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Use of growth regulators for lodging tolerance and increasing productivity of barley (*Hordeum vulgare)*: An empirical study

A S KHARUB[1], HARI RAM[2], ANIL KHIPPAL[1], BHAGAT SINGH[3], SUDESH KUMAR[4], NEELAM BERKESIA[3], MALURAM YADAV[4], B P SINGH[5], MANINDER KAUR[2], DINESH KUMAR[1]*, R P S VERMA[1] and G P SINGH[1]

ICAR-Indian Institute of Wheat and Barley Research, Karnal, Haryana 132 001, India

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ABSTRACT

A field study was carried out during winter (*rabi*) seasons of 2015–16 to 2017–18 at Karnal, Hisar, Ludhiana, Durgapura and Agra to evaluate the efficacy of plant growth regulators (CCC, ethephon and their combination) to reduce lodging and enhance productivity of barley (*Hordeum vulgare* L.) under high nitrogen level. Results revealed that application of 75 kg N/ha increased the grain yield by 3.17% over the recommended 60 kg/ha. The pooled mean lodging score with the application of growth regulators, viz. CCC, ethephon and combination of both was 5.21, 4.28 and 3.03 respectively, while without growth regulators application the lodging score was 9.57. With the application of plant growth regulator, the yield increased in the range of 2.5–4.1 q/ha (5.7–9.4%). The effect of CCC was relatively lesser as compared to ethephon, however the combination of both gave additive effect on yield increment (8.78%). Application of growth regulators increased 1000-grain weight by 6.21% over control. Therefore, the use of plant growth regulators i.e. CCC and ethephon under high nitrogen (75 kg N/ha) can be advocated as a sustainable strategy to enhance the productivity of barley through decreasing lodging problem.

Keywords: Barley, Crop lodging, Crop productivity, Nitrogen management, Plant growth regulators

Barley (*Hordeum vulgare* L.) is widely grown throughout the temperate, tropical and subtropical regions of the world. In India it is grown on marginal, problematic and resource poor soils for cattle feed and under good management conditions for malting purpose. Barley is grown on 690 thousand hectares (Rajasthan, Uttar Pradesh, Madhya Pradesh, Punjab and Haryana) with 1750 thousand tonnes production and 28.8 q/ha productivity (Anonymous 2019). Both barley grains and straw are highly digestible compared to wheat due to low gluten content in grain and high Neutral Detergent Fibre (NDF) in straw. India faces a net deficit of 61.1% green fodder, 21.9% dry crop residues and 64% feed to support about 512 million livestock population (Kumar *et al.* 2012). However, the major industrial use of barley is in malting industry and malt barley needs to be grown under high fertility condions as compared to the feed barley. Under good fertility conditions, the lodging adversely affects the grain quality and hence the productivity. It is estimated that lodging reduces yields from 7–35% with the greatest yield reductions occurring when lodging happens within 20 days after anthesis.

Yield potential of high yielding varieties can be achieved under proper inputs supply with interventions to minimise the lodging. Plant growth regulators (PGRs) enhance the source-sink relationship, thereby stimulating the translocation of photosynthates and as a result, increasing the crop productivity (Anosheh *et al.* 2016). Cycocel is one of the most frequently used plant growth regulator, particularly in Europe and nowadays it is extensively used to reduce lodging especially in grain cereals (Anosheh *et al.* 2016). Ethephon is the another PGR, which differs from the anti-gibberellic compounds, as its stem shortening effect is due to the inter-cellular ethylene release. Ethephon (Ye *et al.* 2016) and chloromequat chloride (Toyota *et al.* 2010), and their mixtures have been tried for managing the problem of lodging in cereals and other crops. Their application results in a decrease in plant height and an increase in stalk strength (Ye *et al.* 2016) and consequently reduced lodging percentage (Zhang *et al.* 2014, Ye *et al.* 2016). Therefore, the current study was undertaken to assess the effect of plant growth regulators at different nitrogen levels on plant height, lodging behaviour, grain yield attributes and grain yield under the Indian climatic conditions.

