Indian Journal of Agronomy **70** (1): 13–19 (March 2025)
DOI: 10.59797/ija.v70.i1.5575

Research Paper

Nitrogen levels and growth regulators effect on wheat (*Triticum aestivum*) lodging, productivity and profitability under restricted irrigation in a Vertisols of Central India

K.C. SHARMA[1] AND K.S. SOLANKI[2]

ICAR-Indian Agricultural Research Institute, Regional Station, Indore, Madhya Pradesh 452 001

Received: June 2024; Revised accepted: January 2025

ABSTRACT

The field experiment was carried out during *rabi* seasons of 2019–20 and 2020–21 at Research Farm of ICAR-Indian Agricultural Research Institute, Regional Station, Indore (M.P). A total nine treatments consisted of absolute control, 50%, 75%, 100%, 125%, 150% doses of recommended N, 100%, 125% and 150% N along with Growth regulators (Grs) spray were laid out in randomized block design with three replications under restricted irrigation condition. Pooled analysis revealed that spray of Grs along with 100 to 150% of recommended N significantly decreased the plant height and ultimately reduced lodging. However, maximum grain yield (4.40 t/ha) recorded with 100% N was statistically at par with 100 and 150% of N applied along with Grs but significantly higher over rest of the treatments. Wheat crop was lodged only in the plots, where nitrogen was applied @ 125 and 150% of the recommended N and lodging score was 5.23 and 12.53, respectively. Application of Grs recorded significantly higher wheat yields only when crop lodged or lower N levels. Highest values of net returns (₹ 85,114/ha), B:C ratio (2.73), energy productivity (256.9 g grain/MJ), energy responsiveness (7.84 MJ/Re), agronomic N-use efficiency (20.5 kg grain/kg-N applied), physiological N-use efficiency (38.5 kg grain/kg N uptake) and apparent recovery efficiency (66.5% N uptake/kg N applied) were recorded at 100% N, however, maximum values of energy ratio (9.46) was obtained with 100% N + Grs, partial factor productivity (68.0 kg grain/kg N applied) in 50% N, nitrogen harvest index (75.0%) under 75% N applied and total N uptakes (125.7 kg) as well as crude protein yield with 150% N + Grs. Overall, concluded that application of growth retardants, viz. 0.2% *Chlormequat chloride* + 0.1% *Tebuconazole* was found effective in shortening of wheat plant and reduced lodging but did not improve productivity and profitability under restricted irrigation condition in Vertisols of Central India.

Key words: Chlormequat chloride, Economic evaluation, Energy relationship, Growth regulators, Limited water supply, Nitrogen levels, Tebuconazole, Wheat

Wheat (*Triticum aestivum* L.) is the second most important cereal crop of India only after rice and during 2021-22, it has been under cultivation in 30.5 million hectares' area and output was pegged at 107.7 million metric tonnes with national average productivity of 3.5 t/ha (ICAR-IIWBR, 2023). In Central Zone of India, monsoon rains determine the recharge of groundwater and harvesting of water in ponds for subsequent use for irrigating the wheat crop during *rabi* season and has a significant bearing on its productivity. Most of the soils of this zone are fine clay dominated soils (*Vertisols*) and water harvested in the ponds of these soils does not last long enough to provide irrigation for the entire growth period of wheat crop because of high losses by seepage through cracks and evaporation. Because of this, farmer having water shortage or in the conditions of low rainfall, prefers wheat varieties sown early and having lower water requirement. Wheat crop lodges in central India owing to vagaries of weather, mainly due to rain and/or storm, during grain filling/physiological maturity stages. Spring wheat yield reduced (8.3%) due lodging at latter part of grain filling stage under high input and irrigated condition and its losses will be more if it occurs at an early part of grain filling stage (Tripathi *et al*., 2004). The adverse effect of plant lodging on the physiological quality of grain/seeds is expected because it happens mainly at the grain filling stage, which limits photosynthesis due to plant shading of upper layer to lower layers (Setter *et al*., 1997). Use of plant growth regulators (PGRs) like CCC and tebuconazole application in wheat resulted in shortening the plant height (10%) and reducing lodging and thereby

