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Effect of spacing and varieties on the growth and yield of wheat (*Triticum aestivum* L.)

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Abstract
A field experiment entitled "Effect of Spacing and Varieties on the Growth and Yield of Wheat (*Triticum aestivum* L.)" was carried out during the rabi season of 2024 at the Crop Research Farm, Department of Agronomy, SHUATS, Prayagraj (U.P.). The experimental soil was sandy loam, moderately alkaline (pH 8.0), containing 0.62% organic carbon, with available 225 kg N, 38.2 kg P, and 240.7 kg K per hectare. The study was laid out in a Randomized Block Design (RBD) comprising ten treatments replicated three times. Treatments consisted of different combinations of row spacings (20 × 10 cm, 25 × 10 cm, 30 × 10 cm) with three wheat varieties (HD-2967, PBW-343, and PBW-502) along with a recommended fertilizer control (NPK @ 120:80:60 kg/ha). The results indicated that closer spacing of 20 × 10 cm with variety HD-2967 (T1) performed superiorly over other treatments. This combination recorded the maximum plant height (104.37 cm), dry matter accumulation (25.65 g/plant), number of tillers (101.93/m²), spikes/m² (84.94), seeds/plant (285.81), and test weight (41.23 g). It also achieved the highest seed yield (5.89 t/ha), stover yield (9.80 t/ha), and harvest index (38.97%). In terms of economics, T1 resulted in the highest gross return (₹1,62,716.75/ha), net return (₹1,19,568.80/ha), and a favorable B:C ratio of 2.77, demonstrating its profitability. Thus, it may be concluded that the 20 × 10 cm spacing with variety HD-2967 proved most effective for achieving higher yield and economic returns under the agro-climatic conditions of Prayagraj.

Keywords: Spacing, varieties, growth and yield, economics, wheat (HD-2967, PBW-343, PBW-502)

Introduction
Wheat (*Triticum aestivum L.*) is one of the most important cereal crops in India and worldwide, playing a pivotal role in national food security. It is highly adaptable and can be cultivated under a wide range of soil types and climatic conditions, from plains to hilly regions across North and South India. In India, wheat is predominantly grown in the northern plains, though it is also cultivated in mountainous and semi-arid areas.

India ranks as the second-largest wheat producer globally, after China. The major wheat-growing states include Uttar Pradesh, Madhya Pradesh, Punjab, Rajasthan, Haryana, Bihar, Gujarat, and Maharashtra. Among these, Uttar Pradesh leads in both area and production, whereas Punjab ranks highest in productivity. In Uttar Pradesh, wheat is grown on 9.65 million hectares, producing 26.87 million tonnes with an average productivity of 2786 kg/ha. At the national level, wheat occupies 29.58 million hectares, yielding 99.70 million tonnes with an average productivity of 3.37 t/ha (Anonymous, 2018) [2].

Wheat is a versatile crop and is consumed in multiple forms, including flour for making chapatis, bread, biscuits, cookies, and noodles, as well as processed products like dalia, vermicelli, semolina, and pasta. Beyond grain, wheat straw serves as valuable fodder for livestock and is also used in packaging and other industrial applications. Nutritionally, wheat grain comprises approximately 70% carbohydrates, 12% protein, 1.7% fat, 2.7% minerals, 2% fiber, and 12% moisture (Gupta *et al*., 2002) [5], making it a staple energy and protein source in the human diet.

Wheat is the leading cereal grain in terms of global production, consumption, and trade, which has spurred significant interest in maximizing winter wheat yields through the adoption of intensive cereal management practices.

These practices integrate the optimization of seeding dates and rates, row spacing, soil fertility, pest and disease management, and lodging control to achieve maximum grain yield.

In India, particularly in Uttar Pradesh, wheat is traditionally sown by broadcasting after the rice harvest. While broadcasting is widely practiced, it often results in uneven plant population and requires higher seed rates. In contrast, line sowing is recommended as it ensures uniform seed distribution at the desired depth, promotes higher germination, and establishes a uniform crop stand. Alongside sowing methods, nitrogen management is a critical agronomic factor influencing crop vigor and ultimately the yield potential of wheat (Alley *et al.*, 1999) [1].

The integrated use of organic and inorganic fertilizers has proven effective in achieving high yields while improving nutrient use efficiency. Incorporation of farmyard manure, compost, or green manure not only supplies nutrients gradually but also enhances soil health and partially meets the nitrogen requirement of subsequent crops. Organic amendments regulate nitrogen release, improve soil structure, and promote sustainable productivity, thereby complementing chemical fertilizers and supporting high wheat yields (Ramdas *et al.*, 2018) [17].