[1]ICAR-Indian Institute of Wheat and Barley Research, Karnal, Haryana; [2]Punjab Agricultural University, Ludhiana, Punjab; [3]CCS Haryana Agricultural University, Hisar, Haryana; [4]Rajashthan Agricultural Research Institute, Durgapura, Rajasthan; [5]Raja Balwant Singh College of Agriculture, Agra, Uttar Pradesh.
*Corresponding author email: dkbiochem69@gmail.com

MATERIALS AND METHODS

A multi locational field experiment was conducted in northwestern plains of India during the winter (*rabi*) seasons of 2015–16 to 2017–18 at ICAR-Indian Institue of Wheat and Barley Research, Karnal, Haryana; CCS Haryana Agricultural University, Hisar, Haryana; Punjab Agricultural University, Ludhiana, Punjab; Rajashthan Agricultural Research Institute, Durgapura, Rajasthan and Raja Balwant Singh College of Agriculture, Agra, Uttar Pradesh. The soils of most of these sites were sandy loam, having *p*H 8.0, low in organic carbon, medium in available phosphorous (P) and potassium (K) (Supplementary Table 1). The experiment was conducted in split-plot design with 3 replications by taking 3 nitrogen levels as the main plots; 60, 75 and 90 kg/ha and 4 sub-plot treatments i.e. control (without growth regulator); CCC (chlormequatchloride) @1.25 litre/ha at GS_{30-31}; ethephon (cerone) @0.5 litre/ha at GS_{39-40} and CCC @1.25 litre/ha at GS_{30-31} + ethephon @0.5 litre/ha at GS_{39-40}. Half dose of nitrogen and full doses of P (30 kg/ha) and K (20 kg/ha) were applied as basal and remaining half dose of nitrogen was top-dressed at first irrigation. Sowing was done using 100 kg seed/ha of recently released barley variety BH 946. Irrigations were applied as per requirement at critical growth stages. The crop was raised using standard plant protection and other cultural practices. Growth attributing parameters were recorded during the crop season as per the standard procedure. Five plants were selected randomly from each treatment to record the observations of yield attributes. The grain and biological yields were recorded from the net plot and converted to q/ha. Lodging was scored as:

Lodging score = [Lodged area/net plot area] × 100 × Angle of lodging/90

The economics of different treatments was calculated by using the prevailing prices of the inputs and output. Barley grain and straw economic were calculated using minimum support price and market prices of grain and straw respectively. Net income was calculated by subtracting total variable costs from gross returns. All data recorded were subjected to analysis of variance (ANOVA) at P=0.05. The means of nitrogen levels and growth regulators were separated as explained in split-plot design.

RESULTS AND DISCUSSION

Lodging is one of major problem in cereal production which causes sizeable reduction in grain yield and thus limits crop productivity either by interfering assimilation of dry matter or by impeding crop harvesting. Lodging may be defined as induced displacement of shoots from their vertical standpoint. This results in leaning or completely horizontal lying of plants on ground. Lodging in barley can result either from buckling of any part of the stem (stem lodging) or failure of the root–soil anchorage system (root lodging). It can reduce the grain yield of barley by 28–65% (Berry *et al.* 2006). Lodging also reduces the size and specific weight of grain, and increases harvesting time and drying costs. The mechanisms of lodging in barley are not well understood. However, the scientific literature shows that lodging in barley can result from anchorage failure, as well as buckling of the stem base, buckling of the middle internodes, known as 'brackling' and buckling of the peduncle just below the ear, known as 'necking' (Berry *et al.* 2004).

Plant growth regulators (PGR's) are synthetic compounds, which are used to reduce the shoot length of plants. This is mainly achieved by reducing cell elongation, but also by decreasing the rate of cell division. In cereals, PGR's are used to reduce lodging. They are most commonly used for this purpose in north and western European countries and in Canada and the USA. In the UK, 84% of the winter wheat is treated with PGR's. The most commonly used are chlormequat chloride and mepiquat chloride. Ethephon is the most commonly used ethylene–releasing compound used on cereals. PGR's applied before the emergence of the ear reduced lodging in almost all the experiments. Herbert (1982) showed that applying chlormequat and choline chloride to winter wheat at the beginning of stem extension could reduce the percentage area lodged from about 73% to less than 8%. Most of the growth regulators are only active for a few days after application and can therefore shorten internodes most effectively when applied during their extension. Application of ethephon (480 g/ha) controlled lodging by reducing plant height but also decreased average grain yield by 8.3% (Tripathi *et al.* 2004). Wheat yields were also improved by 500–1000 kg/ha by application of ethephon (Hobbs *et al.* 1998).

