



Amelioration of lodging in barley (*Hordeum vulgare*) using plant growth regulators

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ABSTRACT

The present study with aim to evaluate the efficacy of plant growth retardants to enhance productivity of barley by reducing lodging behaviour under high nitrogen supply was carried during *rabi* 2016–17 and 2017–18 at Rajasthan Agricultural Research Institute, Durgapura, Jaipur. Results revealed that application of 125% and 150% RDN recorded significantly higher periodic plant height and dry matter accumulation over 100% RDN. The combined application of Chlormequat Chloride *fb* Cerone reduced the plant height by 6.65, 4.49 and 2.93% at 60 DAS, 12.19, 8.58 and 3.57% at 90 DAS and 11.46, 8.50 and 4.63% at harvest, thus, reduced the lodging score by 70.05, 52.01 and 29.40% over water spray, CCC and Cerone, respectively. The significantly maximum lodging score (10.23), number of effective tillers/m² (318.69), spike length (12.03 cm) and number of grains/spike (44.67) were registered with 150% RDN. The combined spray of Chlormequat Chloride *fb* Cerone increased the effective tillers by 14.97, 10.12 and 5.11% and test weight by 8.90, 5.72 and 2.88% over water spray, Chlormequat Chloride and Cerone used alone, respectively. The grain, straw and biological yield of wheat with 150% RDN were 10.98, 5.17 and 7.90% higher compared to 100% RDN, respectively. However, 125% RDN was found statistically at par with 150% RDN. The application of 125 and 150% RDN increased the gross return by 5.72–9.48% and net returns by 7.47–12.02% and B:C ratio by 5.74–8.66% over 100% RDN. The combined application of CCC *fb* Cerone increased gross by 9.65, 6.01 and 2.37% and net returns by 10.31, 7.98 and 2.70% over water spray, Chlormequat Chloride and Cerone used alone, respectively. Therefore, it can be concluded that use of plant growth regulators i.e. Chlormequat Chloride *fb* Cerone under higher use nitrogen (125% RDN) can be advocated as sustainable strategy to manage the problem of lodging and enhancing productivity and profitability of barley cultivation.

Key words: Barley, Crop lodging, Crop productivity, Nitrogen management, Plant growth regulators

Barley (*Hordeum vulgare* L.) is an important cereal crop as imperial source of food, feed, and raw material for the malt industries (Celus *et al.* 2006). It is highly adaptable and can be cultivated in any climate under irrigated and rainfed production areas of world. There are many limiting factors in barley production including low yielding cultivars, poor growing conditions, lodging stress and crop-weed competition (Rajala *et al.* 2002). In spite of all, lodging is one of the severe stress that often limits the use of high nitrogen of crops for realizing their higher productivity. Application of higher dose of nitrogen (N) results in a risk of lodging stress a phenomenon known to

reduce grain yield by 4–65% in barley (Sameri *et al.* 2009). Lodging causes permanently displacement of stem from its upright position due to internal and external factors. Other factors of lodging are increase in weight of mature ears due to moisture accumulation, occurrence of high speed winds at grain filling stage, wide use of flat planting and flood irrigation and the lack of acceptable cultivars that are lodging tolerant at higher N rates etc. (Taiz and Zeiger 2004, Stachecki *et al.* 2004). This lodging of cereals under higher N supply can be controlled by using lodging tolerant cultivars and by applying growth retardant chemicals etc. (Rodrigues *et al.* 2003). The development of dwarf cultivars with lodging resistance is costlier issue and can limit lodging under moderate levels of inputs only, especially fertilizer (N) and irrigation (Tripathi *et al.* 2003). This form of lodging which is most common with well-managed crop occurs near or after flowering and is primarily the result of wind during or soon after irrigation or rainstorms (Hobbs 2007). The reduction in grain yield caused by lodging may be greatest when lodging occurred within a month after anthesis, which is most commonly reported under Indian condition. The

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yield potential of high yielding barley genotypes under irrigated and high N supply could be achieved consistently and efficiently by finding suitable solutions of lodging problem (Sui-Kwong *et al.* 2011).

A number of plant growth retardants such as ethephon (Shekoofa and Emam 2008, Ye *et al.* 2015), DA-6 (diethyl aminoethyl hexanoate) (Nie *et al.* 2010), chlormequat chloride (CCC) (Toyota *et al.* 2010) and the mixtures of them found to be effective for managing the problem of lodging in cereals and other crops and realizing their productivity potential especially when crop supplied with high N (Rajala *et al.* 2002, Tripathi *et al.* 2003). By applying these growth retardant the height decreases and stalk strength and number of vascular bundles in stalk are increased (Xu *et al.* 2017), thus reduces the lodging percentage (Zhang *et al.* 2014, Ye *et al.* 2015). The nature and extent of lodging are closely related to height of the stem, which can be modified using growth retardants (Peng *et al.* 2014). Therefore, the objectives of this study were to quantify the effect of N levels and growth retardants on yield, yield components and lodging of barley, and determine possibility of use of higher N with application of growth retardants for realizing higher crop productivity.