Uttar Pradesh exhibits a wide range of climatic conditions and encompasses areas under three distinct wheat mega zones, resulting in a diverse varietal mosaic adapted to specific agro-ecological conditions. Wheat in the state is cultivated under three major production scenarios:

1. Timely sown irrigated conditions, where wheat is sown during November 1-15, allowing the crop to achieve optimal maturity.
2. Late sown irrigated conditions, where wheat is grown during December 5-15 after the harvest of paddy, sugarcane, early pea, or potato.
3. Timely sown restricted irrigated conditions, where wheat is sown in the first fortnight of November but receives only 1-2 irrigations.

Over the last decade, the All India Coordinated Research Project (AICRP) on Wheat and Barley has evaluated wheat varieties under these conditions, leading to the release and notification of several high-performing cultivars by the Central Varietal Release Committee for commercial cultivation.

Despite these advancements, wheat production in Uttar Pradesh faces multiple constraints that vary regionally. The increasing demand due to a growing population, combined with the crop's vulnerability to climate change, represents a major bottleneck. Other challenges include resource limitations, soil fertility issues, pest and disease pressures, and water availability, all of which affect productivity and sustainability (Sharma *et al.*, 2020) [19]. Addressing these constraints through improved varietal selection, management practices, and adaptive technologies is critical to sustaining wheat production in the state.

The selection of a suitable wheat cultivar at the appropriate sowing time is critical to achieving optimum productivity. As a thermo-sensitive crop, wheat performance is highly influenced by seeding time, making cultivar choice even more important under varying climatic conditions. Through concerted breeding efforts, several high-yielding wheat varieties have been developed, many of which exhibit enhanced adaptability and relatively stable performance under diverse environmental conditions.

Wheat yield is a function of the interaction between genotype, environment, and management practices. Genotypic potential determines the crop's growth characteristics and yield-contributing traits, including tillers per m², spikes per m², grains per spike, and 1000-grain weight. Optimal productivity is achieved through the appropriate combination of these yield attributes, with spikes per m² generally being the most significant contributor to grain yield. Effective tillering of a cultivar plays a key role in attaining optimum ear head density, which can be further optimized through seed rate adjustments. Varieties with high tillering capacity can achieve higher yields even at lower seed rates, whereas cultivars with limited tillering require higher seed rates to attain similar productivity.

This highlights the importance of integrated varietal selection and agronomic management, ensuring that the genetic potential of a cultivar is fully expressed under the prevailing environmental conditions.

Wheat is a major staple crop globally, and improving its yield is vital for food security. Plant spacing and varietal selection are key agronomic factors that significantly influence wheat growth, resource use, and final yield. Improper spacing can lead to competition for light, water, and nutrients, reducing productivity, while different wheat varieties respond differently to spacing due to their genetic traits. By studying the interaction between spacing and variety, we can identify the best combinations for maximum yield and efficient resource use. This research is essential for developing sustainable, high-yielding wheat production systems suitable for diverse agro-climatic conditions.

Materials and Methods

Experiment site and soil analysis

A field experiment was conducted at Crop Research Farm, Department of Agronomy, SHUATS, Prayagraj (U.P) during *Rabi* 2024. The soil of the experimental plot was sandy loam in texture, nearly neutral in soil reaction (pH 8.0), organic carbon (0.62%), available N (225 kg/ha), available P (38.2 kg/ha), and available K (240.7 kg/ha).

Treatment Details

The experiment was conducted using a Randomized Block Design (RBD) with three replications and comprised 10 distinct treatment combinations. These treatments involved three spacing levels (20cmx 10cm, 25cm x 10cm, 30cm x 10cm) along with three variety levels (HD-2967, PBW-343, PBW-502). Additionally, the recommended fertilizer doses of nitrogen, phosphorus, and potassium (120:80:60 N:P:K kg/ha) were uniformly applied across all plots.

Ten different treatments were evaluated

T_1 (20 cm x 10 cm + HD- 2967), T_2 (20 cm x 10 cm + PBW-343), T_3 (20 cm x 10 cm + PBW-502), T_4 (25 cm x 10 cm + HD-2967), T_5 (25 cm x 10 cm + PBW-343), T_6 (25 cm x 10 cm + PBW-502), T_7 (30 cm x 10 cm + HD- 2967), T_8 (30 cm x 10 cm + PBW-343), T_9 (30 cm x 10 cm + PBW-502) and T_{10} (Control).

