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Optimum dose of fertilizer with growth regulators for higher yield of wheat (*Triticum aestivum* L.)

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Abstract
The current study was conducted at the All India Coordinated Research Project (AICRP) on Wheat, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) during the *Rabi* season of 2020. The experiment followed a randomized block design with nine treatments, including various doses of fertilizer, along with the plant growth regulators chlormequat chloride and tebuconazole applied at rates of 0.2% and 0.1%, respectively, and replicated three times. The recommended dose of fertilizer, 120:60:40 kg NPK ha^{-1}, was applied according to each treatment. The results showed that using 150% of the recommended dose of fertilizer with a growth regulator resulted in a higher plant population at 15 days after sowing (DAS) and at harvest. Additionally, the number of tillers per square meter and dry matter accumulation of wheat at all growth stages (60 DAS and 90 DAS) were higher, except for plant height, which was maximized with 150% of the recommended dose of fertilizer. The most significant number of effective tillers (431.13 per square meter) and grains per ear head (31.397) were observed with the application of 150% of the recommended dose of fertilizer with the growth regulator. The maximum grain, straw, and harvest index of wheat were recorded with 150% of the recommended dose of fertilizer with the regulator, yielding 5562.33 kg/ha, 7495.62 kg/ha, and 42.60, respectively. The grain, straw, and harvest index of wheat due to different growth retardant treatments showed no statistically significant differences. In conclusion, it can be recommended that using the optimal dose of fertilizer with a plant growth regulator, such as 150% of the recommended dose, is a sustainable strategy for enhancing the growth and productivity of wheat.

Keywords: Chlormequat chloride, fertilizer, growth parameters, plant growth regulator, tebuconazole, wheat

Introduction
Wheat (*Triticum aestivum* L.) is commonly referred to as the "king of cereals" and is a crucial staple food crop, providing approximately half of the world's dietary calories. Wheat is highly valued for its nutritional content, being rich in carbohydrates and protein (Desai *et al*. 2015; Patel *et al*., 2023) [7, 35]. Wheat grains contain essential nutrients, including about 12% water, 60-80% carbohydrates, 8-15% proteins with sufficient amounts of all essential amino acids (except lysine, tryptophan, and methionine), 1.5-2% fats, vitamins (such as B complex and vitamin E), and 2.2% crude fiber (Sahu *et al*., 2023; Tomar *et al*., 2023) [44, 62]. Wheat also serves as a good source of trace minerals like selenium and magnesium, both crucial for maintaining good health (Kumar *et al*., 2011; Tomar *et al*., 2023) [28, 62].
In India, wheat is cultivated on 31.45 million hectares of land, producing 107.592 million metric tons with a productivity of 3.42 metric tonnes/ha (USDA, 2020). In Madhya Pradesh, wheat is grown on 10.02 million hectares, yielding 16.52 million metric tonnes with a productivity of 3298 kg per hectare (Nirala *et al*., 2022; Jitendra *et al*., 2022) [58, 20]. The global demand for wheat is projected to reach around 840 million tonnes by 2030 (Kumar *et al*. 2016; Singh *et al*., 2013) [27, 55], and India's requirement is estimated to be about 114.6 million tonnes. Meeting this growing demand in the face of limited available land necessitates a concerted effort to enhance wheat productivity (Yadav *et al*., 2023; Patel *et al*., 2023) [81, 35].
Proper nutrient management is a critical factor influencing crop productivity (Tiwari *et al*., 2011; Verma *et al*., 2023) [59-60, 68]. Long-term studies have shown that crop productivity can decline even with the application of appropriate NPK fertilizer doses (Yadav and Kumar, 2009; Jha *et al*., 2008) [77, 19]. Field crops demonstrate a significant economic response to increased fertility levels, and productivity can be further improved by increasing NPK fertilizer doses (Singh, 2016; Jha *et al*., 2011) [53, 16].