Plant height and lodging score: The nitrogen levels were not able to influence the plant height significantly but plant growth regulators (PGRs) individually and in combinations significantly reduced the plant height over the control plot (Table 1). There was an increase in height with the nitrogen level and it increased 2.8 cm and 3.8 cm with 75 and 90 kg N/ha over recommended 60 kg N/ha, respectively. There was a decrease in plant height with the combination of both the growth regulators whereas 10.4 cm and 8.7 cm decrease was noticed with CCC and ethephon, respectively. The behaviour of PGRs for plant height reduction was uniform across different nitrogen levels. Similar to our findings, Zhang *et al.* (2001) also reported that the application of growth regulators decreased the plants' height by 23% as compared to control. Ethephon and mepiquat/ethephon were the most effective in shortening the culm and preventing lodging by improving the stalk strength of maize as reported by Ye *et al.* (2016).

The pooled lodging score significantly increased with the increase of nitrogen level, 128% (2.81) with 75 kg N/ha and 331% (7.22) with 90 kg N/ha level over the recommended 60 kg/ha. The N level of 90 kg/ha increased the lodging score by 4.3 times over the recommended one. It was due to higher N supply to the plants which improves the nutrition of the plant and increased the culm length. The higher nitrogen rates increased the lodging in barley was also reported by Singh *et al.* (2012). The pooled mean lodging score with the application of growth regulators,

Table 1 Effect of nitrogen levels and growth regulators on plant height and lodging score across 5 centres over 3 years

Plant growth regulator	Nitrogen levels (kg/ha)			Mean
	60	75	90	
	Plant height (cm)			
CCC	101	104	105	103.3
Ethephon (Cerone)	103	105	105	104.3
CCC f.b. Ethephon	99	102	103	101.3
Control	111	114	116	113.7
Mean	103.5	106.3	107.3	
	Lodging score			
CCC	2.3	4.52	8.8	5.21
Ethephon (Cerone)	1.42	3.65	7.78	4.28
CCC f.b. Ethephon	0.79	2.7	5.61	3.03
Control	4.22	9.08	15.4	9.57
Mean	2.18	4.99	9.40	
LSD (P=0.05)	Plant height		Lodging score	
Nitrogen levels	3.4		0.46	
PGRs	5.2		0.51	
Interaction	9.6		0.89	

CCC, ethephon and combination of both were 5.21, 4.28 and 3.03 which was significantly lower than control treatment (9.57). So, there was a decrease in lodging score, to the tune of 45.2, 55.3 and 68.3% respectively as compared to control treatment. Interaction effect indicated that the effect of PGRs combination was more effective in reducing lodging score at higher N level than an individual application of PGRs. The positive correlation (r=0.80) was found between reduction in plant height and lodging score. McMillan *et al.* (2020) also reported reduced lodging with the use of PGRs. Combination of ethephon and CCC resulted in decreased plant height and increased stalk strength (Ye *et al.* 2016) which ultimately reduced lodging score (Zhang *et al.* 2014). Sudesh *et al.* (2020) also reported decrease in height and lodging with the application of chlormequat chloride and cerone.

Yield attributes and yield: Progressive increase in nitrogen level increased the tiller density from 338 in 60 kg N/ha to 339 under 75 kg N/ha treatment and 346 under 90 kg N/ha treatment. The treatment of 75 and 60 kg N/ha was statistically at par. More tiller density with higher N level might be due to better nutrition available for plant growth. Donovan *et al.* (2011) also recorded more tiller density under higher N levels. With the application of plant growth regulator, the tiller density increased significantly in the range of 11-19 increase over the control treatment. Chlormequat-chloride (CCC) and ethephon were equally effective individually but there was an additive effect when applied in combination although all 3 PGRs application were statistically similar. Tiller density with PGRs was 4.34% higher as compared to control treatment. Our findings are inconsistent with the findings of Rajala *et al.* (2002). Cycocel in particular, have enhanced tillering, especially production of effective tillers (Zhang *et al.* 2001). The progressive increase in nitrogen level increased the grains/earhead from 38.73 in 60 kg N/ha to 39.37 (1.65%) under 75 kg N/ha and 39.91 (3.04%) under 90 kg N/ha treatment. Grains per earhead recorded in 75 and 90 kg N/ha was significantly higher than recorded in 60 kg N/ha. Hackett (2016) also recorded higher grains/earhead when higher N fertilizer was used. Grains/earhead increased from 38.23–39.21 with chlormequat-chloride, 39.05 with ethephon and 40.76 when both were applied in combination. Although all PGRs treatments improved grains/earhead but only combinations of PGS was able to enhance the grains/earhead significantly over the control. The effect of ethephon on grains/earhead was less as compared to chlormequat-chloride and the combination of both the PGRs.The enhancement in nitrogen level did not influence the 1000-grains weight, it was 42.51 g in 60 kg N/ha, 42.25 g under 75 kg N/ha and 42.18 g under 90 kg N/ha treatment.Thousand grains weight was also not affected by the application of a plant growth regulator. It was 42.23 g with chlormequat-chloride (CCC), 42.31 g with ethephon and 42.54 g with the combination of both, gave additive, which was an increase of 1.33% over the control treatment. Moreover, by reducing the stem elongation, cycocel allocates more assimilates to grain filling and increase of test weight (Rajala *et al.* 2002).