MATERIALS AND METHODS

The present study was conducted during two consecutive *rabi* season of 2016–17 and 2017–18 at research farm of Rajasthan Agricultural Research Institute, Durgapura, Jaipur (26°51' N, 75°47'E and 390 m altitude) under All India Coordinated Wheat and Barley Improvement Project to examine effect of various growth retardants and nitrogen levels lodging behaviour, productivity and profitability of barley. The experimental site falls in the Semi-Arid Eastern Plain Zone of Rajasthan (III-A), characterized by cold winters and hot summers. Occurrence of frost (below 0°C) during December/January in winter season is quite common phenomenon in this climatic zone. The average annual rainfall of the zone is 525 mm of which about 90% is received during later half of June to September with erratic distribution over time and space. The soil of the experimental field was loamy sand in texture having pH 8.4, low in organic carbon (0.22%) and N (180 kg/ha), medium in available phosphorus (19.50 kg/ha) and potassium (235 kg/ha). The experiment was laid out in split plot design and consists of three fertility levels of recommended dose of nitrogen (RDN), viz. 100% RDN (60 kg/ha), 125% RDN (75 kg/ha) and 150% RDN (90 kg/ha) in main plots and four plant growth regulators i.e. spray of CCC @1.25 L/ha at growth stage (GS) 30-31, Ethephon (Cerone) @0.5 L/ha at GS 32-49, CCC @1.25 L/ha at GS 30-31 *fb* Cerone @0.5 L/ha at GS 32-49 and control (water spray) in sub plots and replicated thrice.

Field preparation included one deep ploughing followed by 2 cross harrowing and planking. The malt barley variety BH-946 was sown during third week of November with a recommended seed rate of 100 kg/ha. During both the seasons half quantity of recommended N

and whole amount of P₂O₅ (30 kg/ha) and K₂O (20 kg/ha) were applied as basal at sowing, while remaining quantity of N were applied at the time of first irrigation. Crop was raised under irrigated condition providing five irrigations at critical growth stages. Crop protection measures were followed as and when required. Ten plants from sampling area of crop uprooted and aboveground portions were cut for observations. The sampled plants were dried in hot air oven at 65°C for 48 h and dry weight was expressed in g/m². The growth and yield attributes were recorded as per the standard procedure by sampling from three places in each plot. Lodging was scored with the formula ((% plot area lodged x angle of lodging from the vertical)/90), as described by Tripathi *et al.* 2004. All the plants of barley from one meter square were counted for effective ear heads at harvest. Ten earheads of barley were used to measure the length from the basal whorl to the tip of the spike. The net plots (1.2 m × 7 m), leaving the two border rows on the rows direction and half meter on opposite direction of the plots of wheat were harvested manually with sickles. The produce was kept for sun drying for some days in field and after drying the biological yield was recorded and expressed in q/ha. After threshing the bundles from each plot, the grains were cleaned, dried and weighed. The grain yield was expressed in q/ha. Straw yield was obtained by subtracting the grain yield from the weight of total biological yield for individual plots and was expressed in q/ha. The net returns of each treatment were calculated by deducting the total cost of cultivation from gross returns of respective treatments and the benefit:cost ratio was calculated by dividing the net returns with total cost of cultivation. All data recorded were analyzed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez 1984) for split plot using SAS 9.3 software (SAS Institute, Cary, NC). The least significant test was used to decipher the main the interaction effects of treatments at 5% level of significance (P<0.05).

RESULTS AND DISCUSSION

Effect of fertility levels and growth retardants on growth parameters and lodging of barley: The successive increment in N supply (100% RDN to 150% RDN) led significant difference in periodic plant height and dry matter accumulation of crop (Table 1). At all the crop stages (60, 90 DAS and at harvest) the crop fertilized with 150% RDN recorded significantly maximum plant height over 100% RDN. However, the crop supplied with 125% RDN produced statistically similar plant height compared to 150% RDN during all the growth stages. Similar results were also recorded for dry matter accumulation and application of 125% and 150% RDN enhanced the dry matter of crop with the magnitude of 6.30 to 8.06% (60 DAS) 5.17 to 8.72% (90 DAS) and 4.81 to 6.51% (at harvest) over 100% RDN. Since, nitrogen is well known as an important constituent for cell division and cell elongation and optimum availability of nitrogen might improve photosynthetic area of plants that cumulatively contributed to higher periodic plant height