Data Collection and Statistical Analysis

Plant growth parameters including plant height (cm) and dry weight (g/plant) were recorded at 30-day intervals from 30 to 120 days after sowing (DAS). Yield-related traits such as the number of tillers/m^2, number of spikes/m^2, number of seeds/plant, test weight (g), seed yield (kg/ha), stover yield (kg/ha), and harvest index (%) were measured at harvest. All collected data were subjected to analysis of variance (ANOVA) appropriate for a randomized block design (RBD). The F-value was tested at the 5% significance level, and the critical difference (CD) was computed to compare treatment means.

Results and Discussion

1. Growth attributes

1.1 Plant height (cm)

Among the various treatments evaluated, the combination of 20 cm × 10 cm spacing with variety HD-2967 (T_1) resulted in the greatest plant height, reaching 104.37 cm. This treatment demonstrated a statistically significant advantage over all others. Nonetheless, treatment T_8 (97.91 cm) and T_9 (96.72 cm) exhibited plant heights that were statistically at par with T_1. The enhanced plant growth observed under the 20 cm × 10 cm spacing may be attributed to improved access to light, better air circulation, and more efficient nutrient utilization afforded by the relatively wider spacing. These results align with the findings of Konnepati *et al.* (2023) [13], who reported similar trends.

1.2 Plant Dry weight (g/plant)

The combination of 20 cm × 10 cm spacing with variety HD-2967 (T_1) resulted in the highest plant dry weight, reaching 25.65 g, which was significantly greater than that recorded under all other treatments. Treatments T_7 (22.64 g) and T_8 (24.53 g), however, were statistically comparable to T_1. The superior dry matter accumulation under the 20 cm × 10 cm spacing may be attributed to more efficient utilization of essential growth resources such as nutrients, moisture, and solar radiation. This spacing likely promoted enhanced photosynthetic efficiency, improved nitrogen availability in the soil, and increased microbial activity, collectively contributing to higher biomass production. These observations are in agreement with the findings of Keerthi *et al.* (2015) [9].

1.3 Number of tillers/plant

The highest number of tillers per plant (260.54) was observed under the treatment combining 20 cm × 10 cm spacing with variety HD-2967 (T_1), which was significantly superior to all other treatments. However, treatments T_9 (244.34) and T_8 (246.44) were statistically at par with T_1. The increased tiller production under this treatment can be attributed to the genetic superiority of variety HD-2967, which possesses traits conducive to better growth and development, particularly under favorable climatic conditions. The optimized spacing further facilitated resource efficiency, contributing to higher tiller density. These results are in line with the findings reported by Netam *et al.* (2020).

2. Yield Attributes

2.1 Number of Tillers/m^2

The maximum number of tillers per square meter (101.93) was recorded under the treatment combining 20 cm × 10 cm spacing with variety HD-2967 (T_1), which was significantly higher than all other treatments. Treatments T_8 (100.38) and T_7 (99.98), however, were statistically comparable to T_1. The higher tiller count observed under this spacing may be attributed to improved light interception, enhanced nutrient availability, and overall better plant vigor. Additionally, the superior genetic potential of HD-2967 likely contributed to its enhanced tillering capacity. These findings are consistent with the results reported by Arumugam *et al.* (2023) [3], Kumar *et al.* (2024) [14], and Khalid *et al.* (2023) [10].

2.2 Number of spikes/m^2

At harvest, the highest number of spikes per square meter (84.94) was observed under the treatment comprising 20 cm × 10 cm spacing with variety HD-2967 (T_1), which was significantly superior to all other treatments. However, treatments T_8 (83.65) and T_7 (83.32) were statistically at par with T_1. The increased spike density under this spacing can be attributed to enhanced plant vigor, likely resulting from improved light interception, nutrient uptake, and photosynthetic efficiency. The superior performance of HD-2967 may also be linked to its strong genetic potential for tillering and spike formation. These findings are in agreement with those reported by Arumugam *et al.* (2023) [3], Pal *et al.* (2009) [15], and Singh *et al.* (2021) [23].

2.3 Number of seeds/plant

At harvest, the maximum number of seeds per plant (285.81) was recorded under the treatment involving 20 cm × 10 cm spacing combined with variety HD-2967 (T_1), which significantly outperformed all other treatments. Treatments T_8 (284.61) and T_7 (283.06), however, were statistically at par with T_1. The higher seed count observed under this spacing may be attributed to improved access to essential growth resources such as heat, water, and nutrients, which favor optimal seed development. The superior genetic potential of HD-2967 also contributed to enhanced reproductive efficiency. However, it is noteworthy that seed yield tends to decline with the increasing age of poplar trees, likely due to intensified shading effects. These results are in line with the findings of Konnepati *et al.* (2023) [13] and Khalid *et al.* (2023) [10].

