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Lodging management in upland rice (*Oryza sativa* L.)

Oormila T. P. and Anitha S.*

College of Agriculture, Kerala Agricultural University, Vellanikkara, Thrissur-680 656, Kerala, India

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Abstract

Field experiment was conducted at College of Agriculture Vellanikkara during *Kharif* 2020 to standardize the agronomic practices for crop lodging management in upland rice**.** Upland variety Vaisakh was used for the study. The experiment was laid out in Randomized Block Design (factorial) replicated thrice. The treatment consisted of two levels of growth regulator application *viz*.,50 ppm paclobutrazol and no growth regulator, three levels of planting method *viz*., dibbling at 15 cm × 10 cm, 20 cm × 15 cm and broadcasting and three levels of nutrient application *viz*.,100 % N: P_2O_5: K_2O of soil-test based recommendation,75% N, 100% P_2O_5 125% K_2O of soil test-based recommendation along with 20 kgha^{-1} Si and 50% N, 100% P_2O_5 150% $K_2O$of soil test-based recommendation along with 20 kgha^{-1} Si.Results of the study revealed that combination of increased K and Si fertilization under reduced N conditions and dibbling at wider spacing could help rice plants to withstand lodging. Dibbling at 20 cm×15 cm spacing along with the application of 75% N, 100% P_2O_5 125% K_2O of soil test-based recommendation and 20 kgha^{-1} Si resulted in reduced lodging and increased yield and net return of upland rice variety Vaishak.

Key words: Growth regulator, Lodging management, Nutrient management, Rice**,** Spacing, Yield

Introduction

Rice (*Oryza sativa* L.) is a staple food crop of Asia and it is the key source of nutrition for more than half of the world's population.High-yielding rice varieties with enhanced production are developed through breeding techniques to meet the ever-increasing demand for food grains. However, the high biomass yield of some of these varieties often conflicts with animportant constraint called crop lodging. Heavy lodging hinders water, nutrients, and assimilates from being transported through the vascular bundles, leading to decreased assimilation and grain filling. The grains of a lodged plant may germinate before harvest, particularly in cultivars with poor seed dormancy. Excessive moisture content in a lodged vegetation can promote pathogens and disease development. Lodging also complicates harvesting operations. The recent aberrant climatic conditions like heavy and untimely rainfall aggravate lodging, reducing grain quantity and quality. Plant resistance to lodging can be improved by providing the appropriate growing conditions. Hence, standardizing proper agronomic management strategies is inevitable to avoid lodging problems. Currently, the research information on lodging management is lacking in Kerala's condition. Hence, the experiment entitled 'Lodging management in rice (*Oryza sativa* L.)' was carried out to standardize the agronomic practices for lodging management in upland rice.

Materials and methods

The experiment was carried out in the Agronomy farm of College of Agriculture, Vellanikkara during *Kharif* 2020 with rice variety Vaisakh. The experiment was carried out in soil with sandy loam texture and soil was acidic in nature. The experiment was laid out in randomized block design (factorial) replicated thrice. Plot size adopted was 5m×4m. The treatment consisted of two levels of growth regulator application *viz*., 50 ppm paclobutrazol and control, three levels of planting method *viz*., dibbling at 15 cm × 10 cm, dibbling at 20cm × 15 cm and broadcasting and three levels of nutrient application *viz*., 100 % N: P_2O_5: K_2O of soil-test recommendation,75% N, 100% P_2O_5 125% $K_2O$of soil test-based recommendation along with 20 kgha^{-1} Si and 50% N, 100% P_2O_5 150% $K_2O$of soil test-based recommendation along with 20 kgha^{-1} Si. Soil of the experimental site had an available nutrient status of low N, high P_2O_5 and medium K_2O.Soil-test based N: P_2O_5: K_2O recommendation was 42: 25: 25 kgha^{-1}. Lime application @ 350 kg ha^{-1} was done two weeks before sowing and FYM @ 5 t ha^{-1} was incorporated to the soil, one week before sowing uniformly to all the treatments as per the recommended dose of Rice. Observations on growth parameters, lodging index, yield

* Author for Correspondences: Phone : 9446433292 ; Email: anitha.sarala@kau.in

parameters and yield were taken at periodic intervals. Benefit cost ratio was calculated by dividing the gross return with cost of cultivation. Gross return was calculated using prevailing market priceof grain yield and straw yield from the respective treatments. Cost of cultivation from each treatment was calculated by taking into account the cost for field preparation, input, labour， extra treatment cost etc. and it was expressed in rupees per ha.Data obtained from the experiment were analysed statistically by applying "analysis of variance" as per randomized block design with the help of online statistical package "OP" stat.

Results and discussion

Paclobutrazol application, method of planting, and nutrient management had significantly influenced the growth parameters of rice and resulted in variation in lodging rates and consequent yield difference.