[1]Corresponding author's Email: kc_64sharma@yahoo.com
[1]Principal Scientist, [2]Technical Officer, ICAR-Indian Agricultural Research Institute, Regional Station, Indore, Madhya Pradesh 452 001

increased the wheat tillers/m^2 (10.9%) biomass (7.0%) and yield (10.0 to 12.6%) under irrigated and high fertility conditions of North Western Plain Zone of India (Chhokar *et al.,* 2024; Tripathi *et al.,* 2023). *Chlormequat chloride* is a popular PGR generally used as a foliar spray and inhibits GA production. Moreover, application of tank mixed *Chlormequat chloride* with other growth retardant or fungicide like *Uniconazole* or *Tebuconazole* may have different sites of inhibition in the GA production and can be more effective at suppressing cell multiplication and plant elongation. Further, it is also fact that nitrogen is the most important plant nutrient and play a key role in crop productivity and quality. With the aim of shortening of plant height with application of PGRs, there is a possibility that wheat crop may bear a high dose of nitrogen as such (suited for restricted irrigation) varieties in general are low fertilizer responsive, might be suited to wheat yield maximization. The information on the above for wheat in Central India is meager and keeping above in view present investigation was carried out to find out the effect of graded levels of nitrogen and growth regulators on crop lodging and productivity of wheat in Vertisols of Central India.

MATERIALS AND METHODS

The field experiment was carried out for two consecutive years during 2019–20 and 2020–21 at Research Farm of ICAR-Indian Agricultural Research Institute, Regional Station, Indore (M.P.). The experimental site was situated between 22°37'N latitude to 75°50'E longitude at 557 m above mean sea level and has a semi-arid tropical climate with mean annual rainfall of 758 mm. The soil was very fine clay loam (Vertisols) with the following characteristics in 0-15 cm depth: pH 7.8 (1:2.5 soil/water suspension), EC 0.25 dS/m, medium in organic carbon (0.51%), available in nitrogen (243.5 kg/ha) and phosphorus (15.3 kg P_2O_5/ha), and high in potash (412.0 kg K_2O/ha). Mean weekly meteorological data ranges viz., temperature maximum 23.6 to 39.0 °C and 22.0 to 38.6 °C, minimum 9.4 to 24.0 °C and 6.2 to 22.1°C, relative humidity maximum 75.2 to 90.5% and 72.9 to 90.4%, minimum 66.4 to 81.0% and 60.0 to 87.7%, and total precipitation 164.1 mm and 25.7 mm were observed during crop season of 2019-20 and 2020-21, respectively. Total nine treatments consisted of control (No N and no Grs spray) (T_1), 50% recommended dose of N (T_2), 75% recommended dose of N (T_3), 100% recommended dose of N (T_4), 125% recommended dose of N (T_5), 150% recommended dose of N (T_6), 100% recommended dose of N with Grs spray (T_7), 125% recommended dose of N with Grs spray and 150% recommended dose of N with Grs spray (T_9) were laid out in randomized block design with three replications. Wheat (*Triticum aestivum* L.) cultivar HI 1531 popularly known as '*Harshita*' a suitable wheat variety under limited water supply conditions (restricted irrigation) was used in the trial and recommended dose of N was 90 kg/ha. A common dose of P (17.6 kg/ha) and K (33.2 kg/ha) was applied to each plot at the time of sowing through single super phosphate and muriate of potash, respectively. Half dose of N as per treatment and full doses of P and K were applied as basal as per treatment and remaining N was top-dressed at first irrigation. Total two irrigations, one at late tillering and second at flowering stages were applied. Other recommended agronomic practices were followed for growing a healthy crop. Growth regulators, *Chlormequat chloride* @ 0.2% and *Tebuconazole* @ 0.1% were sprayed at first node and at boot leaf stage. The observations on tillers height and number of tiller/m^2 were undertaken just before harvesting and 5 tillers/plot were cut randomly for post-harvest studies. Grain and biological yields were recorded at harvest. Organic carbon, soil pH, available N, P, K of soil sample and N content (%) in grain and straw of wheat samples were estimated by standard methods of analysis. Nutrient uptake was estimated by multiplying the grain and straw yields by their respective content (%) in grain and straw. Crude protein content (%) in grain and straw were calculated by multiplying the factors to N contents (%) and crude protein yield by multiplying the CP contents to their respective grain and straw yields. The total N uptakes and CP yields were the sum-up values of N uptakes and CP yields in grain and straw. All the data recorded on growth, yield attributes, yield and quality were statistically analysed as per standard procedures. The lodging score was worked out by using following formula:

Lodging Score = [{(Lodged area/Net plot area) x100 x Angle of lodging)}/90]

Economics was calculated on the basis of prevailing market prices of different inputs and output. Partial Factor Productivity (PFP) of Nitrogen, Agronomic and physiological N-use efficiencies (ANUE and PNUE), Apparent Recovery Efficiency (ARE) of N and Nitrogen Harvest Index (NHI) were worked out by using the standard formulae. Energy inputs and outputs were calculated using the energy equivalents viz., manpower 1.96 MJ/hour, dry fodder 18 MJ/kg, sheep manure 0.3 MJ/kg, nitrogen 60.6 MJ/kg, P_2O_5 11.1 MJ/kg, K_2O 6.7 MJ/kg etc. as suggested by Panesar and Bhatnagar (1987) and Devasenapathy *et al.* (2009).

RESULTS AND DISCUSSION

Growth and yield attributes

Perusal of data from Table 1 revealed that application of graded levels of N and spray of growth regulators (Grs) viz., *Chlormequat Chloride + Tebuconazole* along-with 100, 125 and 150% of recommended N brought about

Table 1. Yields, growth and yields attributes of wheat as influenced by treatments (pooled data over 2 years)

Treatment	Grain yield (t/ha)	Biological yield (t/ha)	Harvest Index (%)	Tillers/ m^2	Plant height (cm.)	Grains/ Spike	1,000 grain weight (g)	Lodging score
T_1, Control	2.55	7.43	34.3	243.2	89.3	25.7	40.6	0
T_2, 50% N	3.06	8.32	36.8	261.2	99.6	29.0	40.4	0
T_3, 75% N	3.80	9.93	38.3	300.5	103.2	31.5	39.8	0
T_4, 100% N	4.40	11.23	39.2	354.0	108.9	32.5	39.1	0
T_5, 125% N	3.82	10.21	37.4	348.3	109.6	28.4	38.9	5.98
T_6, 150% N	3.76	10.47	35.9	345.0	109.8	25.0	38.3	12.53
T_7, 100% N + Grs	4.16	12.45	33.4	442.0	93.1	25.8	37.5	0
T_8, 125% N + Grs	4.10	12.31	33.3	453.3	94.3	25.1	36.1	0
T_9, 150% N + Grs	4.26	12.36	34.5	452.2	95.1	25.5	37.0	0
SEm±	0.085	0.207	-	6.30	1.08	0.76	0.57	-
CD (P=0.05)	0.256	0.621	-	18.90	3.23	2.29	1.70	-

significant effect on all growth and yield attributes viz., plant height, number of tillers per unit area, number of grains/spike and 1000 grain weight. Application of Grs along-with 100% and above recommended N (T_7 to T_9) significantly decreased the plant height, number of grains/ spike and 1000 grain weight as compared to same respective doses of N without Grs. It has also been completely saved the crop from lodging as occurred in the plots where N doses were applied without Grs @ 125 and 150% (T_5 and T_6). Noteworthy that number of tillers, where Grs were sprayed were significantly increased compared to their respective N levels without Grs. Increased growth attributes due to increasing N levels might be due to adequate availability of N to the crop, which being a constituent of amino acid and chlorophyll enhanced the chlorophyll formation leading to increased photosynthetic activity with the eventual improvement in the growth attributes. Increase in growth attributes of fodder oats with each increase in N levels was also reported by Singh and Dubey (2007). Data observed on inter-nodal length from ground level to ups (upto peduncle) showed that there was substantial reduction in inter-nodal length in all nodes (Fig. 1 to 6).