The grain yield was not influenced by different N levels significantly. However, there was an increase of 3.37 (47.55 q/ha) and 3.13% (47.44 q/ha) in 75 and 90 kg N/ha, respectively over the recommended nitrogen of 60 kg/ha (46.00 q/ha). Donovan *et al.* (2011), Singh *et al.* (2012) and Hackett (2016) recorded more grain yield under higher N levels. The PGRs also had a significant effect on grain yield. It was noticed and chlormequat-chloride (CCC) and ethephon were less effective in enhancing grain yield as compared to the combination of both PGRs. The grain yield increased from 44.84 q/ha (control) to 46.82 q/ha with chlormequat-chloride, 47.55 q/ha with ethephon and 48.78 q/ha (8.78% increase) when both were applied in combination. However, CCC and ethephon were equally effective in improving grain yield. In this manner, without growth regulator, the yield was 8.08% less compared to the growth regulator application.With the application of plant growth regulator, the yield increased in the range of 2.5–4.1 q/ha (5.7-9.4%). The more increase was in the treatment of 60 kg N/ha application followed by 75 and 90 kg N/ha of application. The use of PGRs increased the grain yield compared to the control treatment by affecting decreasing plant height and lodging, and enhancing the yield components. Behrami *et al.* (2014) reported that the grain yield of cycocel+cerone was 4.25%, 5.36% and 12.61% higher over cycocel, cerone and control, respectively. By increasing the number and survival of effective tillers and less lodging, PGRs causes more photosynthesis and more assimilates are mobilized towards grains and lead to an increase of grain yield. Zhang *et al.* (2001) and Tripathi *et al.* (2004) reported that PGRs application decreased the plants' height by 23% which resulted in a significant increase of cereal grain yield. PGRs enhances the growth and development, reduced lodging thereby sustaining the production potential of barley (Anosheh *et al.* 2016). McMillan *et al.* (2020) noticed that lodging negatively affect the yield and quality of barley grain.

Biological yield and economics: The highest biological yield was recorded in 90 kg N/ha which was statistically similar to other N levels. However, increased N level showed an increasing trend of biological yield (Table 2). Combination recorded the highest biological yield which was 3.7% higher than control plot. It might be due to higher grain yield recorded in combination treatment.Anosheh *et al.* (2016) also recorded 4.7% higher biomass yield in cycocel over the control plot.

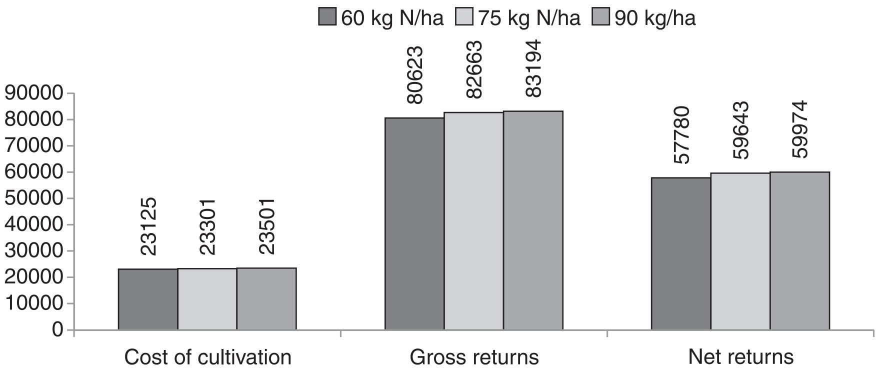
The N level of 75 kg/ha was able to increase the gross and net returns significantly over the 60 kg N/ha (Fig 1). The gross and net returns recorded in 90 kg N/ha was statistically similar to 75 kg N/ha. It might be due to yield enhancement in 75 kg N/ha treatment. Among PGRs, the combination recorded the highest gross and net returns which were statistically similar to ethephone alone but significantly better than control plot (Fig 2). There was a net profit advantage of ₹3,743 in combinations and ₹2,649 in ethephone alone. It was due to higher grain yield recorded in these treatments. Sudesh *et al.* (2020) reported an increase in gross return by 5.72–9.48% and net returns by 7.47–12.02% by using growth regulators.

