	23.78	2.82	2.86	109.87	113.70	80.52	84.22	24.33	24.38	
N ₂ 150	358.17	361.74	23.53	23.59	2.80	2.83	105.21	108.05	78.52	81.48	24.25	24.28	
N ₃ 180	355.43	357.57	23.36	23.40	2.77	2.80	100.04	102.30	76.35	79.16	24.12	24.17	
SEm±	1.30	1.28	0.04	0.06	0.005	0.06	1.44	1.41	0.55	0.53	0.07	0.08	
LSD (p≤0.05)	3.82	3.78	0.14	0.19	0.016	0.019	4.23	4.15	1.62	1.57	NS	NS	
Silicon applications (%)													
Si ₀ Control	348.08	352.57	23.22	23.29	2.75	2.78	97.84	98.37	74.53	77.40	24.11	24.15	
Si ₁ 5	359.68	362.49	23.48	23.53	2.80	2.83	104.47	107.29	78.79	81.71	24.21	24.25	
Si ₂ 10	360.84	363.70	23.61	23.65	2.80	2.84	106.37	110.05	79.04	82.35	24.26	24.30	
Si ₃ 15	366.53	369.39	23.80	23.89	2.84	2.87	111.48	116.35	81.49	85.02	24.37	24.42	
SEm±	1.50	1.48	0.05	0.07	0.006	0.007	1.66	1.63	0.63	0.61	0.08	0.09	
LSD (p≤0.05)	4.41	4.36	0.16	0.22	0.019	0.022	4.89	4.79	1.87	1.81	NS	NS	