Effect of paclobutrazol application on the growth parameters of rice was presented in Table 1. Foliar spray of paclobutrazol at 45 DAS, significantly influenced the plant height and leaf area of rice at 60 DAS. Plant height was reduced by 8 % compared to control. It was consistent with the previous studies that showed the efficiency of paclobutrazol in retarding plant height (Yim et al., 1997). As the treatment application was before the panicle initiation, the crop had nearly attained maximum vegetative growth. Further growth could be retarded by the treatment. It is known that the shoot growth in rice is controlled by the plant hormone gibberellin. Paclobutrazol reduces the levels of gibberellins (GAs) in plants by inhibiting the synthesis of these plant hormones. Paclobutrazol blocks the enzymes that catalyze the metabolic reaction for the production of gibberellins. This prevents the conversion of ent-kauren to ent-kaurenic acid, which is an early step in the gibberellin biosynthetic pathway(Desta and Amare, 2021). Gibberellins stimulate cell elongation, but when their production is inhibited, new cells do not elongate. This results in shorter stems and reduced plant height. According to Desta and Amare (2021), when gibberellin synthesis is suppressed, cell division continues but subsequent cells do not elongate. As a result, the same number of leaves and internodes are compacted into a shorter length of the shoot without affecting the grain production. Ribeiro et al. (2011) reported that when paclobutrazol is sprayed onto the plant canopy, its action is limited to the moist contact area with less persistence in the crop when compared to its soil drenching. This might be the reason for getting a non-significant influence of paclobutrazol treatment on plant height at 90 DAS.

Observations at 60 DAS also showed a significant reduction in leaf area in plants which received paclobutrazol foliar spray. Leaf area was reduced by 15 % compared to control (Table 3). The results were in line with the study conducted by Dewi and Darussalam (2018). The result indicates that reduced endogenous gibberellin levels might restrain cell division in leaves thereby reducing the leaf area. The reduction in leaf area might have helped in better leaf orientation, facilitating better photosynthesis compared to the control. The reports from Yim et al. (1997) also support this result.

Effect of planting methods on growth parameters of rice was given in Table 1. Among planting methods, dibbling resulted in the overall improvement of growth parameters of rice viz. plant height, number of tillers per hill, leaf area and dry matter production compared to broadcasting.Plant height recorded

Table 1. Effect of treatments on plant height and dry matter production of rice

Treatment	Plant height (cm)			Dry matter production (kg/ha)
	30 DAS	60 DAS	90 DAS	At harvest
Factor 1 - Growth regulator (G)				
G1- 50 ppm Paclobutrazol	65.20	123.85b	144.61	13,359
G2- No paclobutrazol	66.29	134.13a	144.07	12,926
SE (m)	0.95	0.31	0.31	178.88
CD (0.05)	NS	1.88	NS	NS
Factor 2- Method of planting (M)				
M1- Dibbling at 15cm × 10cm spacing	63.39b	128.38	142.70b	12,088b
M2- Dibbling at 20cm × 15cm spacing	69.31a	129.36	145.41a	13,630a
M3- Broadcasting	64.55b	129.23	143.25b	13,709a
SE (m)	1.16	0.37	0.38	219.08
CD (0.05)	3.34	NS	1.11	629.65
Factor 3 - Nutrient management (N)				
N1- Soil test recommendation of N: P2O5: K2O (42:25:25 kg/ ha)	66.36	138.90a	153.83a	14,906a
N2- 75% N, 100% P2O5 125% K2O of N1 and 20 kg/ha Si	66.44	127.84b	144.85b	13,192b
N3- 50% N, 100% P2O5 150% K2O of N1 and 20 kg/ha Si	64.44	120.22c	133.70c	11,329c
SE (m)	1.16	0.38	0.38	219.08
CD (0.05)	NS	1.08	1.11	629.65

Table 2. Effect of treatments on number of tillers per hill

Treatment	30 DAS	60 DAS	90 DAS
Factor 1 - Growth regulator (G)			
G_1= 50 ppm paclobutrazol	4.52	8.55	10.59
G_2= No paclobutrazol	4.88	8.88	10.96
SE (m)	0.13	0.15	0.15
CD (0.05)	NS	NS	NS
Factor 2- Method of planting (M)			
M_1= Dibbling at 15cm × 10cm spacing	4.94^a	8.66	10.78
M_2= Dibbling at 20cm × 15cm spacing	5.05^a	8.66	10.67
M_3= Broadcasting	4.11^b	8.63	10.89
SE (m)	0.16	0.19	0.19
CD (0.05)	0.47	NS	NS
Factor 3 - Nutrient management (N)			
N_1- Soil test recommendation of N: P_2O_5: K_2O (42:25:25 kg/ ha)	4.88	9.11^a	11.17^a
N_2= 75% N, 100% P_2O_5 125% K_2O of N_1 and 20 kg/ha Si	4.61	9.16^a	11.16^a
N_3= 50% N, 100% P_2O_5, 150% K_2O of N_1 and 20 kg/ha Si	4.61	7.88^b	10.00^b
SE (m)	0.16	0.19	0.19
CD (0.05)	NS	0.56	0.54