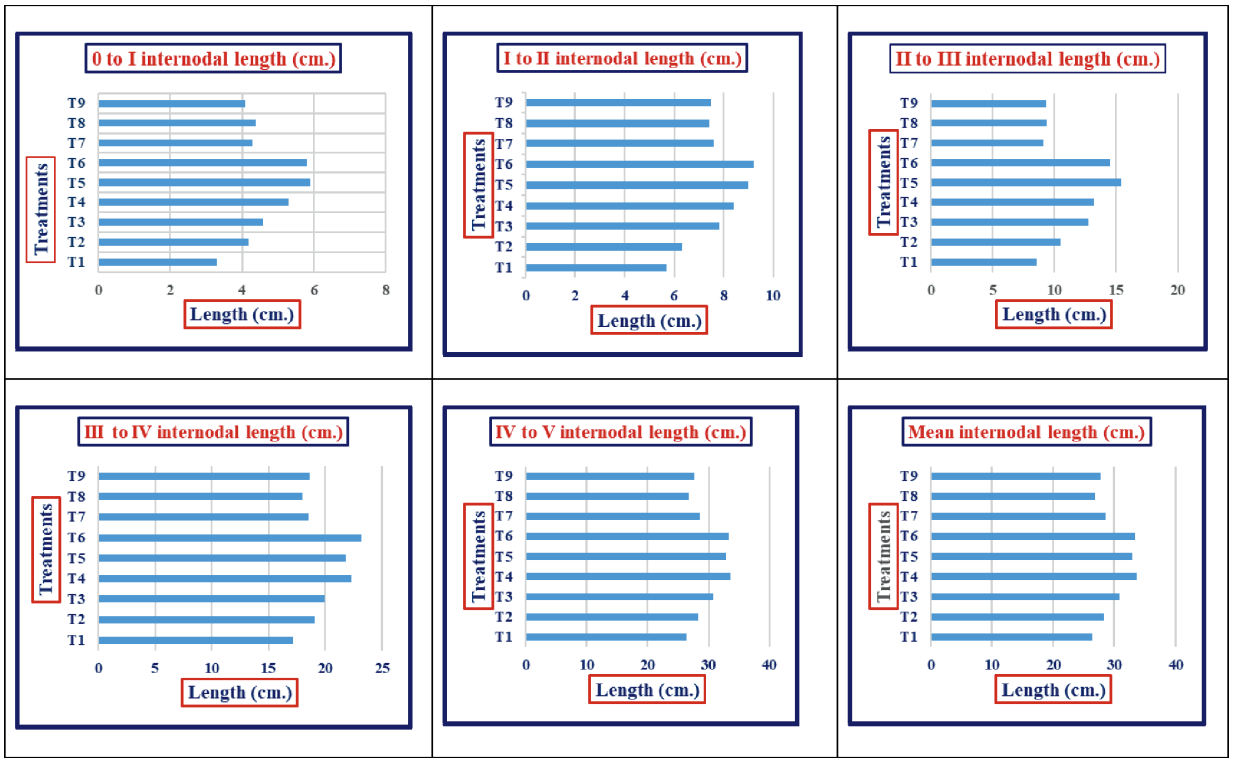

Fig. 1 to 6. Mean values of inter-nodal length as influenced by treatments

Decrease in plant height due to Grs application might be because of their act by reducing plant cell expansion, resulted shorter and possibly thicker stems, which saved the crop from lodging. Ali *et al.* (2021) and Tripathi *et al.* (2023) also reported reduction in plant height of wheat due to application of growth retardants.

Crop lodging

Application of increased N doses than recommended one in treatments T_5 and T_6, crop of wheat was lodged and lodging score worked out to be 5.98 and 12.53%, respectively. Increase in N from 125 to 150% of recommended dose recorded greater lodging score to the extent of 109.5%. However, Grs spray in the plots where 100 to 150% of recommended doses of N were applied that completely saved the crop from lodging. The main reason of crop lodging might be that high doses of N than recommended increased the plant succulence and higher plant height, which become responsible for crop lodging. However, application of tank mixed *Chlormequat chloride* along-with *Tebuconazole* by inhibition of GA production and reducing plant cell expansion, decreased the plant height resulted shorter and possibly thicker stems, which saved the crop from lodging.