Table 1 Effect of different N doses and lodging preventers on growth parameters of barley (values pooled over 2 years)

Treatments	Plant height (cm)			Dry matter accumulation (g/m ²)		
	60 DAS	90 DAS	At harvest	60 DAS	90 DAS	At harvest
<i>N levels</i>						
100% RDN	60.69	75.29	87.83	442.17	821.89	1167.88
125% RDN	63.87	79.84	98.52	471.91	866.71	1226.93
150% RDN	64.61	82.05	100.18	480.96	900.43	1249.14
CD (P=0.05)	2.00	2.37	5.35	13.94	44.69	60.91
<i>Plant growth regulators</i>						
CCC	65.21	83.97	97.62	475.94	899.12	1241.12
Cerone	64.24	80.10	94.15	483.20	917.23	1282.23
CCC <i>fb</i> Cerone	62.41	77.34	89.98	494.52	945.12	1335.12
Water spray	66.56	86.77	100.29	470.17	840.26	1138.10
CD (P=0.05)	2.39	3.23	3.41	18.59	28.99	61.63

and dry matter accumulation (Leifeld *et al.* 2009, Berry and Spink 2012). The successive increment in N doses (100% RDN to 150% RDN) led to significant increase in lodging score of barley (Table 2). The crop fertilized with 150% RDN recorded maximum lodging score (10.03) over 100% RDN (2.23) and 125% RDN (5.13).

Application of CCC *fb* Cerone reduced the plant height with the magnitude of 6.65, 4.49 and 2.93% at 60 DAS, 12.19, 8.58 and 3.57% at 90 DAS and 11.46, 8.50 and 4.63% at harvest over water spray, CCC and Cerone, respectively (Table 1). At the same time, application of CCC *fb* Cerone enhanced the dry matter accumulations by 4.92, 3.76 and 2.29% at 60 DAS, 11.09, 4.86 and 2.95% at 90 DAS and 14.75, 7.04 and 3.96% at harvest over water spray, CCC and Cerone, respectively. The plant growth regulators had significant effect on lodging score of barley (Table 2). Application of CCC *fb* Cerone reduced the lodging score of barley with the magnitude of 70.05, 52.01 and 29.40% over water spray, CCC and Cerone, respectively. Plant height and strength of basal internodes are closely related to lodging resistance (Ramburan and Greenfield 2007, Zhang *et al.* 2010). Based on the present results, it is suggested that application of CCC *fb* Cerone can avoid risk of lodging that occurs under high N supply by altering the plant height and reducing the lodging score.

Effect of fertility levels and growth retardants on yield attributes of barley: The analysis of variance data indicated that nitrogen levels had significant effect on yield attributes of barley (Table 3). The significantly maximum number of effective tillers/m² (318.69), spike length (12.03 cm) and number of grains/spike (44.67) were registered with 150% RDN. However, crop supplied with 125% RDN recorded statistically similar results for aforesaid yield attributes compared crop supplied with 150% RDN. The application of 125% and 150% RDN enhanced the number of effective tillers by 5.27 and 8.98%, spike length by 11.31 and 13.91% and number of grains/spike by 5.30 and 9.50% over 100% RDN, respectively. The optimal and balanced supply of N led to higher growth and development of plants

Table 2 Effect of different N doses and lodging preventers on yield attributes and lodging of barley (values pooled over 2 years)

Treatment	Effective tillers/m ²	Spike length (cm)	Number of grains/spike	Test weight (g)
<i>N levels</i>				
100% RDN	290.06	10.36	40.43	42.84
125% RDN	306.22	11.68	42.69	43.62
150% RDN	318.69	12.03	44.67	43.89
CD (P=0.05)	15.73	1.17	2.87	3.23
<i>Plant growth regulators</i>				
CCC	296.51	12.05	42.90	42.84
Cerone	313.05	11.95	42.30	44.13
CCC <i>fb</i> Cerone	329.89	11.82	41.97	45.44
Water spray	280.51	12.30	43.22	41.40
CD (P=0.05)	24.10	0.32	1.20	1.12

Table 3 Effect of different N levels and lodging preventers on barley productivity (values pooled over 2 years)