from dibbling at both wider and closer spacing was slightly higher than broadcasting. This result can be attributed to the differences in plant density and geometry. Dibbling at a wider spacing of 20 cm ×15 cm had the lowest plant density and better crop geometry. Studies conducted by Berhanu (2014) also support this result. He reported that the highest average plant height was obtained from plots with the lowest plant density. This increase in plant height might be due to the better plant geometry and reduced competition for space, nutrients, and sunlight in widely spaced plants.The results showing a higher number of tillers per hill (Table 2) and a higher leaf area (Table 3) from dibbling compared to broadcasting is also indicating a better availability of resources for crop growth. Basak et al. (1962) also made similar observations and reported that closer spacings and non-uniform planting produced fewer tillers per plant and the slight yellowing of leaves.

The dry matter production at harvest from dibbling at 20 cm×15 cm spacing and broadcasting were at par despite the difference in plant density (Table 1). Even with a lower plant density, dibbling at 20 cm ×15 cm spacing resulted in the same level of dry matter production as broadcasting with a higher plant density. Better crop environment and the overall improvement of growth parameters in dibbling at wider spacing might have facilitated better photosynthesis and dry matter accumulation.

Growth parameters of rice *viz.* plant height, culm length and dry matter production at harvest were significantly higher from the nutrient level of 100 % N: P_2O_5: K_2O of soil test-based recommendation (Table 1). Plant height showed a decreasing trend when the N level was reduced to 75 % and 50 % than when 100 % N application was done. This

Table 3. Effect of treatments on leaf area (cm^2)

Treatment	30 DAS	60 DAS	90 DAS
Factor 1 - Growth regulator (G)			
G_1= 50 ppm paclobutrazol	308	943^b	943
G_2= No paclobutrazol	321	$1,119^a$	1,357
SE (m)	15	59	261
CD (0.05)	NS	169.42	NS
Factor 2- Method of planting (M)			
M_1= Dibbling at 15cm × 10cm spacing	326^a	$1,063^{ab}$	1,039
M_2= Dibbling at 20cm × 15cm spacing	354^a	$1,173^a$	1,094
M_3= Broadcasting	264^b	858^b	1,036
SE (m)	18	72	320
CD (0.05)	51.49	207.49	NS
Factor 3 - Nutrient management (N)			
N_1- Soil test recommendation of N: P_2O_5: K_2O (42:25:25 kg/ ha)	337	1,114	1,123
N_2= 75% N, 100% P_2O_5 125% K_2O of N_1 and 20 kg/ha Si	299	964	1,421
N_3= 50% N, 100% P_2O_5 150% K_2O of N_1 and 20 kg/ha Si	307	997	906
SE (m)	18	72	320
CD (0.05)	NS	NS	NS

confirms the influence of N on the plant height of rice. This result was in agreement with the observations made by Jahan et al. (2022). They reported a similar trend in height reduction at lower N levels. N nutrition is associated with vegetative growth in plants. The increase in plant height and culm length in response to the application of a higher amount of N fertilizer is probably due to the enhanced availability of N which increased the leaf area resulting in higher assimilate production and dry matter accumulation. This is also indicated by a significantly higher number of tillers per hill at higher doses of N. Tiller production at 60 DAS was significantly higher when soil test-based N: P_2O_5: K_2O treatment was applied (Table 2).

Similarly, results on dry matter production at harvest showed a decreasing trend by 12 % and 16 % successively at lower N levels. The highest dry matter production was obtained fromsoil test-based N: P_2O_5: K_2O treatment (Table 1). Ahmed et al. (2016) also reported that the dry matter production increased significantly with increasing N rates.

Lodging parameters in rice were influenced by various treatments. Culm thickness, culm length, number of internodes and lodging index were the different lodging-related parameters under investigation in the present study. There was no incidence of lodging upto 40 DAS. Lodging as influenced by different treatments thereafter is discussed below.

Foliar spray of paclobutrazol at 45 DAS significantly reduced the culm length at 60 DAS compared to control (Table 4). The decrease might be due to internode retardation. A difference of about 10 cm was observed in culm length between paclobutrazol treated and control plants at 60 DAS. Control of lodging at the stage of panicle initiation is highly crucial. According to Hoshikawa and Wang (1990), the elongation of lower internodes in rice is initiated at the end of the vegetative phase. The length of the lower internodes is a determining factor in lodging. They also reported that culm length has a positive correlation with the length of the lower internode. Hence, a significant reduction in culm elongation at this stage helped the crop to withstand lodging. The reduced culm length, plant height, and inter nodal length by paclobutrazol treatment is attributed to the reduced production of gibberellins by hindering any of the three steps in the terpenoid pathway of its synthesis (Setia et al., 1995). As in the case of plant height, the effect was non-significant at 90 DAS. Lower persistence of foliar spray compared to soil drenching of paclobutrazol might be a more possible explanation for this. All the other lodging parameters like culm thickness, number of internodes and lodging index were not significantly influenced by paclobutrazol treatment The lodging index was reduced by 47 % by the application of paclobutrazol when compared to the control at 60 DAS (Table 6). The significant influence of paclobutrazol on growth components such as plant height and culm length might have contributed to this reduction in the lodging index. Chandler (1969) reported that the reduction in plant height shifts the centre of gravity downwards thereby imparting lodging resistance. Plant height and culm length have a pivotal role in imparting lodging resistance. Tall plants with shallow roots, under weather conditions like strong winds and heavy rainfall after heading, can result in severe lodging (Sinniah et al., 2012)