Effective nitrogen (N) fertilization is vital for both economic wheat production and environmental sustainability, safeguarding ground and surface waters (Alley *et al*., 1999; Singh *et al.*, 2013) [3, 55]. Managing nitrogen fertilizer rates and timing after planting are key tools for optimizing wheat growth and development to achieve higher grain yields per unit area (Jha & Kewat, 2013; Alley *et al*., 1999) [15, 3].

Phosphorus is a crucial nutrient for plant growth, and its importance in plant metabolism is well established (Tiwari *et al*., 2011; Verma *et al*., 2023) [59-60, 68]. After nitrogen stress, phosphorus (P) deficiency is the second most widespread nutrient deficiency in cereal systems worldwide (Balemi and Negisho, 2012; Raghuwanshi *et al*., 2023) [5, 70]. The application of potassium significantly increased wheat grain yield from 2468 kg/ha in the control to 2789 kg/ha in the treatment receiving 60 kg/ha of potassium, representing a 13% increase over the control (Verma *et al.*, 2023; Sairam *et al*., 2023) [68, 46].

Recent reports suggest that plant growth regulators can enhance wheat growth and yield (Yang *et al*. 2006; Jha & Soni, 2008) [82, 56]. Plant Growth Regulators (PGRs) are commonly used in winter wheat cultivation with high N rates (Van *et al.*, 1989; Pahade *et al*., 2023) [67, 34]. PGRs can be applied at various growth stages to modify plant growth and development. For instance, chlormequat chloride (CCC) can be applied at the beginning of stem elongation, and another PGR, ethephon, can be used at later stages before heading to reduce cereal straw height (Rajala and Peltonen, 2001; Jha *et al*., 2023) [38, 18]. Evidence suggests that timely application of growth retardants like chlormequat chloride (CCC) or ethephon can increase wheat and barley grain yields, independent of lodging control (Turk and Tawaha, 2002; Verma *et al.,* 2023) [66, 68]. The application of plant growth regulators, such as chlormequat chloride (CCC) and ethephon, reduces plant height, playing a significant role in enhancing wheat grain yield by altering dry matter distribution into the spikes (Yadav *et al*., 2023; Sahu *et al.*, 2023) [81, 44]. Notably, CCC applied at 2.20 kg/ha at Zadoks growth stage (ZGS) 25 led to a significantly higher grain yield (8.9 t/ha) compared to ethephon (8.2 t/ha) and the control (7.2 t/ha) treatments. The highest grain yield (8.9 t/ha) was achieved with 200 kg/ha of nitrogen and 2.20 kg/ha of CCC application (Shekoofa and Emam, 2008; Raghuwanshi *et al.*, 2023) [50, 37].

Considering these factors, this study was conducted to determine the optimal fertilizer dosage levels in combination with growth regulators to achieve higher wheat yields (*Triticum aestivum* L).

Material and Methods

The field experiment conducted during the *Rabi* season of the year 2020-21 at the research farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya in Jabalpur, Madhya Pradesh. This study was conducted as part of the All India Coordinated Wheat Improvement Project to investigate the optimal fertilizer dosage levels in combination with growth regulators for increasing wheat yield (*Triticum aestivum* L). The region receives an average annual rainfall of 1350 mm, with approximately 90% falling between mid-June and September, exhibiting erratic distribution over time and space. The experimental field had clay loam soil with a pH of 7.2, medium organic carbon content (0.62%), low available nitrogen (288.00 kg ha^{-1}), medium available phosphorus (16.66 kg ha^{-1}), and available potassium (302.00 kg ha^{-1}), and soluble salts concentration (0.33 ds m^{-1}) below harmful levels. The experiment conducted in randomized block design with three replications, featuring nine treatments: T1 - 50% recommended doses of NPK, T2 - 75% recommended doses of NPK, T3 - 100% recommended doses of NPK, T4 - 125% recommended doses of NPK, T5 - 150% recommended doses of NPK, T6 - 100% recommended doses of NPK with growth regulators applied at the first node stage and boot leaf stage (45 and 65 DAS, respectively), T7 - 125% recommended doses of NPK with growth regulators applied at the first node stage and boot leaf stage, T8 - 150% recommended doses of NPK with growth regulators applied at the first node stage and boot leaf stage, and T9 - Control (No fertilizer and growth regulators spray). The plant growth regulators used were chlormequat chloride (available as Lihocin) and tebuconazole (available as Folicur).