Wheat yields and harvest index

The wheat crop responded to N significantly in terms of grain and biological yields. Pooled over analysis of two years' data revealed that application of 100% N (T_4) recorded maximum grain yield (4.40 t/ha), which being statistically at par with 100 and 150% of N applied with Grs (T_7 and T_9) was significantly higher over rest of the treatments (Table 1). Lodging of crop under treatment T_5 and T_6 significantly decreased the wheat grain yields to the tune of 13.2 and 14.5%, respectively. It was also noted that grain yields recorded with high doses of N along-with Grs (T_8 and T_9) were significantly higher to the extent of 7.32 and 13.3% over the same doses of N applied without Grs in treatments T_5 and T_6, respectively. Above results showed that application of high doses of N did not influence the wheat yields, rather crop become prone to lodging. Furthermore, despite of production of more number of tillers under Grs application, due to lower values of number of grains per spike and substantial reduction in 1000 grain weight, it could not be converted as gain in wheat grain yields. Higher grain yield in Treatment T_4 was the function of more number of grains/spike and comparatively greater 1000 grain weight than application of same or higher doses of N with Grs. Increased wheat yields may be attributed to the function of improvement in the growth attributes due to N sufficiency under recommended dose of N application. Whereas, contrast to above, biological yields recorded with 100% recommended N or more doses with Grs were statistically at par but significantly higher over rest of the treatments. The main reason of increased biological yield was significant increase in number of tillers per unit area, which led to higher biological yields. Decreased grain yields under high doses of N (T_5 and T_6) was mainly because of crop lodging, which generally reduced the amount of reserves accumulated for translocation at seed filling and decreases capacity of the sink (yield organs) to mobilize assimilates which lead to reduction in grain number and weight (Guoping *et al.* 2001). Guoping *et al.* (2001) also reported that when growth retardants were applied to crops as anti-lodging agent, yield losses occurred as compared to when lodging was absent. This study clearly indicates that application of Grs is beneficial and can produce comparatively higher yields than lodged crop, but if crop is not lodged than Grs application is of no use and wheat grain yields may slightly decreases and impairs the grain quality. In case of harvest index (HI), maximum value of HI was obtained with 100% N dose (39.2), which was greater than all the other treatments. HI values were increased with gradual increase in N levels from control to 100% recommended dose (T_1 to T_4) and decreased thereafter at 125 and 150% doses of N (T_5 and T_6). But, surprisingly HI values observed with N recommended as well as higher doses of N (T_7 to T_9) were drastically decreased. It was mainly because of increased the number of tillers due to Grs application, thereby increased the biological yields but did not increased the grain yield in same proportion of straw in total biological yield, that is why recorded lower values of HI.

Nitrogen and crude protein content (%), N uptake and CP yield

Data from Table 2 indicated that nitrogen application brought about significant variation in N content (%) of grain and straw of wheat. Maximum N contents (%) in wheat grain (2.15%) and straw (0.47%) were analysed with T_6 (150% of recommended N), which were at par with T_4, T_5, T_7, T_8 and T_9 but significantly higher over rest of the treatments. Whereas, treatment T_4 recorded highest N uptakes in grain (92.6 kg/ha), but treatment T_8 observed highest values (36.4 kg/ha) in straw. Overall, maximum total N uptakes obtained with treatment T_9 (125.7 kg/ha) followed by T_4 (123.8 kg) and which being at par with T_5, T_6, T_7 and T_8 was significantly higher over rest of the treatments. Higher N uptake may be attributed to the beneficial effect of nitrogen sufficiency in the soil solution and higher wheat grain and straw yields leading to improved N uptake to a significance level. Whereas, crude protein (CP) content (%) and CP yields also showed similar trend as these were multiple of respective factors to N content (%) for CP con-

Table 2. Nitrogen and crude protein contents, N uptakes, Crude Protein yield and nitrogen use efficiency expressions