The lodging parameters such as culm thickness, culm length and number of internodes were not significantly influenced by method of planting. However, the lodging index was significantly affected by the planting method. At 60 DAS, no lodging was observed in plots where dibblingwas done at 20cm ×15 cm spacing (Table 6). The same treatment recorded 17 percent lesser lodging at 90 DAS compared to broadcasting which recorded the highest lodging index throughout.The highest value was on par with dibbling at 15cm ×10 cm spacing. This result is in line with the study conducted by Tereshima et al. (1995) where a higher occurrence of root lodging was recorded in broadcasting than in dibbling in rice. This might be due to the reduced root anchorage capacity and non-uniform plant arrangement in broadcasting. Even though the plant height was higher from plots dibbled at 20cm ×15 cm spacing, the crop could perform better under the lodging susceptible conditions as discussed earlier. This might be the reason for obtaining a lower lodging index from dibbling at 20cm ×15 cm spacing. Broadcasting resulted in non-uniform growth with poor root anchorage which increased the lodging susceptibility.

Effect of nutrient management on lodging parameters was given in Tables 4,5 and 6.A significantly higher value of culm length was obtained at 90 DAS from the application of soil test-based N: P_2O_5: K_2O. The improved vegetative growth of rice as a result of high N rates in this treatment might be the reason. The higher values of culm length obtained with increasing rates of N by Zhang et al. (2014) are in agreement with the present study.

Culm thickness at 60 and 90 DAS was significantly influenced by nutrient management. At 90 DAS, the highest culm thickness was obtained when 50% N, 100% P_2O_5, 150% K_2O, and 20 kg ha^{-1} Si were applied (Table 5). This suggests the importance of K and Si in improving the rice culm thickness. This result is in conformity with the results of Vaithilingam and Balasubrahmanian (1976) who found increased thickness of sclerenchyma tissue layers in rice

Table 4. Effect of treatments on culm length (cm)

Treatment	30 DAS	60 DAS	90 DAS
Factor 1 - Growth regulator (G)			
G_1 - 50 ppm paclobutrazol	22.20	60.85[b]	105.74
G_2- No paclobutrazol	22.06	71.52[a]	104.72
SE (m)	0.41	1.49	1.61
CD (0.05)	NS	4.28	NS
Factor 2 - Method of planting (M)			
M_1- Dibbling at 15 cm × 10 cm spacing	22.86	66.33	104.44
M_2- Dibbling at 20 cm × 15 cm spacing	21.072	66.67	106.64
M_3- Broadcasting	21.77	65.56	104.61
SE (m)	0.50	1.82	1.97
CD (0.05)	NS	NS	NS
Factor 3 - Nutrient management (N)			
N_1- Soil test recommendation of N: P_2O_5: K_2O (42:25:25 kg/ ha)	21.79	66.33	110.83[a]
N_2- 75% N, 100% P_2O_5, 125% K_2O of N_1 and 20 kg/ha Si	22.21	68.00	101.56[b]
N_3- 50% N, 100% P_2O_5, 150% K_2O of N_1 and 20 kg/ha Si	21.71	64.22	103.31[b]
SE (m)	0.50	1.82	1.97
CD (0.05)	NS	NS	5.67

Table 5. Effect of treatments on culm thickness (mm)

Treatment	30 DAS	60 DAS	90 DAS
Factor 1 - Growth regulator (G)			
G_1- 50 ppm paclobutrazol	1.97	3.88	5.30
G_2- No paclobutrazol	1.69	3.93	5.59
SE (m)	0.14	0.04	0.05
CD (0.05)	NS	NS	NS
Factor 2- Method of planting (M)			
M_1- Dibbling at 15cm × 10cm spacing	1.80	3.89	5.28
M_2- Dibbling at 20cm × 15cm spacing	1.96	3.83	5.31
M_3- Broadcasting	1.74	4.06	5.44
SE (m)	0.18	0.05	0.06
CD (0.05)	NS	NS	NS
Factor 3 - Nutrient management (N)			
N_1- Soil test recommendation of N: P_2O_5: K_2O (42:25:25 kg/ ha)	1.77	3.58[b]	4.39[c]
N_2- 75% N, 100% P_2O_5, 125% K_2O of N_1 and 20 kg/ha Si	1.65	4.07[a]	5.24[b]
N_3- 50% N, 100% P_2O_5, 150% K_2O of N_1 and 20 kg/ha Si	2.08	4.12[a]	6.41[a]
SE (m)	0.18	0.05	0.06
CD (0.05)	NS	0.15	0.16