Field preparation involved one deep ploughing using a moldboard plow, followed by two cross harrowings and planking. Wheat variety MP 3382 was sown on November 16, 2020 and harvested on April 8, 2021, with a seeding rate of 100 kg/ha at a row-to-row spacing of 20 cm. The recommended fertilizer dose, i.e., 120:60:40 kg NPK ha^{-1}, was applied according to the treatment. Half of the nitrogen was supplied through Di-ammonium phosphate (DAP) and urea, with the full dose of phosphorus (P_2O_5) as DAP and potash (K_2O) as muriate of potash applied before seed sowing as basal application. The remaining half of the nitrogen was applied in two equal splits as top-dressing during the Crown Root Initiation (CRI) and jointing stage, following the treatment. The crop was grown under irrigated conditions, receiving a total of six irrigations at critical growth stages. Weed control was achieved through two manual weedings in all treatment plots using a weeding hook as needed. Gap filling was conducted ten days after planting to maintain the desired plant population. Biometric observations were recorded at intervals of 15 DAS, 30 DAS, 60 DAS, 90 DAS, and at the harvest stage. Data on yield attributes and yield were collected using standard procedures (Rana *et al.*, 2014) [40]. Statistical analysis was performed using the ANOVA technique recommended by Panse and Sukhatme (1967), and treatment comparisons were made at a 5% level of significance.

Results and Discussions

Growth Parameters

Results shows that the plant population per square meter did not show significant difference among different doses of fertilizer levels and growth regulators at 15 DAS and at harvest. However, maximum stand count was recorded with the application of 150% recommended doses of NPK with growth regulators and lowest were recorded in 150% recommended doses of NPK. The plant height was significantly influenced by the application of different doses of fertilizers at all the stages of observation. Maximum plant height at 60 and 90 DAS were recorded under the application of 150% recommended doses of NPK in which no growth regulator was applied and only water was sprayed and the lowest height reported with control treatment (no fertilizer and growth regulators spray). The plant height of wheat increased significantly with different nutrient levels. Maximum plant height was recorded in 150% recommended dose of NPK followed by 150% recommended doses of NPK with growth regulators at 60 and 90 DAS because higher nutrient levels enhanced N uptake, which might have resulted in more rapid synthesis of carbohydrates and protein that in turn led to rapid cell division and cell enlargement (Yousaf *et al*., 2014; Verma *et al.*, 2023) [83, 60]. The application of growth retardants did not influence plant height at early stages, obviously due to the non-imposition of treatment at this stage of crop growth. However, Cycocel+ Folicur application significantly reduced plant height at 60 and 90. Growth retardants primarily reduced plant height due to reduction of stem elongation and decreased rate of cell division (Rajala, 2004; Toppo *et al.*, 2023) [39, 78]. Similar results were recorded by Emam (2011) [9], Verma *et al*. (2023) [68], Latifkar *et al.* (2014) [29-30].

The data reveals that the highest number of tillers at 60 and 90 days after sowing (DAS) were significantly higher in the treatment using 150% of the recommended NPK doses with growth regulators, followed by the application of 125% recommended NPK doses with growth regulators and 100% recommended NPK doses with growth regulators, in that respective order. Each of these treatments exhibited a significant difference from one another. Conversely, the lowest number of tillers per square meter was observed in the absolute control group, where no fertilizer or growth regulators were applied. Ali *et al.* (2003) [84] also observed that an increase in nutrient levels led to a rise in the number of fertile tillers, likely due to a decrease in tiller mortality, allowing for more tillers to develop from the main stem. Similar findings were reported by Maqsood *et al.* (2002) [31] and Verma *et al.* (2016) [60]. The application of Cycocel spray appeared to enhance the transfer of cytokinin hormones from the root to the area responsible for branch shoot production in the plant. This lengthened the developmental period of branch-forming shoots and potentially increased the number of branches in the plant, as suggested by Mohaghegh and Imam (2007) [33] and Sairam *et al*. (2023) [46]. According to Ilikaei and Emam (2003) [12] and Verma *et al.* (2016) [60], the combination of Cycocel and Folicur (Cycocel+ Folicur) also resulted in a non-significant increase in the number of branches on each plant.