Treatment	Grain Yield (q/ha)	Straw yield (q/ha)	Biomass yield (q/ha)	Lodging score
<i>N levels</i>				
100% RDN	50.10	60.74	110.84	2.23
125% RDN	53.60	62.94	116.54	5.13
150% RDN	56.28	64.06	120.34	10.03
CD (P=0.05)	4.51	2.78	6.45	-
<i>Plant growth regulators</i>				
CCC	52.04	63.05	115.09	6.13
Cerone	55.29	61.50	116.79	4.15
CCC <i>fb</i> Cerone	57.73	59.40	117.13	2.93
Water spray	48.25	66.38	114.63	9.95
CD (P=0.05)	4.12	7.04	5.36	-

reflected by higher yield attributes of barley (Zaman *et al.* 2014) and wheat (Mavi and Benbi 2008). The N levels found statistically at par for test weight, although highest value (43.89 g) was recorded with 150% RDN (Table 2). The growth regulators led significant effect on number of tillers and test weight of crop. The spray of CCC *fb* Cerone increased the effective tillers by 14.97, 10.12 and 5.11% and test weight by 8.90, 5.72 and 2.88% over water spray, CCC and Cerone, respectively. However, significantly maximum values of number of grains/spike (43.22) were recorded with water spray compared to spray of CCC *fb* Cerone (41.97). The spike length under different growth retardant was found statistically at par, although highest values were recorded with water spray. Similar results with the use of plant growth retardants with different rates of N were also reported by Zaman *et al.* (2014) for barley and Guoping *et al.* (2001) for wheat.

Effect of fertility levels and growth retardants on crop productivity: Present findings revealed that N levels had significant effect on barley productivity (Table 3). The significantly maximum grain, straw and biological yields were recorded with 150% RDN which were 10.98, 5.17 and 7.90% higher compared to 100% RDN, respectively. However, the crop fertilized using 125% RDN was found statistically at par with 150% RDN. This increment in crop productivity might be result of higher plant growth, dry matter accumulation and yield attributes of crop with the higher dose of N. Similar results were also reported by many other researchers (Yadav *et al.* 2017, Shah *et al.* 2017). Plant growth regulators had significant effect on grain yield of barley (Table 3) and maximum was recorded with spray of CCC *fb* Cerone which were 16.42, 9.86 and 4.24% higher compared to water spray and CCC and Cerone, respectively. However, all the growth retardants were found statistically at par for straw and biomass yield. These results are in close agreement with the results of earlier researchers (Tripathi *et al.* 2003, Ramburan and Greenfield 2007) who stated that growth inhibitor significantly reduced plant height and simultaneously produced equal biomass over no application.

Effect of fertility levels and growth retardants on economics: The highest cost of cultivation (₹ 30267), gross returns (₹ 98792), net returns (₹ 68524) and B:C ratio (2.26) were observed with application of 150% RDN compared to 100% RDN and 125% RDN (Table 4). The application of 125 and 150% RDN increased the gross return by 5.72–9.48%, net returns by 7.47–12.02% and B:C ratio by 5.74–8.66 % over 100% RDN. Among the growth retardant treatments, highest cost of cultivation (₹ 30581), gross returns (₹ 98810), net returns (₹ 68229) and B:C ratio (2.23) were recorded with application of CCC *fb* Cerone (Table 4). The combined application of CCC *fb* Cerone increased gross returns by 9.65, 6.01 and 2.37% and net returns by 10.31, 7.98 and 2.70% over water spray and when CCC and Cerone used alone, respectively. Thus, application of CCC *fb* Cerone provided additional net reruns of ₹ 7032 to the farmers over water spray (control). The higher crop productivity of crop might be the principal

Table 4 Effect of different N doses and lodging preventers on economics of barley (values pooled over 2 years)

Treatment	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C ratio
<i>N levels</i>				
100% RDN	29145	89426	60281	2.07
125% RDN	29706	94854	65148	2.19
150% RDN	30267	98792	68524	2.26
<i>Plant growth regulators</i>				
CCC	30081	92868	62787	2.09
Cerone	30081	96472	66391	2.21
CCC <i>fb</i> Cerone	30581	98810	68229	2.23
Water spray	28081	89278	61197	2.18

reason for higher net returns under higher N levels (125 and 150% RDN) and combined application of CCC *fb* Cerone. Similar results of higher farm profitability of cereals were also reported by Bhandari *et al.* (2002) and Benbi *et al.* (2012) for higher N levels and by Guoping *et al.* 2001 for plant growth regulators.

This study demonstrated that cultivation of barley with the combined use CCC *fb* Cerone and 125% RDN resulted in significant improvement in the growth, productivity and profitability over 100% RDN. Therefore, it can be concluded that higher use of N (125% RDN) with combined application of CCC *fb* Cerone plant growth regulators can be advocated as sustainable strategy manage the problem of lodging and enhancing productivity and profitability of barley.

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