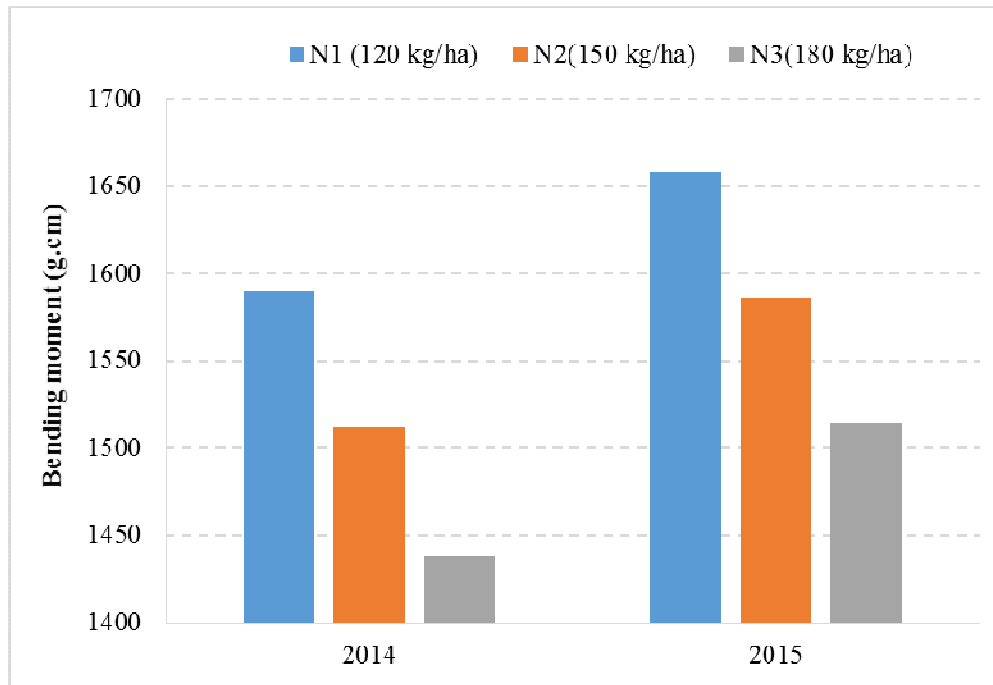


Fig. 15: Impact of nitrogen on bending moment (g.cm) of transplanted rice

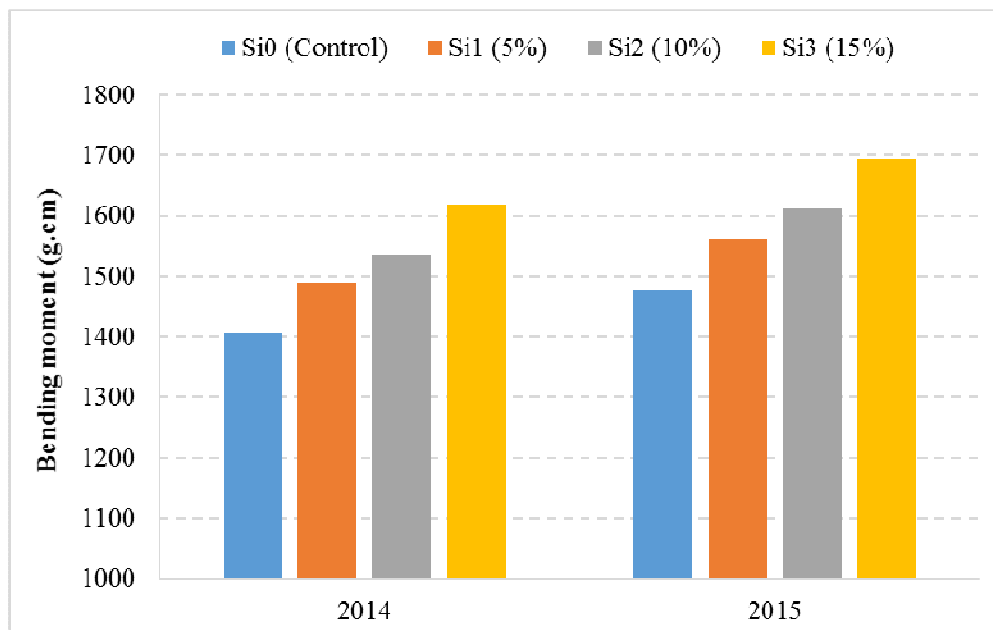


Fig. 16: Impact of silicon on bending moment (g.cm) of transplanted rice

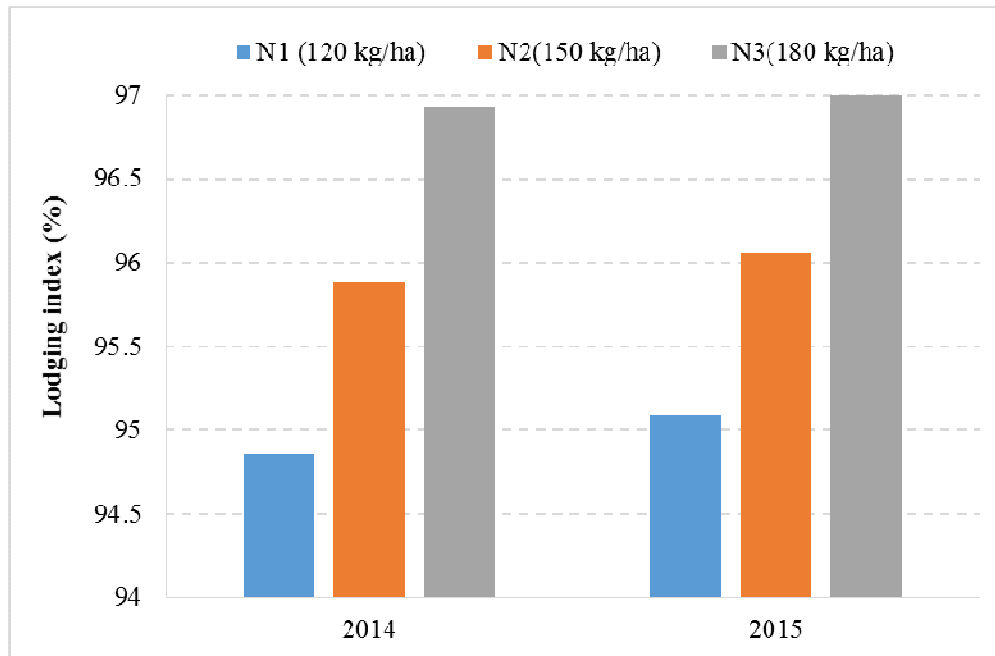


Fig. 17: Impact of nitrogen on lodging index (%) of transplanted rice

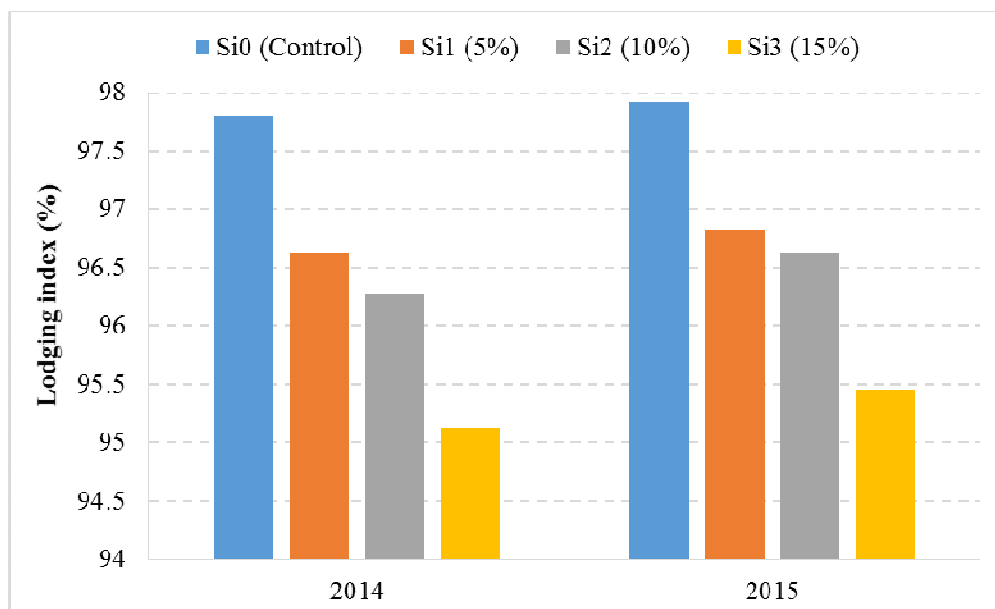


Fig. 18: Impact of silicon on lodging index (%) of transplanted rice

and 361.74) and lowest number of panicles m^{-2} were recorded with 180 kg N ha^{-1} (355.43 and 357.57) during 2014 and 2015.

The data also revealed that among different silicon applications, 15%Si was recorded significantly highest number of panicles m^{-2} (366.53 and 369.39) followed by 10%Si (360.84 and 363.70) though statistically at par with 5%Si (359.68 and 362.49) and lowest was recorded with control (348.08 and 352.57) during both the years.

4.3.2 Panicle length (cm)

The data regarding panicle length is presented in Table 12 showed that 120 kg N ha^{-1} created significant variation in panicle length. 120 kg N ha^{-1} proved significantly superior (23.68 and 23.78 cm) than other two nitrogen levels viz. 150 kg N ha^{-1} (23.53 and 23.59 cm) and 180 kg N ha^{-1} (23.36 and 23.40 cm) during both the years.

Among silicon applications, panicle length was significantly highest with 15%Si (23.80cm and 23.89cm) followed by 10%Si (23.61cm and 23.65cm) but it remained at par with 5%Si (23.48cm and 23.53cm) and significantly lowest was recorded with control (23.22cm and 23.29cm) during both the consecutive years.

4.3.3 Panicle weight (g)

Perusal of the data (Table 12) on panicle weight indicated that 120 kg N ha^{-1} proved significantly superior panicle weight (2.82 and 2.86g) followed by 150 kg N ha^{-1} (2.80 and 2.83g) and lowest was observed with 180 kg N ha^{-1} (2.77 and 2.80g) during 2014 and 2015.

An examination of the data on panicle weight revealed that significantly highest panicle weight was recorded with 15%Si (2.84 and 2.87g) followed by 10%Si (2.80 and 2.84g) but it remained at par with 5%Si (2.80 and 2.83g) and significantly lowest was observed with control (2.75 and 2.78g) during both the years.

4.3.4 Spikelets panicle⁻¹

An examination of the data (Table 12) on spikelets panicle⁻¹ revealed that treatment levels of nitrogen viz. 120, 150 and 180 kg N ha⁻¹ differed significantly with each other. However, significantly highest number of spikelets panicle⁻¹ was observed with 120 kg N ha⁻¹ (109.87 and 113.70) followed by 150 kg N ha⁻¹ (105.21 and 108.05) and lowest with 180 kg N ha⁻¹ (100.04 and 102.30) during 2014 and 2015.

Pertaining to data on different silicon applications, highest spikelets panicle⁻¹ were recorded with 15%Si (111.48 and 116.35) followed by 10%Si (106.37 and 110.05) being at par with 5%Si (104.47 and 107.29) and lowest were recorded with control (97.84 and 98.37) during both the years.

4.3.5 Grains panicle⁻¹

Perusal of the data on grains panicle⁻¹ presented in Table 12 revealed that 120 kg N ha⁻¹ recorded significantly highest number of grains panicle⁻¹ (80.52 and 84.22) followed by 150 kg N ha⁻¹ (78.52 and 81.48) and lowest was observed with 180 kg N ha⁻¹ (76.35 and 79.16) during 2014 and 2015.

The data also revealed that 15%Si significantly improved the number of grains panicle⁻¹ (81.49 and 85.02) followed by 10%Si (79.04 and 82.35) which was at par with 5% (78.79 and 81.71) and lowest was observed with control (74.53 and 77.40) during both the years.