The accumulation of dry matter was not affected by the presence of growth regulators during the initial stage, but the maximum accumulation at 60 and 90 days after sowing (DAS) was observed when 150% of the recommended NPK doses with growth regulators were applied, while significantly lower values were recorded in the control plot. Balanced nutrition plays a vital role in achieving higher dry matter accumulation by promoting increased canopy cover, as suggested by Singh *et al.* (2017) [54] and Yadav *et al.* (2023) [81]. Similar results were reported by Alam (2013) [1] and Kumar *et al.* (2023) [26]. The use of Cycocel as a growth retardant had a reducing effect on plant height, as also observed by Chaudhari *et al.* (1980) [6] and Ranjan *et al*. (2016) [41], who reported a reduction in the dry weight of wheat due to Cycocel treatment.

Yield and yield attributes

The results demonstrated that different fertilizer doses and growth regulator treatments had a significant positive impact on yield attributes, including the number of effective tillers and the number of grains per ear head (Table 2). In this study, the maximum number of effective tillers per square meter, with significantly higher values, was observed with the application of 150% of the recommended NPK doses along with growth regulators. This treatment was followed by the application of 125% of the recommended NPK doses with growth regulators and 100% of the recommended NPK doses with growth regulators, in that order. Each treatment showed significant differences from one another, with significantly lower values recorded in the control treatment. Similar findings were observed by Thakur (2009) [85] and Verma *et al.* (2023) [68] in wheat regarding effective tillers per square meter. Latifkar *et al.* (2014) [29-30] and Jha *et al.* (2014) [14] noted that the application of growth retardants increased the number of spikes per square meter, 1000-grain weight, and grain yield significantly over the control.

The number of grains per ear head was significantly affected by the application of different fertilizer levels and plant growth regulators. The maximum number of grains per ear head (31.39) was recorded with the application of 150% of the recommended NPK doses with growth regulators, and it was on par with the application of 125% of the recommended NPK doses with growth regulators. Conversely, the minimum number of grains per ear head (27.76) was observed in the control treatment. These results are consistent with the findings of Kantwa *et al.* (2019) [21] and Yadav *et al*. (2023) [81].

The data revealed that grain yield was significantly influenced by the application of different fertilizer levels and plant growth regulators. Under the practices of nutrient management and growth regulators, the application of 150% of the recommended NPK doses with growth regulators produced the maximum grain yield (5562.33), significantly surpassing the absolute control and the recommended dose (120:60:40). It was also at par with the application of 125% of the recommended NPK doses with growth regulators, which produced significantly higher grain yield than all the other treatments. However, the minimum grain yield (2754.7) was recorded in the control. The beneficial effect of balanced nutrition on grain yield can be explained by the fact that nutrient application increased the number of effective tillers per square meter, the number of grains per ear head, and grain weight per ear head, ultimately contributing to a higher grain yield. Ali *et al.* (2008) [2] and Gautam *et al.* (2021) [11] also found that a combination of nutrients improved yield attributes and the yield of wheat. The increase in seed yield with growth retardant treatment was attributed to its reduction in plant height, which was found to be useful in increasing the efficiency of food material translocation towards grains. Similar results were recorded by Sharif *et al.* (2007) [48], Soni *et al*. (2012) [56], Latifkar *et al.* (2014) [29-30] and Sepat *et al*. (2010) [47].