under high K fertilization. Zaman et al. (2015)reported that increased concentration of acid detergent fiber and cellulose in shoot by application of K along with N may also contribute to stem strength. Positive correlation of shoot-K concentration with shoot-cellulose and Si and negative correlation with basal internode space indicate the contribution of K to stem strength of rice plants to decrease lodging losses.Studies conducted by Cui et al. (2018) suggested that the mechanical force with which the rice stem resists lodging is closely associated with the lignin content and cell wall thickness. Hence, the application of high K levels might have contributed to lignin production and culm thickening. Further research is needed to establish the underlying mechanism of lignin and sclerenchyma tissue accumulation through K nutrition.

Silicon plays an important role in imparting the biotic and abiotic stress tolerance in rice and improving productivity.

Table 6. Effect of treatments on lodging index at 60 and 90 DAS

Treatment	60 DAS	90 DAS
Factor 1 - Growth regulator (G)		
G_1= 50 ppm paclorbutrazol	0.096	0.649
G_2= No paclobutrazol	0.182	0.657
SE (m)	0.042	0.031
CD (0.05)	NS	NS
Factor 2- Method of planting (M)		
M_1= Dibbling at 15cm × 10cm spacing	0.154[a]	0.698
M_2= Dibbling at 20cm × 15cm spacing	0[b]	0.579
M_3=Broadcasting	0.263[a]	0.682
SE (m)	0.052	0.038
CD (0.05)	0.149	NS
Factor 3 - Nutrient management (N)		
N_1- Soil test recommendation of N: P_2O_5: K_2O (42:25:25 kg/ ha)	0.155	0.923[a]
N_2= 75% N, 100% P_2O_5, 125% K_2O of N_1 and 20 kg/ha Si	0.140	0.728[b]
N_3= 50% N, 100% P_2O_5, 150% K_2O of N_1 and 20 kg/ha Si	0.122	0.308[c]
SE (m)	0.052	0.038
CD (0.05)	NS	0.108

The role of Si in providing mechanical strength for rice stems is already known. This can be primarily associated with the increased culm thickness observed in Si-treated plants. This might be due to the deposition of applied Si in the leaf blades, leaf sheaths, stem, and vascular tissues. Kido et al. (2015) reported that Si gets deposited in the epidermal cell wall and gets polymerized to form a Si-cuticle double layer. The results indicate that the increase in culm thickness was remarkably higher at lower doses of N. Similar trends were observed by Idris et al. (1975) who reported that with the increase in N dose, the efficiency of Si to resist lodging was reduced.

The overall improvement in parameters like culm length and culm thickness which are responsible for lodging resistance had reflected in the lodging index too. The lodging index was significantly higher in plants treated with the application of soil test-basedN: P_2O_5: K_2O. The lodging index value showed a decreasing trend with successive nutrient levels (Table 6). At 90 DAS, the least lodging index was observed in plants treated with 50% N, 100% P_2O_5, 150% K_2O, and 20 $kgha^{-1}$ Si. These reduced lodging rates can be attributed to the reduced plant height and overall vegetative growth and an increased culm thickness obtained from this treatment as discussed earlier.

Increased resistance to pests and pathogens under high K fertilizers might have helped the plants to perform better especially under a lodged crop environment with high disease susceptibility. Idris et al. (1975) also observed a better weight-bearing capacity of Si-treated plants due to the increased straw stiffness and culm strength when compared to the control. The study hence suggests that the combination of increased K and Si fertilization under reduced N conditions can help plants to withstand lodging. The resistance to lodging is manifested by a reduced centre of gravity and an appropriate balance between the weight of the upper and lower portions of the plant

Yield of rice was influenced by treatmentsand the effect of treatments on the overall growth of rice as well as the occurrence of lodging caused variations in the yield attributes, grain yield, straw yield and harvest index.

The number of panicles per square meter was significantly higher other yield parameters were not significantly different in paclobutrazol-treated plants(Table 7). But it was not reflected in the final grain yield. The increase in number of panicles per square meter might be associated with the decreased lodging index. The results showed that straw yield was significantly reduced by paclobutrazol application (Table 8). According to Lolaei et al. (2013), the application of paclobutrazol significantly reduces the rate of vegetative growth by decreasing the length of the shoot and the area of leaves in plants. These resulted in the achievement of a significantly higher harvest index (Table 8) by paclobutrazol application. Street et al. (1986) also claimed that rice height can be reduced by paclobutrazol application thereby achieving lodging reduction while maintaining or increasing the rough rice yield.