4.3.6 1000-grain weight (g)

The data regarding test weight presented in table indicated that different nitrogen levels failed to influence the 1000-grain weight significantly. 120 kg N ha⁻¹ tended to acquire a bit more test weight than other two nitrogen levels during 2014 and 2015.

Perusal of data revealed that among different silicon applications, no significant difference was observed during both the years.

4.4 Post harvest observations

4.4.1 Grain yield (q ha⁻¹)

From the Table 13 (Fig. 19 and 20) indicated that the grain yield showed the significant variation among the nitrogen levels. It was observed that 120 kg N ha⁻¹ was significantly superior (75.61 and 76.39 q ha⁻¹) followed by 150 kg N ha⁻¹ (73.55 and 74.52 q ha⁻¹) and significantly lowest was recorded with 180 kg N ha⁻¹ (68.45 and 69.21 q ha⁻¹) during 2014 and 2015.

Examination of the data indicated that among different silicon applications, 15%Si recorded the highest grain yield (76.41 and 77.11 q ha⁻¹) followed by 10%Si (74.12 and 75.04 q ha⁻¹) being at par with 5%Si (72.75 and 73.67 q ha⁻¹) and lowest was observed with control (66.87 and 67.67 q ha⁻¹) during both the years.

4.4.2 Straw yield (q ha⁻¹)

An examination of the data (Table 13) indicated that 120 kg N ha⁻¹ provided significantly higher straw yield (93.38 and 94.56 q ha⁻¹) followed by 150 kg N ha⁻¹ (91.23 and 91.09 q ha⁻¹) and lowest was recorded with 180 kg N ha⁻¹ (87.69 and 88.70 q ha⁻¹) during both the years.

Among different silicon applications, 15%Si produced significantly highest straw yield (94.36 and 95.09 q ha⁻¹) followed by 10%Si (92.52 and 93.26q ha⁻¹) which was statistically at par with 5%Si (91.63 and 92.30 q ha⁻¹) and lowest was observed with control (84.55 and 86.49 q ha⁻¹) during 2014 and 2015.

4.4.3 Harvest index (%)

The data regarding harvest index as affected by nitrogen levels and silicon applications are presented in Table 13. Nitrogen levels caused significant differences on harvest index of rice. 120 kg N ha⁻¹ markedly improved the harvest index (44.72 and 44.96%) as compared to 150 kg N ha⁻¹ (44.38 and 44.65%) and

lowest harvest index was recorded with 180 kg N ha⁻¹ (43.81 and 44.11%) during 2014 and 2015.

Examination of the data indicated that different silicon applications in rice did vary significantly from each other with respect to harvest index. 15%Si recorded significantly highest harvest index (44.69 and 44.92%) followed by 10%Si (44.24 and 44.56%) which was statistically at par with 5%Si (44.13 and 44.35%) while control recorded lowest harvest index (43.72 and 43.96%) during both the years.

4.4.2 Interaction effect of nitrogen levels and silicon applications on grain yield

Data (Table 14 and 15) revealed that interaction between nitrogen levels and silicon applications were significant. Lowest grain yield was achieved in treatment combination 180 kg N ha⁻¹ and control (64.17 and 64.83 q ha⁻¹) during 2014 and 2015. Significantly higher grain yield was (80.05 and 80.62 q ha⁻¹) recorded in treatment combination 120 kg N ha⁻¹ and 15%Si but remained at par with 150 kg N ha⁻¹ and 15%Si (78.76 and 79.53 q ha⁻¹) followed by 120 kg N ha⁻¹ and 10%Si (76.89 and 77.72 q ha⁻¹) being at par with 150 kg N ha⁻¹ and 10%Si (75.33 and 76.39 q ha⁻¹), 120 kg N ha⁻¹ and 5%Si (75.23 and 76.19 q ha⁻¹), 150 kg N ha⁻¹ and 5%Si (73.95 and 75.01 q ha⁻¹) and then significantly higher grain yield was recorded with 180 kg N ha⁻¹ and 15%Si (70.42 and 71.18 q ha⁻¹) remained at par with 180 kg N ha⁻¹ and 10%Si (70.28 and 71.04 q ha⁻¹), 120 kg N ha⁻¹ and control (70.15 and 71.01 q ha⁻¹) and 180 kg N ha⁻¹ and 5%Si (69.08 and 69.81 q ha⁻¹) followed by 150 kg N ha⁻¹ and control (66.17 and 67.13 q ha⁻¹) and 180 kg N ha⁻¹ and control (64.17 and 64.83 q ha⁻¹) during 2014 and 2015.

Table 13: Impact of nitrogen and silicon on grain yield, straw yield and harvest index of transplanted rice

↓Treatments		Grain yield (q ha ⁻¹)		Straw yield (q ha ⁻¹)		Harvest index (%)	
		Year→	2014	2015	2014	2015	2014
Nitrogen levels (kg ha⁻¹)							
N ₁	120	75.61	76.39	93.38	94.56	44.72	44.96
N ₂	150	73.55	74.52	91.23	92.09	44.38	44.65
N ₃	180	68.45	69.21	87.69	88.70	43.81	44.11
SEm±		0.48	0.54	0.53	0.55	0.11	0.08
LSD (p≤0.05)		1.42	1.62	1.57	1.62	0.33	0.24
Silicon applications (%)							
Si ₀	Control	66.87	67.67	84.55	86.49	43.72	43.96
Si ₁	5	72.75	73.67	91.63	92.30	44.13	44.35
Si ₂	10	74.12	75.04	92.52	93.26	44.24	44.56
Si ₃	15	76.41	77.11	94.36	95.09	44.69	44.92
SEm±		0.56	0.59	0.62	0.64	0.13	0.12
LSD (p≤0.05)		1.65	1.77	1.82	1.87	0.38	0.36