The data revealed that different fertilizer doses and growth regulators significantly influenced the straw yield of wheat. The application of 150% of the recommended NPK doses with growth regulators produced the significantly highest yield (10495.67 kg/ha), primarily due to the significantly highest number of tillers per square meter in this treatment. This was followed by the application of 125% of the recommended NPK doses with growth regulators and 100% of the recommended NPK doses with growth regulators, in that order. The lowest straw yield was recorded in the control due to the soil's inability to provide an adequate amount of nutrients to the plants in the absence of applied fertilizers (Jha *et al.*, 2016; Kewat *et al.*, 2009) [13, 22]. Similar findings were reported by Kumar *et al.* (2015) [25]. Increased plant height and dry matter accumulation in these treatments contributed to a higher straw yield. The increase in biological yield was due to increased dry matter accumulation, resulting from a higher number of tillers per square meter in this treatment. Another possible reason for the increased yield may be the adequate availability of nutrients during the crucial growth period. These findings were consistent with Kumar *et al*. (2015) [25] and Shukla *et al*. (2023) [26].

The data indicated that the highest harvest index (42.60) was recorded with the application of 150% of the recommended NPK doses with growth regulators, followed by 125% of the recommended NPK doses with growth regulators, while the lowest value (38.77) was recorded in the absolute control treatment. Similar results were also reported by Swati *et al.* (2023) [57] and Tripathi *et al.* (2013) [64].

Table 1: Effect of nutrient management on growth parameters at different time intervals in wheat

Treatments	Plant population (m^{-2})		Plant height (cm)		Number of tillers (m^{-2})		Dry Matter Accumulation (m^{-2})	
	15 DAS	Harvest	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
50% recommended doses of NPK	217.50	213.21	53.89	65.02	281.35	270.65	523.51	995.43
75% recommended doses of NPK	222.59	215.61	54.96	71.78	299.40	292.55	531.55	1004.64
100% recommended doses of NPK	216.57	209.31	60.00	86.28	363.66	348.25	561.99	1090.26
125% recommended doses of NPK	219.83	212.57	62.08	84.92	380.95	367.69	606.30	1120.72
150% recommended doses of NPK	214.36	208.89	62.91	91.77	396.45	382.88	731.36	1212.14
100% recommended doses of NPK with growth regulators	218.22	211.33	57.51	74.37	407.93	394.55	688.74	1115.87
125% recommended doses of NPK with growth regulators	220.33	210.11	58.61	80.13	424.76	415.70	734.60	1212.45
150% recommended doses of NPK with growth regulators	223.71	216.95	59.28	80.48	469.15	454.30	751.72	1224.99
Control (No fertilizer and growth regulators spray)	215.69	208.23	52.53	60.42	254.17	241.49	495.81	786.98
S.Em ±	2.55	2.77	0.257	1.03	2.252	33.244	1.92	3.35
C.D. (5%)	NS	NS	0.773	3.10	6.751	99.668	5.78	10.05

Table 2: Effect of nutrient management on yield attributes and yield of wheat

Treatments	Effective tillers (m^{-2})	Grains/ear head	Grain yield (Kg ha^{-1})	Straw yield (Kg ha^{-1})	Harvest index
50% recommended doses of NPK	250.40	30.35	3113.3	4854.6	39.07
75% recommended doses of NPK	269.90	29.17	3340.3	5116.3	39.50
100% recommended doses of NPK	326.16	28.15	4114.3	6153.6	40.07
125% recommended doses of NPK	344.01	29.873	4473.3	6467.0	40.89
150% recommended doses of NPK	368.52	29.437	4787.6	6802.3	41.31
100% recommended doses of NPK with growth regulators	371.78	30.28	5061.6	7138.0	41.49
125% recommended doses of NPK with growth regulators	385.11	30.477	5225.6	7233.0	41.94
150% recommended doses of NPK with growth regulators	431.13	31.397	5562.3	7495.6	42.60
Control (No fertilizer and growth regulators spray)	224.43	27.763	2754.6	4351.0	38.77
S.Em ±	2.76	0.45	50.13	111.63	0.81
C.D. (5%)	8.27	1.36	150.31	334.69	2.43

Conclusion
The results of this study demonstrated that cultivation of wheat with application of 150% recommended doses of NPK with growth regulator (CCC and Tebuconazole) resulted in significant improvement in the growth parameter and yield attributing character of wheat. It was found more remunerative as compare to other treatments to obtain better growth parameters, yield attributing characters and yield of wheat.

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