Even though the plant population was comparable in dibbling at 15cm ×10 cm spacing and in broadcasting, higher values for the number of panicles per square meter were obtained fromdibbling at 15 cm×10 cm spacing. This can be attributed to the lower lodging index observed in dibbling at 15cm ×10 cm spacing than in broadcasting. The better crop conditions available for plants that were dibbled at a spacing of 20cm×15 cm might have contributed to the higher number of grains per panicle in them.

The lowest lodging index from dibbling at 20cm cm×15 cm spacing have reflected in the grain yield also by recording the highest grain yield which was 27percent higher than broadcasting. Straw yield was statistically superior from dibbling at 15cm ×10 cm spacing and was significantly lower from dibbling at 20cm × 15cm spacing. Consequently, the higher harvest index of 0.35 was also registered from dibbling at 20cm × 15cm spacing. Dibbling at a wider spacing helps the crop to establish better in a healthy microclimate that enables the crop to withstand lodging better compared to broadcasting.

Nutrient management had a significant impact on the yield of rice. In the present study, the highest N level treatment of soil test-based N: P_2O_5: K_2O gave a significantly lower number of panicles per square meter and grain yield due to the effect of lodging (Table 7). However, 1000 grain weight was found to be higher at high N levels (Table 8). The lodging index insoil test-based N: P_2O_5: K_2O application was significantly high and hence, lodging might have interrupted the grain formation. However, the straw yield was recorded to be significantly higher under this fertilizer treatment. Lodging intervention before the grain filling stage might be the reason for grain yield not commiserating with the straw yield. Based on the findings of similar studies conducted by Basak et al. (1962) a more plausible explanation is the failure of proper blooming and fertilization of the ears in rice due to lodging before heading. Metabolic and photosynthetic disturbances might have contributed to improper kernel development. N uptake was significantly higher from high N fertilization. But this high uptake could not reflect in the grain yield. Under high N fertilization, the unbalanced distribution of absorbed N between grain and straw might

Table 7. Effect of treatments on yield attributes of rice

Treatment	Days to 50 % flowering	No. of panicles/m^2	No. of grains/panicle	% filled grains	1000 grain weight (g)
Factor 1 - Growth regulator (G)					
G_1- 50 ppm paclobutrazol	72.52	241.85^a	128.07	77.15	28.96
G_2- No paclobutrazol	71.68	223.08^b	128.00	78.78	28.74
SE (m)	0.53	0.29	2.14	0.90	0.27
CD (0.05)	NS	0.82	NS	NS	NS
Factor 2- Method of planting (M)					
M_1- Dibbling at 15cm × 10cm spacing	71.50	271.04^a	121^b	78.88	29.00
M_2- Dibbling at 20cm × 15cm spacing	71.83	230.43^c	132^a	78.00	28.66
M_3- Broadcasting	72.94	235.92^b	131^a	78.06	28.88
SE (m)	0.65	0.35	2.62	1.11	0.33
CD (0.05)	NS	1.00	7.53	NS	NS
Factor 3 - Nutrient management (N)					
N_1- Soil test recommendation of N: P_2O_5: K_2O (42:25:25 kg/ ha)	72.39	220.79^c	126.66	77.50	29.00
N_2- 75% N, 100% P_2O_5, 125% K_2O of N_1 and 20 kg/ha Si	71.28	249.19^a	128.55	79.11	28.72
N_3- 50% N, 100% P_2O_5, 150% K_2O of N_1 and20 kg/ha Si	72.61	227.41^b	128.89	78.33	28.83
SE (m)	0.65	0.35	2.62	1.11	0.33
CD (0.05)	NS	1.00	NS	NS	NS