Treatment	N contents (%)		N uptakes (Kg/ha)			CP contents (%)		CP yield (kg/ha)			Nitrogen use efficiency expressions*				
	Grain	Straw	Grain	Straw	Total	Grain	Straw	Grain	Straw	Total	PFPN	ANUE	PNUE	ANR	NHI
T_1, Control	1.75	0.40	44.5	19.4	63.9	10.05	2.48	255.7	121.2	376.9	-	-	-	-	-
T_2, 50% N	1.92	0.42	58.7	22.1	80.8	11.03	2.62	337.3	138.1	475.4	68.0	11.3	35.9	37.5	72.6
T_3, 75% N	2.03	0.42	77.2	25.7	102.9	11.63	2.60	443.7	160.4	604.1	56.3	18.5	38.2	57.8	75.0
T_4, 100% N	2.10	0.46	92.6	31.2	123.8	12.10	2.73	532.4	194.8	727.2	48.9	20.5	38.5	66.5	74.8
T_5, 125% N	2.14	0.45	81.8	29.0	110.8	12.33	2.83	470.5	181.4	652.0	33.9	11.3	34.0	41.7	73.8
T_6, 150% N	2.15	0.47	80.6	31.3	111.9	12.33	2.91	463.6	195.6	652.2	27.8	8.96	33.5	35.5	72.0
T_7, 100% N + Grs	2.11	0.43	87.8	35.3	123.1	12.13	2.60	505.0	220.8	725.8	46.2	17.9	37.2	65.8	71.3
T_8, 125% N + Grs	2.12	0.44	86.8	36.4	123.2	12.17	2.77	499.3	227.5	726.8	36.4	13.8	36.6	52.7	70.4
T_9, 150% N + Grs	2.14	0.43	91.1	34.6	125.7	12.30	2.66	523.8	216.0	739.8	31.5	12.7	36.7	45.8	72.5
SEm±	0.017	0.013	2.15	1.23	2.93	0.099	0.078	12.38	7.70	16.60	-	-	-	-	-
CD (P=0.05)	0.052	0.040	6.51	3.73	8.86	0.298	0.236	37.43	23.29	50.19	-	-	-	-	-

*PFPN, Partial factor productivity of nitrogen (kg grain/kg-N applied); ANUE, agronomic nitrogen use efficiency (additional yield Kg grain/kg-N), PNUE, physiological nitrogen use efficiency (kg grain/kg N uptake), ANR, apparent nitrogen recovery efficiency (% N uptake/kg N applied) and NHI, nitrogen harvest index (%).

tent (%) and further multiplication of CP content (%) to respective grain and straw yields to get CP yields. Increase in crude protein yield at gradual increase of N application may be because of N sufficiency under increased rates of N, which proved instrumental in activating the growth, regenerative growth and N uptake by the plants.

Nitrogen use efficiency

On the basis of pooled wheat yield data of two years, nitrogen use efficiency expressions viz., partial factor productivity (PFP), agronomic nitrogen use efficiency (ANUE), physiological nitrogen use efficiency (PNUE), apparent recovery efficiency (ARE) and nitrogen harvest index (NHI) were worked out (Table 3). PFP which is also known as nitrogen use efficiency showed that every increase in N dose decreased the PFP value and lowest N dose treatment (50% of recommended dose of N - T_2) recorded highest value of PFP (68.0 kg grain/kg N applied) followed by T_3 (56.3 kg grain/kg N applied), where 75% of recommended dose was applied and minimum with highest dose of N in treatment T_6 (27.8 kg grain/kg N applied), where 150% dose of recommended N was applied. This decrease in PFP values with increase in N dose was mainly because of not increasing the grain yield of wheat in same proportion of increased N dose. The reason of lowest PFP value under T_6 was mainly lodging of crop, consequently poor wheat grain yield, led to lower PFP values. However, same dose of N applied in treatment T_9 along-with Grs application, which saved the crop from lodging and recorded comparatively higher wheat grain yield and improved the value of PFP from 27.8 in T_6 to 31.5 kg grain/kg N applied in treatment T_9. Whereas, the maximum values of ANUE (20.5 kg grain/kg N applied), PNUE (38.5 kg grain/kg N uptake) and ARE of N (66.5%) were obtained with T_4, where 100% recommended dose of N was applied followed by T_7 where 100% recommended dose of N was applied with Grs application. Application of lower or higher doses of N recorded lowest values of above traits by virtue of poor wheat grain yields and lower N uptakes. Lodging in T_5 and T_6 further aggravated it due to poor wheat yields and recorded lower values of ANUE, PNUE and ARE. While the same doses of N applied with Grs in treatment T_8 and T_9 recorded higher values of all above indices due to improved wheat grain yield by saving the crop from lodging. In case of NHI, the values recorded with T_3 and T_4 (75.0 and 74.8%) were almost same, but substantially greater than rest of the treatments. Despite of highest values of N uptakes, the reason of lower values of NHI in treatment T_7 to T_9 was mainly because of the N uptakes were not increased in same proportion of applied N doses.