Based on 3 years data across 5 locations in India, it can be concluded that, increased nitrogen level from 60–75 kg/ha increased grain yield to 3.37%, although lodging was also increased. Plant growth regulators, viz. CCC, ethepon and their combinations reduced the plant height and lodging but also improved the grain yield. So CCC and ethephon or their combinations should be used in barley

Table 2 Effect of nitrogen levels and growth regulators on yield attributes and grain yield at 5 locations over 3 years

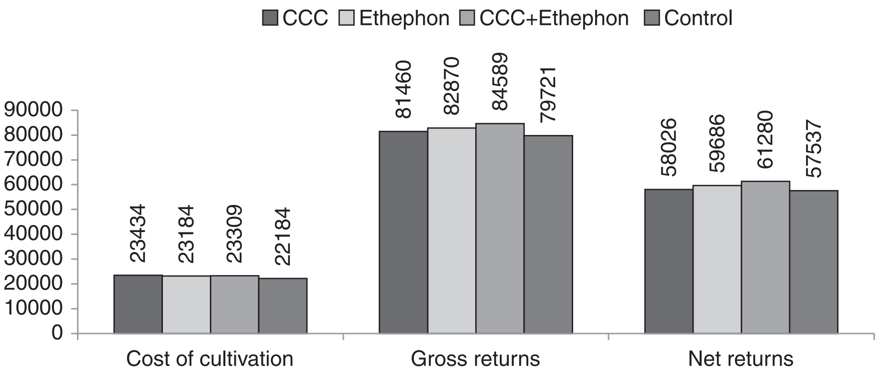
Plant growth regulator	Nitrogen levels (kg/ha)			
	60	75	90	Mean
		Earheads (No./m^2)		
CCC	340	341	347	343
Ethephon (Cerone)	337	339	345	341
CCC f.b. Ethephon	347	347	353	349
Control	328	327	336	330
Mean	338	339	346	
		Grains/earhead		
CCC	38.13	38.95	40.21	39.21
Ethephon (Cerone)	38.33	39.29	39.88	39.05
CCC f.b. Ethephon	39.79	41.12	40.99	40.76
Control	38.03	38.12	38.84	38.23
Mean	38.73	39.37	39.91	39.21
		1000-grains weight (g)		
CCC	42.70	42.46	42.13	42.43
Ethephon (Cerone)	42.68	42.09	42.16	42.31
CCC f.b. Ethephon	42.62	42.53	42.45	42.54
Control	42.04	41.90	41.99	41.98
Mean	42.51	42.25	42.18	
		Yield (q/ha)		
CCC	46.28	47.03	47.17	46.82
Ethephon (Cerone)	46.20	48.42	48.01	47.55
CCC f.b. Ethephon	47.83	49.35	49.17	48.78
Control	43.70	45.42	45.39	44.84
Mean	46.00	47.55	47.44	
		*Biological yield (q/h*a)		
CCC	111.86	115.96	116.00	114.6
Ethephon (Cerone)	115.80	117.56	117.12	116.8
CCC f.b. Ethephon	117.81	116.72	121.30	118.6
Control	111.71	114.58	117.68	114.7
Mean	114.3	116.2	118.0	

LSD (P=0.05)	*Earheads*	*Grains/earhead*	*1000-grain weight*	*Grain yield*	*Biological yield*
Nitrogen levels	8	0.83	NS	4.29	NS
PGRs	9	1.09	NS	0.80	NS
Interaction	NS	NS	NS	NS	NS



CD (P=0.05) Gross returns Net returns
1012 2013

Fig 1 Economics of nitrogen levels.



CD (P=0.05) Gross returns Net returns
1011 2012

Fig 2 Economics of plant growth regulators.

for lowering the lodging score through shortening of height and maximizing the yield at 75 kg N/ha. PGRs application on malting barley needs to be considered in combination with potential benefits of PGRs in mitigating lodging and their effects on the agronomic performance, especially under optimum input conditions.

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