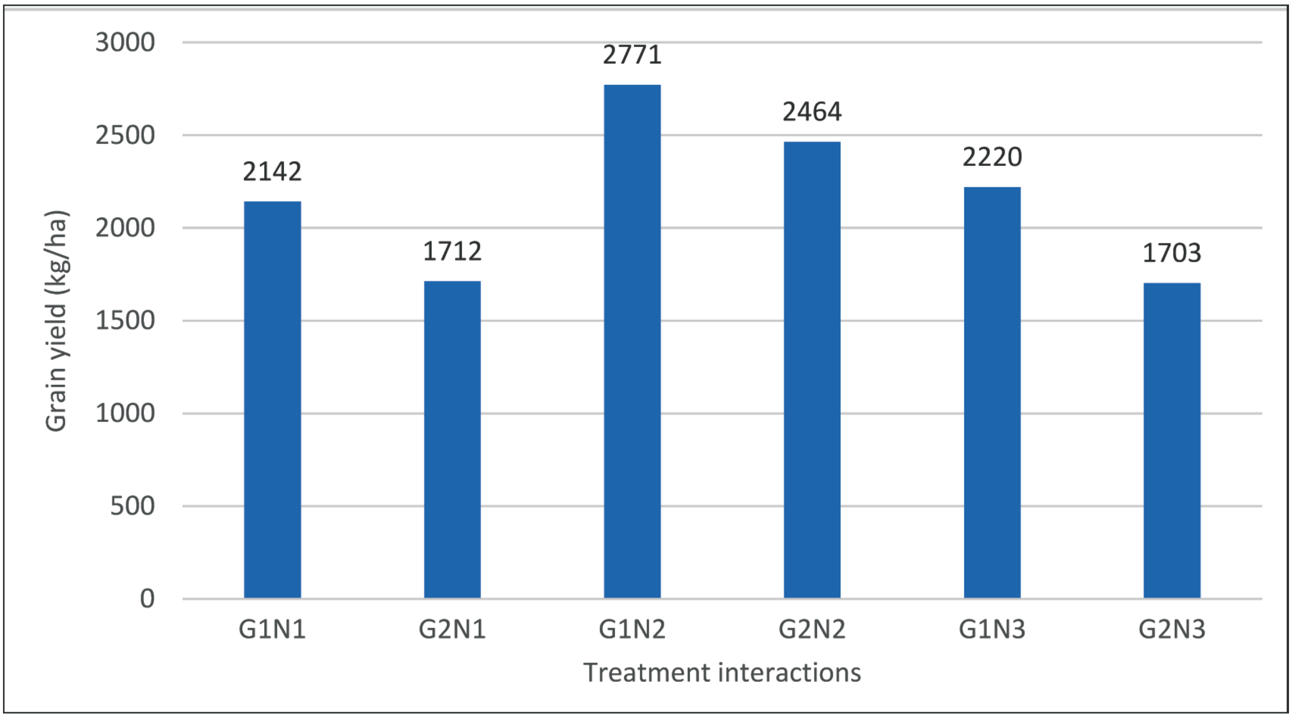
be the reason for the reduced harvest index. The absorbed N is used in straw production and that has resulted in lodging and the subsequent reduction in grain yield.

As the Si application resulted in a significant reduction in lodging, grain yield was higher in the treatments with Si application. The statistically superior grain yield obtained from the application of 75% N, 100% P_2O_5, 125% K_2O and 20 kg ha^{-1} Si can also be attributed to the positive effect of Si. Several studies have reported the significance of Si in improving the yield attributing parameters in rice. In the present study, even though the several yield attributing parameters recorded no significant variation among treatments; better results were obtained from treatments with Si when compared to the control treatment without Si. The straw yield from Si-treated plants was significantly lower than the control. A decreasing trend was observed in straw yield with decreasing N levels irrespective of the applied Si. This indicates that Si does not increase vegetative growth in rice instead the applied Si is accumulated in the existing vegetation imparting stiffness and thereby lodging resistance. The increased grain yield can also be attributed to the erect leaves due to Si nutrition which would otherwise droop in a lodged crop environment and affect photosynthesis. Idris et al. (1975) also observed a better weight-bearing capacity of Si-treated plants when compared to the control explaining the better lodging withstanding power of Si treated plants.

The significantly higher number of panicles per square meter from higher K levels might be associated with the reduced lodging rate. It is assumed that the combined effect of reduced N and increased K levels along with added Si can provide the best grain yield under lodging susceptible conditions. However, the highest grain yield was obtained from the

Table 8. Effect of treatments on grain yield, straw yield (kg/ha) and Harvest Index

Treatment	Grain yield (kg/ha)	Straw yield (kg/ha)	HI
Factor 1 - Growth regulator (G)			
G_1- 50 ppm paclobutrazol	2377	4710^b	0.34^a
G_2- No paclobutrazol	2293	5385^a	0.29^b
SE (m)	37.31	46.86	0.004
CD (0.05)	NS	134.69	0.012
Factor 2- Method of planting (M)			
M_1- Dibbling at 15cm × 10cm spacing	2140^b	5279^a	0.28^c
M_2- Dibbling at 20cm × 15cm spacing	2728^a	5067^b	0.35^a
M_3- Broadcasting	2139^b	4796^c	0.30^b
SE (m)	45.69	57.4	0.005
CD (0.05)	131.33	164.97	0.014
Factor 3 - Nutrient management (N)			
N_1- Soil test recommendation of N: P_2O_5: K_2O (42:25:25 kg/ ha)	1927^b	6180^a	0.23^c
N_2- 75% N, 100% P_2O_5, 125% K_2O of N_1 and 20 kg/ha Si	3118^a	5060^b	0.38^a
N_3- 50% N, 100% P_2O_5, 150% K_2O of N_1 and 20 kg/ha Si	1961^b	3901^c	0.32^b
SE (m)	45.69	57.4	0.00
CD (0.05)	131.33	164.97	0.014



G_1 = 50 ppm paclobutrazol; G_2 = No paclobutrazol; N_1 = 100 % N: P_2O_5: K_2O; N_2 = 75% N, 100% P_2O_5 125% K_2O and 20 kg/ha Si; N_3 = 50% N, 100% P_2O_5 150% K_2O and 20 kg/ha Si

Figure 1. Interaction effect of growth regulators and nutrient management on grain yield

treatment of 75% N, 100% P_2O_5, 125% K_2O, and 20 kg ha^{-1} Si. Even though the lodging index was 66 percent lower in the treatment with application of 50% N, 100% P_2O_5, 150% K_2O, and 20 kg ha^{-1} Si than in 100 % N: P_2O_5: K_2O, the grain yield from both these treatments were on par.This result implies that reducing N fertilization can reduce the lodging rate only at the expense of grain yield. Hence, an optimum level of 75 % N and 125% K of general recommendation along with added Si can be standardized as it provides a reduced lodging index (Table 6) as well as increased grain yield. The straw yield is also in agreement with this recommendation. A significantly lower straw yield was obtained from the above said optimum level of fertilizer resulting in the highest harvest index (Table 8).