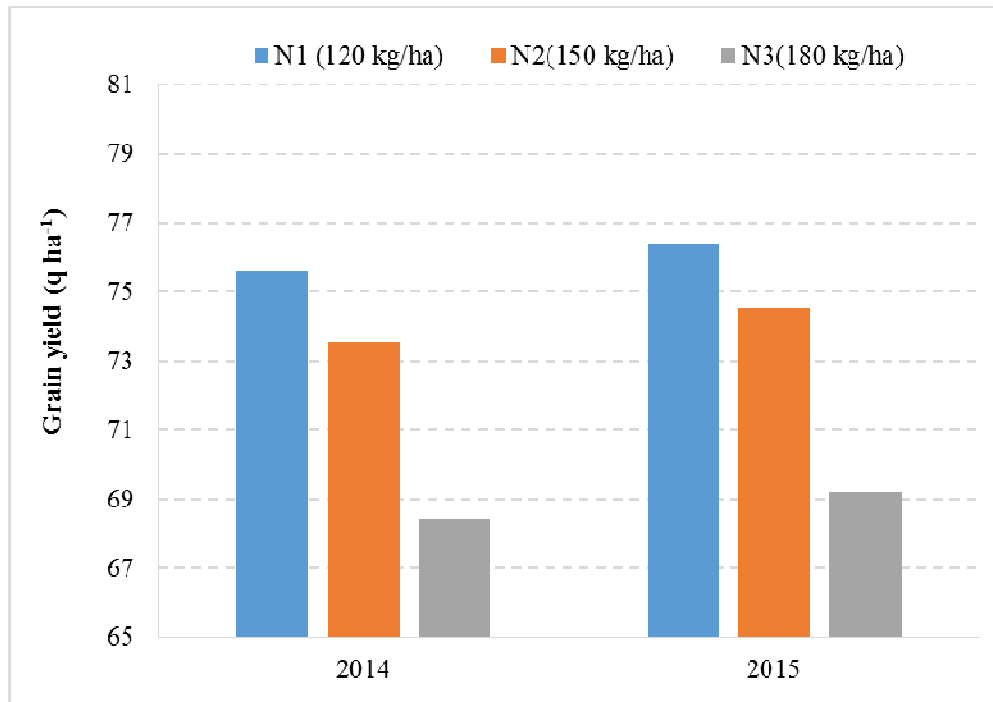


Fig. 19: Impact of nitrogen on grain yield ($q\ ha^{-1}$) of transplanted rice

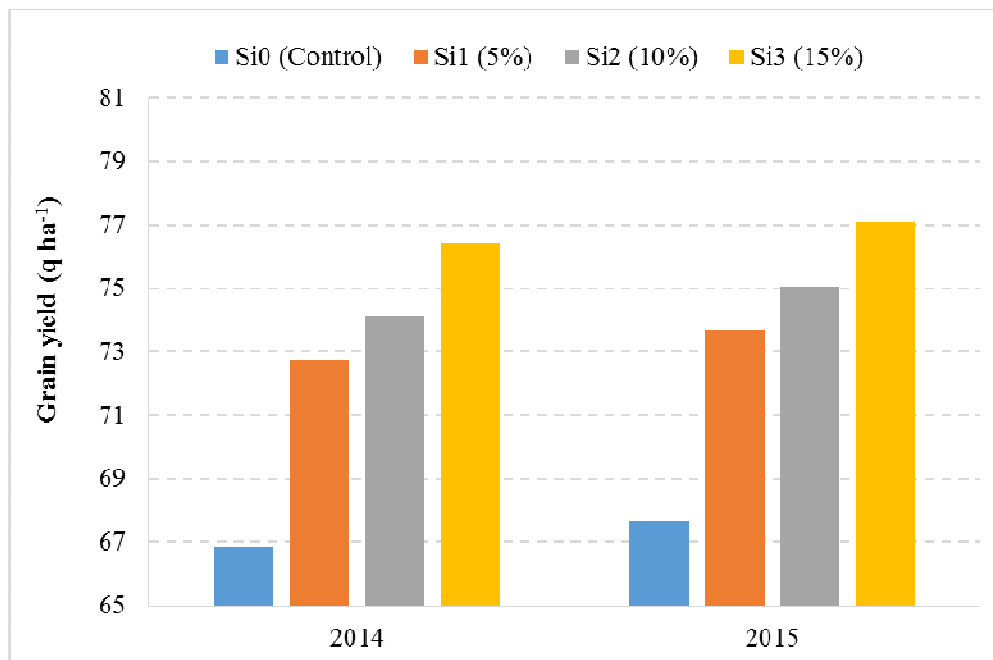


Fig. 20: Impact of silicon on grain yield ($q\ ha^{-1}$) of transplanted rice

Table 14: Interaction of nitrogen and silicon on grain yield of transplanted rice of year 2014

Treatments	Silicon applications (%)			
Nitrogen levels (kg ha⁻¹)	Control (Si₀)	5 (Si₁)	10 (Si₂)	15 (Si₃)
N ₁ 120	70.15	75.23	76.89	80.05
N ₂ 150	66.17	73.95	75.33	78.76
N ₃ 180	64.17	69.08	70.28	70.42
SEm±	0.61			
LSD (p≤0.05)	1.85			

Table 15: Interaction of nitrogen and silicon on grain yield of transplanted rice of year 2015

Treatments	Silicon applications (%)			
Nitrogen levels (kg ha⁻¹)	Control (Si₀)	5 (Si₁)	10 (Si₂)	15 (Si₃)
N ₁ 120	71.01	76.19	77.72	80.62
N ₂ 150	67.13	75.01	76.39	79.53
N ₃ 180	64.83	69.81	71.04	71.18
SEm±	0.67			
LSD (p≤0.05)	2.01			

4.5 Nutrient content and uptake

4.5.1 Nutrient content (%)

The data on nitrogen and silicon content as affected by different treatments presented in Table 16 showed that nitrogen and silicon content of grain was higher than that of straw but for silicon content, the trend was reverse during 2014 and 2015.

The data revealed that nitrogen levels and silicon applications could not make any significant difference in nutrient content of grain and straw during both the years.

4.5.2 Nutrient uptake (kg ha⁻¹)

The data regarding nitrogen and silicon uptake presented in Table 17 indicated that 120 kg N ha⁻¹ recorded significantly highest nitrogen uptake of grain (81.55 and 82.55 kg N ha⁻¹) and straw (44.77 and 45.52 kg ha⁻¹) followed by 150 kg N ha⁻¹ of grain (79.24 and 80.46 kg ha⁻¹) and straw (43.60kg ha⁻¹ and 44.19kg ha⁻¹) during 2014 and 2015. Significantly lowest grain uptake (73.65 and 74.69 kg ha⁻¹) and straw uptake (41.76 and 42.42 kg ha⁻¹) were recorded with 180 kg N ha⁻¹ during both the years.

Data further revealed that among different silicon applications, 15%Si recorded significantly highest silicon uptake of grain (82.46kg ha⁻¹ and 83.40kg ha⁻¹) and straw uptake (45.22 and 45.75 kg ha⁻¹) followed by 10%Si of grain (79.94 and 81.09 kg ha⁻¹) and straw uptake (44.23 and 44.78 kg ha⁻¹) though statistically at par with 5%Si of grain (78.29 and 79.51 kg ha⁻¹) and straw uptake (43.78 and 44.28 kg ha⁻¹) while control recorded a lowest silicon uptake of grain (71.90 and 72.94 kg ha⁻¹) and straw uptake (40.28 and 41.35 kg ha⁻¹) during both the years.