Table 3. Energy relationships and economics as influenced by treatments

Treatment	Energy Relationships					Economics			
	Energy input (×10³ MJ/ha)	Energy output (×10³ MJ/ha)	Energy ratio (or Energy Efficiency)	Energy productivity (grain in g/MJ)	Energy responsiveness	Cost of cultivation (× 10³ ₹/ha)	Gross returns (× 10³₹/ha)	Net returns (×10³₹/ha)	Benefit: cost ratio
T_1, Control	11.6	98.5	8.45	218.9	7.07	47.5	82.4	34.9	1.73
T_2, 50% N	14.4	101.7	7.69	212.5	6.66	48.6	95.9	47.3	1.97
T_3, 75% N	15.8	132.5	8.40	241.1	7.43	48.8	117.1	68.2	2.39
T_4, 100% N	17.1	150.0	8.76	256.9	7.84	49.1	134.2	85.1	2.73
T_5, 125% N	18.4	136.0	7.36	206.6	6.43	49.4	118.9	69.4	2.40
T_6, 150% N	19.9	139.1	7.01	189.4	6.00	49.7	119.1	49.4	2.39
T_7, 100% N + Grs	17.4	164.8	9.46	238.8	7.81	54.6	136.1	81.5	2.49
T_8, 125% N + Grs	18.8	162.9	8.67	218.3	7.15	54.9	134.3	79.5	2.45
T_9, 150% N + Grs	20.1	163.9	8.13	211.4	6.82	55.1	137.4	82.3	2.49

Labourers wages ₹450/manday, wheat prices, grain ₹2175 and straw ₹500/q

Energy relationships

Computation of energetics viz., energy input, energy output, energy ratio, energy productivity and energy responsiveness on the basis of mean data of two years showed that the difference in energy input values under different treatments was due to use of varied levels of inputs and variation in output energy is because of difference in values of produce harvested in the form of grain and straw (Table 3). Maximum input energy (20.1 thousand MJ/ha) was observed with treatment T_9 due to use of highest dose of nitrogen along-with growth regulators followed by T_8 (18.8 thousand/ha) and minimum with control (No nitrogen and no growth regulators). Treatment T_7 recorded highest value of output energy (164.8 thousand/ha) and energy ratio (9.46). This was mainly because of production of higher biological yields. Whereas, treatment T_4, where 100% N was applied, registered maximum energy productivity (256.9 g grain/MJ) and energy responsiveness (7.84). The main reason of higher values of energy productivity and energy responsiveness under T_4 was due to the production of higher grain yield and comparatively lower use of input energy. Despite of higher application of N under treatment T_5 and T_6, lower values of above traits was mainly because of poor wheat yields and comparatively higher use of input energy.

Economics

Working out of economic parameters viz., cost of cultivation, gross returns, net returns and benefit: cost ratio on the basis of mean wheat yield data over two years and prevalent market prices of inputs and outputs revealed that every increase in N dose as well as application of Grs increased the cost of cultivation and gross returns. Among treatments, T_9 (150% N + Grs) consumes highest cost of inputs (₹55.1 thousands/ha) and also recorded highest values of gross returns (₹137.4 thousands/ha). But, maximum net returns (₹85.1 thousands/ha) and B:C ratio (2.73) were obtained with T_4 (100% N). The reason for the same was mainly due to almost similar gross returns in T_4 but proportionately lower values of cost of cultivation, that led to higher values of net returns and B:C ratio. Although, net returns and B:C ratio recorded with higher N doses applied with Grs (T_7 to T_9) were slightly lower than T_4 as net returns (₹81.5, ₹79.5 and ₹82.3 thousands/ha) and B:C ratio (2.48, 2.45 and 2.49) but these values were substantially higher over T_5 and T_6, where N doses were applied @ 125 and 150% higher than the recommended dose (net returns ₹69.4 and ₹49.4 thousands/ha, B:C ratio 2.40 and 2.39). Whereas, due to lodging in plots where 125 and 150% of recommended N were applied (T_5 and T_6) treatments, drastically decreased the wheat yields but increased the cost of cultivation, consequently recorded lower values of net returns and B:C ratios. It shows that application of Grs is beneficial in comparison of lodged crop and lodging is absent than Grs application is not worth to apply and it may also slightly have decreased the wheat grain yields. Singh *et al.* (2019) has also reported that favourable effect of PGRs with N revealed that gross return and