The results on interaction between growth regulator and nutrient management indicate that with the paclobutrazol application, grain yield is significantly higher compared to control even at high N levels (Figure 1). The experiment provides new insight into combining the paclobutrazol application with increased N fertilization so that while meeting the N requirement of the crop for reaching the

Table 9. Effect of treatments on economics of cultivation

Treatment	Gross return (Rs./ha)	Net return (Rs./ha)	B:C Ratio
Factor 1 - Growth regulator (G)			
G_1= 50 ppm paclobutrazol	87,754	43,087[b]	1.96[b]
G_2= No paclobutrazol	88,845	51,178[a]	2.36[a]
SE (m)	1068.86	1068.87	0.028
CD (0.05)	NS	3762	0.08
Factor 2- Method of planting (M)			
M_1= Dibbling at 15cm × 10cm spacing	84,153[b]	42,987[b]	2.03[b]
M_2= Dibbling at 20cm × 15cm spacing	99,000[a]	57,833[a]	2.41[a]
M_3=Broadcasting	81,745[b]	40,579[b]	2.03[b]
SE (m)	1309	1309	0.034
CD (0.05)	3762	3762	0.098
Factor 3 - Nutrient management (N)			
N_1- Soil test recommendation of N: P_2O_5: K_2O (42:25:25 kg/ ha)	82,941[b]	42,441[b]	2.05[b]
N_2= 75% N, 100% P_2O_5 125% K_2O of N_1 and 20 kg/ha Si	1,09,483[a]	67,983[a]	2.68[a]
N_3= 50% N, 100% P_2O_5 150% K_2O of N_1 and 20 kg/ha Si	72,475[c]	30,975[c]	1.74[c]
SE (m)	1309	1309	0.034
CD (0.05)	3762	3762	0.098

potential economic yield, excess vegetative growth can be kept under check avoiding chances of losses by lodging.

Economics of rice cultivation as influenced by treatments

The net return and B:C ratio were significantly less inpaclobutrazol treatment due to the cost incurred in the treatment. The grain yield was not significantly different in treatments with and without paclobutrazol application thus resulted in a non-significant variation in gross return (Table 9)

The highest gross return, net return and B:C ratio obtained from dibbling at 20cm × 15cm spacing can be attributed to the highest grain yield and harvest index obtained from this treatment. The high lodging rates and the resultant reduction in grain yield in the other two planting methods might be the reason for obtaining low gross return, net return and B:C ratio.

Among the different treatment combinations, dibbling at 20cm × 15cm spacing with a nutrient level of 75% N, 100% P_2O_5, 125% K_2O and 20 kg/ha Si without paclobutrazol application resulted in the highest gross return, net return and B:C ratio. The lowest values were obtained from broadcasting along with application of 50% N, 100% P_2O_5 150% K_2O and 20 kgha^{-1} Si.

The high grain yield and harvest index values and low lodging index of 75% N, 100% P_2O_5, 125% K_2O and 20 kg ha^{-1} Si treatment have reflected in the B:C ratio also. The high occurrence of lodging in 100 % N: P_2O_5: K_2O resulted in reduced grain yield. However, straw yield was higher from this treatment. Even though lodging was less, the reduced level of N in the treatment 50% N, 100% P_2O_5 150% K_2O and 20 kg ha^{-1} Si have resulted in reduced grain yield as well as straw yield and consequently low gross return, net return and harvest index.

Conclusion

Result of the study indicated that foliar spray of 50 ppm paclobutrazol application just before panicle initiation stage was effective in reducing the plant height, culm length and leaf area and lodging up to 60 DAS. Grain yield was increased inpaclobutrazol treatment with a reduction in straw yield and an improvement in harvest index.Due to the high cost it is not economically viable. The study suggested that the combination of increased K and Si fertilization under reduced N conditions and dibbling at wider spacing could help rice plants to withstand lodging with higher productivity and profitability. Dibbling at 20cm ×15 cm spacing along with the application of 75% N, 100% P_2O_5 125% K_2O of soil test-based recommendation and 20 kgha^{-1} Si is a viable management option for reduced lodging, increased yield and net return of upland rice variety Vaishak, when grown in a soil with available nutrient status of low N, high P_2O_5 and medium K_2O.

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