Table 16: Impact of nitrogen and silicon on nitrogen and silicon content of transplanted rice

↓Treatments	Nitrogen content (%)				Silicon content (%)				
	Grain		Straw		Grain		Straw		
	Year→		2014	2015	2014	2015	2014	2015	
Nitrogen levels (kg ha⁻¹)									
N ₁	120	1.078	1.080	0.478	0.480	2.58	2.59	3.69	3.70
N ₂	150	1.077	1.079	0.477	0.479	2.56	2.58	3.67	3.68
N ₃	180	1.075	1.078	0.475	0.477	2.52	2.56	3.65	3.68
SEm±		0.0009	0.003	0.0008	0.0009	0.01	0.02	0.01	0.02
LSD (p≤0.05)		NS	NS	NS	NS	NS	NS	NS	NS
Silicon applications (%)									
Si ₀	Control	1.075	1.077	0.475	0.477	2.53	2.54	3.63	3.66
Si ₁	5	1.075	1.079	0.477	0.479	2.54	2.57	3.66	3.68
Si ₂	10	1.078	1.080	0.477	0.479	2.55	2.59	3.68	3.70
Si ₃	15	1.079	1.081	0.478	0.480	2.59	2.63	3.69	3.72
SEm±		0.001	0.003	0.001	0.001	0.01	0.03	0.02	0.02
LSD (p≤0.05)		NS	NS	NS	NS	NS	NS	NS	NS

4.6 Relative economics

The data relative economics presented in Table 18 revealed that benefit cost ratio remained highest (Rs. 2.11 and Rs. 2.13) when 120 kg N ha⁻¹ and 15%Si were applied during 2014 and 2015. The same treatment also recorded the highest net returns of Rs. 105160ha⁻¹ and Rs. 106107 ha⁻¹ during both the years.

Table 17: Impact of nitrogen and silicon on nitrogen and silicon uptake of transplanted rice

↓Treatments		Nitrogen uptake (kg ha ⁻¹)				Silicon uptake (kg ha ⁻¹)			
		Grain		Straw		Grain		Straw	
Year→		2014	2015	2014	2015	2014	2015	2014	2015
Nitrogen levels (kg ha⁻¹)									
N ₁	120	81.55	82.55	44.77	45.52	195.57	198.89	345.13	351.11
N ₁	150	79.24	80.46	43.60	44.19	188.77	191.35	335.24	339.87
N ₁	180	73.65	74.69	41.76	42.42	172.65	177.83	320.24	327.42
SEm±		0.51	0.54	0.24	0.25	1.56	2.57	2.44	3.15
LSD (p≤0.05)		1.49	1.60	0.71	0.73	4.58	7.54	7.18	9.24
Silicon applications (%)									
Si ₀	Control	71.90	72.94	40.28	41.35	169.19	172.48	307.94	317.40
Si ₁	5	78.29	79.51	43.78	44.28	185.00	189.68	335.70	340.38
Si ₂	10	79.94	81.09	44.23	44.78	189.74	194.48	340.50	343.65
Si ₃	15	82.46	83.40	45.22	45.75	198.74	203.36	349.00	354.35
SEm±		0.59	0.63	0.27	0.28	1.80	2.97	2.82	3.64
LSD (p≤0.05)		1.73	1.84	0.81	0.84	5.29	8.71	8.29	10.67

Table 18: Relative economics of transplanted rice as influenced by nitrogen and silicon

↓Treatments Year→	Cost of cultivation (Rs. ha ⁻¹)		Gross returns (Rs. ha ⁻¹)		Net returns (Rs. ha ⁻¹)		B: C	
	2014	2015	2014	2015	2014	2015	2014	2015
N ₁ Si ₀	48522	48522	136237	138929	87715	90407	1.80	1.86
N ₁ Si ₁	49146	49146	146727	148280	97581	99134	1.98	2.01
N ₁ Si ₂	49490	49490	148737	150174	99247	100684	2.00	2.03
N ₁ Si ₃	49834	49834	154994	155941	105160	106107	2.11	2.13
N ₂ Si ₀	48687	48687	130369	132364	81682	83677	1.67	1.71
N ₂ Si ₁	49311	49311	144524	145581	95213	96270	1.93	1.95
N ₂ Si ₂	49655	49655	146432	147330	96777	97675	1.94	1.96
N ₂ Si ₃	49999	49999	152270	153206	102271	103207	2.04	2.06
N ₃ Si ₀	48852	48852	126565	128447	77713	79595	1.59	1.62
N ₃ Si ₁	49476	49476	135767	137549	86291	88073	1.74	1.78
N ₃ Si ₂	49820	49820	137093	139223	87273	89403	1.75	1.79
N ₃ Si ₃	50164	50164	138689	140566	88525	90402	1.76	1.80

Cost of seed Rs 22 kg⁻¹ Cost of butachlor Rs 28 kg⁻¹ Cost of Calcium silicate Rs 400 kg⁻¹
 Cost of urea Rs 550/q Cost of labour Rs 150 day⁻¹ Cost of DAP Rs 2200/q
 Cost of grain Rs 1100/q Cost of MOP Rs 1650/q Cost of straw Rs 40 shieve⁻¹
 Cost of FYM Rs 500/q Cost of tractorization Rs 4000/ha

N₁ = 120 kg ha⁻¹, N₂ = 150 kg ha⁻¹, N₃ = 180 kg ha⁻¹
 Si₀ = Control, Si₁ = 5%, Si₂ = 10%, Si₃ = 15%

Chapter 5

DISCUSSION

The results obtained during two years of investigation “Impact of silicon and nitrogen on growth, lodging and yield of transplanted rice (*Oryza sativa* L.) under temperate conditions” are discussed in this chapter under appropriate heads showing cause and effect in light of available scientific evidences.

The experimental site is located in mid to high altitude temperate zone characterized by hot summers and very cold winters. The average annual precipitation is 944.6 mm (average of past 25 years) most of which is received from December to April in the form of snow and rain.

The mean meteorological data for the cropping season recorded at meteorological observatory, Division of Agronomy, Shalimar is presented in Appendix-I and illustrated in fig.1. It is evident from the data that mean maximum and mean minimum temperatures were 27.50°C and 12.60°C and 27.30°C and 13.20°C during cropping seasons of 2014 and 2015, respectively, whereas mean maximum and mean minimum relative humidities during 2014 were 82.50 and 55.30 per cent and during 2015 were 82.80 and 56.20 per cent, respectively. The total rainfall received during the experimentation period was 33.3mm during 2014 and 29.5 mm during 2015.

5.1 Growth characters

The data on plant height of rice at various growth stages depicted a marked influence with various nitrogen levels. Higher nitrogen level (180 kg N ha⁻¹) recorded significantly taller plants compared to lesser nitrogen levels at all growth stages during both the years. This could be attributed to the fact that nitrogen induced maximum vegetative growth with higher rates of nitrogen. These findings are in conformity with the results obtained by Mallick (1992) and Roy *et al.* (2004). Nitrogen is associated with increase in protoplasm, cell division and cell enlargement resulting in taller plants (Tisdale *et al.*, 1985).

Among different silicon applications, 15%Si resulted in higher plant height than other silicon applications at all growth stages during both the years. This may be attributed to the fact that silicon helps in increase the erectness of leaves thereby increasing photosynthetic capacity which results in higher plant height. Similar findings were reported by Fallah (2012).