net return obtained from higher dose of N with *Chloremequat chloride* + *Tebuconazol* was quite higher to lower N doses with *Chloremequat chloride* + *Tebuconazol* in wheat crop.

On the basis of two years' study, it was inferred that application of growth regulators viz., 0.2% *Chlormequat chloride* and 0.1% *Tebuconazole* had reduced the plant height and lodging, increased tillering and biomass at higher N application but did not yielded higher than RDN. Recommended N @ 90 kg/ha was found sufficient for providing higher, energy efficient and economical yield of wheat variety HI 1531 suitable for growing under limited water supply condition in Vertisols of Central India.

REFERENCES

Ali, N., Alam, P., Sah, A., Izhar, T. and Kumar, S. 2021. Influence of Fertility Levels and Plant Growth Retardants on Growth and Productivity of Wheat (*Triticum aestivum* L.) in Jharkhand. *International Journal of Current Microbiology and Applied Science* **10**(1): 2,779–2,786.

Chhokar, R.S., Kumar, N., Gill, S.C., Tripathi, S.C. and Singh, G. 2024. Enhancing wheat productivity through genotypes and growth regulators application under high fertility condition in sub humid climate. *International Journal of Plant Production*. https://doi.org/10.1007/s42106-023-00277-w.

Guoping, Zhang, Jianxing, Chen and Bull, D.A. 2001. The effects of timing of N application and plant growth regulators on morphogenesis and yield formation in wheat. *Plant Growth Regulation* **35**: 239–245.

ICAR-IIWBR. 2023. Director's Report of AICRP on Wheat and Barley 2023–23. **Ed**: Gyanendra Singh, ICAR- Indian Institute of Wheat and Barley Research, Karnal, Haryana, India. P. 90.

Kiran Kumar, K.A., Patil, B.C. and Chetti, M.B. 2003. Effect of Plant Growth Regulators on Biophysical, Biochemical Parameters and Yield of Hybrid Cotton. *Karnataka Journal of Agricultural Sciences* **16**(4): 591–594.

Panesar, S.B. and Bhatnagar, A.P. 1987. Energy norms for input and output of agricultural sector. pp. 8–26. In.: *Proceedings of National Conference on "Energy in Production Agriculture and Feed Processing*", during 30–31 October held at Punjab Agricultural University, Ludhiana.

Setter, T.L., Laureles, E.V., Mazaredo, A.M. 1997. Lodging reduces yield of rice by self-shading and reductions in canopy photosynthesis. *Field Crops Research* **49**: 95–106.

Singh, S.D. and Dubey, S.N. 2007. Soil properties and yield of fodder oat (*Avena sativa* L.) as influenced by sources of plant nutrient and cutting management. *Forage Research* **33**: 101–103.

Singh, S., Singh, T., Singh, A.K. and Singh R.K. 2019. Effect of nitrogen levels and plant growth regulators on growth, lodging, yield and economics of wheat (*Triticum aestivum* L.). *Journal of Pharmacognosy and Phytochemistry* **8**(4): 665–671.

Tripathi, S.C., Kumar, N. and Samota S. R. 2023. Farmer's fertilizer practices in wheat: A case study for high yield in north western plain zone. *Indian Farming* **73**(09): 37–39.

Tripathi, S.C., Sayre, K.D., Kaul, J.N. and Narang, R.S. 2004. Lodging behavior and yield potential of spring wheat (*Triticum aestivum* L.): Effects of ethephon and genotypes. *Field Crops Research* **87**(2-3): 207–220.