With regard to nitrogen level viz. 180 kg N ha⁻¹ recorded significantly higher tillers m⁻² from 30-45 DAT during both the years. This could be attributed to the fact that higher dose of nitrogen being constituent of enzymes and protein enhanced cell expansion and various metabolic processes. Similar findings reported by Lawlor (2002) and Arnold *et al.* (2006). But from 60 DAT upto at harvest during both the years, number of tillers m⁻² were significantly highest with 120 kg N ha⁻¹. It is because of reduction of tiller number per plant at later growth stages might be due to tiller mortality and competition was more for growth resources. These results are in agreement with those obtained by Mesquita and Pinto (2000) and Pathan *et al.* (2010).

Among different silicon applications, 15%Si significantly increased the tiller number m⁻² at all growth stages during both the years. It might be due to silicon helps in increase the erectness of leaves, reduces leaf shading, increases light interception thereby increasing photosynthetic capacity which may result in increased tiller number. Fallah (2000) concluded, by increasing the amount of silicon in nutrient solution feeding, the tillering of rice has increased.

In general, there was linear increase in leaf area index upto 60 DAT and thereafter leaf area index showed decreasing trend. Lowest leaf area index was recorded at harvest. This could be attributed to shading of lower leaves after flowering stage causing their senescence with advancement in growth. Similar findings were reported by Shukla *et al.* (1995).

Leaf area index is a major component in determining solar radiation interception thereby influencing yield of crop. With regard to nitrogen levels,

significantly higher leaf area index was recorded with 180 kg N ha⁻¹ from 30-45 DAT during both the years. This might be due to more vegetative growth in higher level of nitrogen and the increasing trend of leaf area index at higher nitrogen levels can be attributed to the positive effect of nitrogen on both leaf development and leaf area duration. Similar findings are in conformity with Fageria (2007) and Fageria and Baligar (2005). But from 60 DAT upto at harvest during both the years, leaf area index was significantly highest with 120 kg N ha⁻¹. It might be due to the more number of tillers.

Among silicon applications, 15%Si significantly increased leaf area index of crop at various growth stages during both the years. This could be ascribed to the fact that silicon increased number of tillers which ultimately results in higher leaf area index. Dobermann and Fairhurst (1997) were also mentioned positive effect of silicon on rice plant growth.

Dry matter accumulation considered as a reliable index of crop vigour. The optimal accumulation of dry matter by the crop is important as it may be followed by adequate transfer of assimilation to the sink resulting in higher yields.

Nitrogen level viz. 180 kg N ha⁻¹ from 30-45 DAT during both the years accumulated significantly highest dry matter. There are many reports on the increased of total dry matter due to increased nitrogen fertilizer application (Prasad,1981 and Park, 1987). But from 60 DAT upto at harvest during both the years, significantly highest dry matter accumulation was recorded with 120 kg N ha⁻¹. It is because of increased number of tillers thereby increased dry matter production. Similar results were also reported by Stalin *et al.* (1999), Rao *et al.* (2004) and Prasad *et al.* (2011).

Among silicon applications, highest dry matter accumulation was recorded with 15%Si at various growth stages during both the years. It might be the maintenance of photosynthetic activity due to silicon fertilization could be one of the reason for the increased dry matter production (Arurie *et al.*, 1992) and they

also observed an increase in water use efficiency in silicon amended rice plants probably due to prevention of excessive transpiration.

Relative growth rate were significantly highest with 180 kg N ha⁻¹ from 30-45 DAT but from 60 DAT upto at harvest during both the years, relative growth rate were significantly highest with 120 kg N ha⁻¹. It might be due to higher dry weight.

So far as silicon applications are concerned, 15%Si recorded significantly highest relative growth rate at all growth stages during both the years. It is because of silicon nutrition increases the antioxidant production and reduces the generation of reactive oxygen species which in turn reduces the photooxidative damage and maintains the integrity of chloroplast membrane which caused more dry weight results in higher relative growth rate and also shown that when it is readily available to plants, it plays a significant role in plant growth.

Nitrogen level viz. 120 kg N ha⁻¹ increased significantly culm thickness at various growth stages during both the years. Reason is being that optimum nitrogen level viz. 120 kg N ha⁻¹ helps in stem strength and higher nitrogen fertilizer levels primarily induced significant reduction of dry weight which resulted in lower breaking resistance and consequently, reduced stem physical strength which caused a reduction in culm thickness thereby, resulted in poor lodging resistance of rice plants. Similar findings were reported by Wei *et al.* (2008), Yang *et al.* (2009), Wang *et al.* (2012) and Zhang *et al.* (2013).

Among different silicon applications, significantly highest culm thickness was recorded with 15%Si at all growth stages during both the years. It might be due to silicon improved epidermal cell wall thickness and size of vascular bundles which resulted in increases culm thickness. Fallah (2012) were also studied the same results.

Internode length was significantly highest with 180 kg N ha⁻¹ at all growth stages except mid tillering during both the years. It might be due to higher plant height.

Among silicon applications, internode length were significantly lower with 15%Si during both the years. It is also because of higher plant height. These results were confirmed by Fallah (2012). Ma *et al.* (1989) also mentioned positive effects of silicon on rice plant growth.

5.2 Days taken to different phenological stages

Phenology is a descriptive study of organisms in relation to their environment. Knowledge of crop phenology is important because for optimal yield in an environment, it is necessary to match the life cycle of the crop to the length of growing season.

Nitrogen level viz. 180 kg N ha⁻¹ took more number of days to reach different phenological stages during both the years. It may be due to increase in the amount of nitrogen. These results are supported by the findings of Haque *et al.* (2006).

So far as silicon applications are concerned, all silicon applications as well as control failed to bring about any significant change with respect to all phenological stages during 2014 and 2015.

5.3 Lodging parameters

5.3.1 Breaking resistance and bending moment

Breaking resistance and bending moment were significantly highest with 120 kg N ha⁻¹ during both the years. It may be due to lower plant height and internode length. Guo *et al.* (2003) were reported the similar results.

Among silicon applications, 15%Si recorded significantly highest breaking resistance and bending moment during both the years. It may be due to the thickening of cell wall of the sclerenchyma tissue in the culm and/or shortening

and thickening of internodes or increase in silicon content of lower internodes provides mechanical strength to enable plant to resist lodging and also this study showed that breaking resistance and bending moment increased with increasing silicon concentration. Lee (1990); Liang (1994) and Takahashi (1995) were also noticed an increase in resistance to lodging due to application of silicon fertilizer to rice.

5.3.2 Lodging index

Nitrogen level viz. 180 kg N ha⁻¹ showed significant higher lodging index during both the years. This is in accordance to the study of Hui *et al.* (2013) where high nitrogen input increased basal internode length, breaking resistance and lodging index.

15%Si recorded significantly lowest lodging index during both the years. It could be ascribed to the fact that increased silicon content plant has been reported to increase mechanical strength of plant tissue, which resulted in reduced lodging index (Takahashi *et al.*, 1990 and Liang, 1994). Shimoyama (1958) has mentioned that thickness of culm walls and vascular bundles becomes larger when silicon is applied. Silica deposited in these plant sections also contributes to an increase in the mechanical strength of culms. Therefore, sufficient supply of silicon has an effect on the stability of culms and serves to decrease the risk of lodging.

5.4 Yield attributing characters

Nitrogen levels caused the variation in yield parameters. The nitrogen level viz. 120 kg N ha⁻¹ was recorded significantly higher number of panicles m⁻², panicle length, panicle weight, spikelets panicle⁻¹ and grains panicle⁻¹ during both the years. It might be due to the optimum availability of nitrogen, resulting in more synthesis of photosynthesis and a positive source to sink relationship (Zaheen *et al.*, 2006 and Islam *et al.*, 2008). Yield attributes thereafter tends to decreased with further increasing the fertilizer levels. Fertilizer application with optimum quantity had profound effect to increase the yield attributing characters

which ultimately reflected on grain yield. This investigation is in agreement with Sardar *et al.* (1988) and Mandal *et al.* (1986).

1000-grain weight were non-significant with all nitrogen levels during 2014 and 2015. Similar findings were confirmed by Khorshida *et al.* (2011).

Out of various silicon applications, 15%Si significantly increased all the yield attributing characters viz. number of panicles m^{-2} , panicle length, panicle weight, spikelets panicle⁻¹ and grains panicle⁻¹ during both the years. This could be ascribed to the fact that silicon might have been improved the photosynthetic activity which enable rice plant to accumulate sufficient photosynthetes which increased dry matter production and these together with efficient translocation resulted in more number of these yield attributing characters. Similar results were also studied by Kim *et al.* (2012). Pereira *et al.* (2004) reported that increase in applied silicon amount enhanced the number of panicles m^{-2} . However, 1000-grain weight were non-significant with all silicon applications as well as control during both the years. Mobasser *et al.* (2008) reported that silicon application does not affect the 1000-grain weight in rice.

5.5 Post harvest observations

During present study it was found that nitrogen levels exerted significant influence on grain yield and straw yield of rice. 120 kg N ha^{-1} gave significantly more grain yield and straw yield during both years. It is because of highest yield attributing characters which ultimately caused the increase of rice grain yield. Similar results were reported by Huang *et al.* (2011). Also, the increment of grain yield by the application of nitrogen upto a certain level was reported by Zhaowen *et al.* (2013). And more number of dry matter accumulation which ultimately confirmed the greater yield of straw in this study. Similar trend of the effect of nitrogen levels on straw yield were also reported by Pramanik and Bera (2013), Hasanuzzaman *et al.* (2012), Alim (2012), Awan *et al.* (2011), Nori *et al.* (2008) and Rahman *et al.* (2007). However, harvest index were significantly highest with

120 kg N ha⁻¹ during both the years. Similar findings were endorsed by Rahman *et al.* (2007).

There was a significant increase in grain yield of rice with 15%Si during both the years. It is because of silicon is responsible to control stomatal activity, photosynthesis, water use efficiency which ultimately results in better vegetative growth results in higher grain yield. Also straw yield was significantly highest with 15%Si during both the years. It may be attributed to leaf erectness which facilitated better penetration of sunlight leading to higher photosynthetic activity of plant and higher production of carbohydrates. Similar results were also noticed by Ma *et al.* (1989), Rani *et al.* (1997), Korndorfer *et al.* (2001), Rodrigues *et al.* (2003) and Singh *et al.* (2006). The study revealed a significant increase in harvest index with 15%Si during both the years. Similar findings were reported by Pati *et al.* (2015).

Perusal of the data on nutrient content showed nitrogen levels and silicon applications during 2014 and 2015 could not make any significant difference in nutrient content of grain and straw. This attributed to the fact that uptake of nutrients is accompanied by increase in growth (biomass production) of plant. Thus the increased absorption of nutrients well buffered by increased dry matter production failed to show any significant change in nutrient content of grain and straw. This is in agreement with the findings of Alfoldi *et al.* (1994). Higher silicon content in the straw than in the grain suggests that silicon is linked in shoot and straw and silicon content in the straw increased with increase in silicon application (Malidareh *et al.*, 2009). The accumulation of silicon in the straw may be related to a number of factors such as transpiration, growth duration, growth rate etc.

As far as nutrient uptake is concerned, 120 kg N ha⁻¹ recorded higher nutrient uptake of grain and straw during both the years. This may be associated with maximum grain and straw yield. Fageria *et al.* (2003), Fageria *et al.* (2009) and Shinano *et al.* (1995) obtained the same results.

Among different silicon applications, 15%Si recorded significantly highest nutrient uptake of grain and straw during both the years. This might be due to increase in root and shoot growth and enhanced silicon availability with higher rate of silicon application. This findings is in agreement with the reports of Singh *et al.* (2006).

5.6 Interaction effect of nitrogen and silicon

Higher yields resulting from interaction effects of 120 kg N ha⁻¹ and 15%Si. It might be due to the increases nitrogen application, number of blank spikelets per panicle was decreased but by increases silicon concentration, number of blank spikelets per panicle was decreased. These results are in close conformity with Rajamani *et al.* (2013).

5.7 Relative economics

The efficiency of a treatment is finally decided in terms of economics (benefit cost ratio) of the treatment. The present investigation revealed that during the course of investigation, benefit cost ratio remained highest with N₁S₃ (120 kg N ha⁻¹ and 15%Si) treatment combination during both the years. It is possible due to the higher grain and straw yield and minimum cost of nitrogen fertilizers as cost of silicon does not have a greater effect.

Chapter 6

SUMMARY AND CONCLUSION

The field experiment entitled “Impact of silicon and nitrogen on growth, lodging and yield of transplanted rice (*Oryza sativa* L.) under temperate Kashmir conditions” during Kharif season 2014 and 2015 at Agronomy Research Farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar Campus, Srinagar. The experiment was laid out in a factorial Randomised Completely block design with three nitrogen levels (120, 150, 180 kg ha⁻¹) and four silicon applications (control, 5, 10 and 15%). The soil of the experimental field was silty clay loam in texture, medium available nitrogen, phosphorus, potassium and low available silicon 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 here under.

6.1 Effect of nitrogen

- Growth parameters like number of tillers m⁻², leaf area index, dry matter accumulation and relative growth rate were significantly higher with 180 kg N ha⁻¹ than other two nitrogen applications viz. (150 and 120 kg N ha⁻¹) from 30-45 DAT. But from 60 DAT upto at harvest, these growth parameters were significantly highest with 120 kg N ha⁻¹ as compared to other two nitrogen levels viz. (150 and 120 kg N ha⁻¹) during 2014 and 2015.
- Culm thickness was significantly highest with 120 kg N ha⁻¹ as compared to 150 and 180 kg N ha⁻¹ during both the years.
- Plant height and internode length were significantly highest with 180 kg N ha⁻¹ than other two nitrogen levels (150 and 120 kg N ha⁻¹) during both the years.
- Days taken to reach various phenological stages were curtailed with

120 and 150 kg N ha⁻¹ compared to 180 kg N ha⁻¹ during 2014 and 2015.

- Breaking resistance and bending moment were significantly highest with 120 kg N ha⁻¹ while lodging index decreased with the same treatment as compared to 150 and 180 kg N ha⁻¹ during both the years.
- 120 kg N ha⁻¹ gave maximum number of panicles m⁻², panicle length, panicle weight, number of spikelets panicle⁻¹ and number of grains panicle⁻¹ as compared to 150 and 180 kg N ha⁻¹ during both the years. However 1000-grain weight did not differ significantly during both years.
- Highest grain yield, straw yield and harvest index were recorded with 120 kg N ha⁻¹ than other two nitrogen levels during both years.
- Nutrient (N and Si) uptake of grain and straw were highest with 120 kg N ha⁻¹ than other nitrogen levels. But the nutrient (N and Si) content of grain and straw were not affected significantly during both the years.

6.2 Effect of silicon

- 15%Si significantly increased plant height, number of tillers m⁻², leaf area index, dry matter accumulation, relative growth rate, internode length and culm thickness compared to other silicon treatments during 2014 and 2015.
- Phenological stages were not affected significantly with different silicon applications and control treatment during both years.
- Breaking resistance and bending moment were significantly highest with 15%Si while lodging index decreased with the same treatment followed by 10%Si which remained at par with 5% Si as compared to control during both years.
- 15%Si significantly improved yield attributing characters viz. Number

of panicles m^{-2} , panicle length, panicle weight, number of spikelets panicle⁻¹ and number of grains panicle⁻¹ than other two silicon treatments and control during both the years.

- Both grain and straw yield as well as harvest index showed significant improvement with the application of 15%Si compared to other two silicon applications and control during both years.
- Highest nutrient (N and Si) content of grain and straw were not affected significantly. But the highest nutrient (N and Si) uptake of grain and straw were recorded with 15%Si compared to other two Si applications and control during both the years.

6.3 Interaction effects of nitrogen and silicon

- 120 kg N ha⁻¹ and 15%Si helped to improve grain yield of rice which remained at par 150 kg N ha⁻¹ and 15%Si during both the years.

CONCLUSION

The two year study revealed that silicon applications can significantly regulate plant growth, lodging and yield if applied at proper time with feasible concentration. As far as fertilization of rice crop is concerned-application of nitrogen fertilizer is an important practice for increasing rice yield. However, nitrogen applied in excess may limit yield due to lodging which promoted shading and susceptibility to insects and diseases. These effects could be minimized by the use of silicon. Due to a synergetic effect, the application of silicon has the potential to raise the nitrogen uptake, thus enhancing productivity of existing lowland rice.

Considering the influence of nitrogen levels and silicon applications, it can be suggested that for realising economically higher grain yield of rice and reducing lodging with 120 kg ha⁻¹ with 15%Si based nutrient management, as it helped to achieve the highest net returns equal to Rs.105160 and Rs.106107 and the highest B: C ratio of Rs. 2.11 and Rs. 2.13 during 2014 and 2015 respectively.

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APPENDIX-I**Standard weekly meteorological data for 2014 and 2015 of SKUAST-Kashmir, Shalimar**

2014 Standard week	Temperature (°C)		Rainfall (mm)	Relative humidity (%)		Sunshine (hrs)
	Max. Temp. I	Min. Temp. I		Min.	Max.	
24	30.9	10.6	0.0	68.9	39.3	9.1
25	27.4	12.9	0.1	76.3	46.7	6.8
26	30.4	13.8	1.3	76.1	42.1	8.2
27	27.5	14.3	8.1	81.1	48.6	7.2
28	31.9	16.5	0.0	73.1	45.9	9.1
29	29.2	16.3	1.9	78.9	59.4	6.9
30	33.0	19.6	0.2	82.9	44.9	8.4
31	32.3	17.2	0.1	76.7	43.6	9.3
32	31.1	16.4	0.0	76.9	52.1	5.9
33	27.9	14.9	6.6	81.6	54.6	7.7
34	28.9	13.4	1.1	78.0	54.6	9.1
35	23.9	13.0	5.9	88.4	68.0	3.6
36	18.5	11.7	24.8	95.7	84.9	2.1
37	27.2	7.4	2.3	87.4	65.1	8.1
38	28.3	10.0	0.0	84.6	55.7	8.7
39	26.6	10.0	0.9	83.4	51.6	7.9
40	27.7	10.6	0.0	93.6	50.9	7.2
41	20.0	5.7	2.5	90.7	72.4	4.6
42	20.2	6.1	0.8	93.1	70.0	6.1
2015						
24	26.6	11.3	1.3	76.1	52.1	9.0
25	27.5	13.5	1.2	73.9	51.3	8.2
26	26.0	13.1	9.8	77.9	56.7	6.4
27	31.4	17.3	1.5	74.1	53.6	10.1
28	25.6	17.5	9.4	88.6	70.4	2.5
29	28.9	18.0	13.3	88.4	70.3	4.9
30	29.6	17.7	6.1	84.0	61.4	8.2
31	29.5	18.8	21.1	89.1	60.3	5.1
32	31.6	18.4	0.0	83.0	57.3	7.6
33	29.7	15.8	0.5	78.3	56.3	7.8
34	29.8	14.8	11.3	81.9	47.9	8.4
35	29.1	12.5	0.0	81.0	48.9	8.0
36	25.7	11.2	1.9	87.0	53.9	7.0
37	29.4	10.0	0.0	82.7	46.7	9.3
38	24.9	10.1	8.3	81.9	57.6	6.1
39	24.4	8.7	0.5	77.9	54.4	8.0
40	25.9	6.5	0.0	87.1	49.3	8.2
41	25.0	7.5	0.0	90.4	53.3	7.1
42	19.1	7.4	7.7	89.6	66.7	4.1

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

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Faculty of Agriculture, Division of Agronomy

CERTIFICATE

Certified that all the corrections/amendments as suggested by External Examiner Dr. Anil Kumar, Associate Director Research, SKUAST-Jammu during Viva-Voce examination held on 04-08-2017 have been incorporated in the manuscript entitled **“Impact of silicon and nitrogen on growth, lodging and yield of transplanted rice (*Oryza sativa* L.) under temperate Kashmir conditions”** submitted by Ms. Rukhsana Jan (Regd. No. 2013-478-D).

(Dr. Farooq Ahmad Aga)
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