2.4 Test weight (g)

At harvest, the highest test weight (41.23 g) was recorded under the treatment comprising 20 cm × 10 cm spacing with variety HD-2967 (T_1), which was significantly superior to all other treatments. Treatments T_8 (40.36 g) and T_7 (38.41 g) were statistically at par with T_1. The increase in test weight under this spacing regime can be attributed to improved light availability, which likely enhanced photosynthetic efficiency, overall plant vigor, and grain filling processes, thereby contributing to superior grain development. These findings are supported by the results of Arumugam *et al.* (2023) [3].

2.5 Seed yield (kg/ha)

At harvest, the highest seed yield (5.89 q/ha) was recorded under the treatment involving 20 cm × 10 cm spacing in combination with variety HD-2967 (T_1), which was significantly superior to all other treatments. However, treatment T_8 (5.57 q/ha) was found to be statistically at par with T_1. The increased seed yield observed under this spacing may be attributed to improved access to essential growth resources such as heat, moisture, and nutrients, which collectively supported optimal plant development and productivity. The superior performance of HD-2967 can also be ascribed to its high genetic yield potential. Nonetheless, it is important to note that yield reductions under poplar-based agroforestry systems have been documented, primarily due to intensified competition for resources and alterations in the microclimate. These findings are in accordance with the results reported by Konnepati *et al.* (2023) [13], Sharma *et al.* (2005) [21], and Jitendra *et al.* (2022) [8].

2.6 Stover yield (kg/ha)

At harvest, the maximum stover yield (9.80 q/ha) was recorded under the treatment combining 20 cm × 10 cm spacing with variety HD-2967 (T_1), which was significantly higher than all other treatments. Treatments T_8 (9.27 q/ha) and T_7 (8.80 q/ha) were statistically comparable to T_1. The increased stover yield under this spacing regime may be attributed to improved nutrient uptake, efficient partitioning of assimilates, and enhanced translocation of photosynthates to vegetative organs. Furthermore, the superior performance of HD-2967 can be linked to its taller stature and greater potential for vegetative biomass accumulation. These results are in line with the findings of Dasthari and Debbarma (2023) [13] and Khalid *et al*. (2023) [10].

2.7 Harvest index (%)
At harvest, no significant differences were observed among the treatments. However, the highest harvest index (38.97%) was recorded under the 20 cm × 10 cm spacing in combination with the HD-2967 variety (T_1).

3. Economics
3.1 Cost of Cultivation (INR/ha)
The highest cost of cultivation (43,147.95 INR/ha) was incurred under the treatment combining 20 cm × 10 cm spacing with variety HD-2967 (T_1), exceeding that of all other treatments.

3.2 Gross return (INR/ha)
The highest gross return (162,716.75 INR/ha) was achieved under the treatment combining 20 cm × 10 cm spacing with variety HD-2967 (T_1), surpassing all other treatments.

3.3 Net return (INR/ha)
The maximum net return (119,568.80 INR/ha) was obtained under the treatment combining 20 cm × 10 cm spacing with variety HD-2967 (T_1), outperforming all other treatments.

3.4 Benefit cost ratio
The highest benefit-cost ratio (2.77) was observed under the treatment combining 20 cm × 10 cm spacing with variety HD-2967 (T_1), exceeding that of all other treatments. The improved benefit-cost ratio can be attributed to the increased grain and stover yields achieved through optimal spacing and varietal selection, which led to higher gross returns and consequently enhanced profitability. Similar findings were reported by Dhillon *et al*. (2016) [4].

Conclusion
It can be concluded that the wheat variety HD-2967, when grown at a spacing of 20 cm × 10 cm (T_1), recorded the highest grain yield, gross returns, net returns, and benefit-cost ratio, making it the most economically and agronomically efficient treatment.

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Table 1: Effect of spacing and varieties on growth of wheat.

S. No.	Treatment Combinations	Plant height (cm)	Dry weight (g)	Number of tillers/plant
1.	20 cm x 10 cm + HD-2967	104.37	25.65	260.54
2.	20 cm x 10 cm + PBW-343	99.27	21.29	238.48
3.	20 cm x 10 cm + PBW-502	97.72	20.75	241.40
4.	25 cm x 10 cm + HD-2967	93.51	20.31	239.99
5.	25 cm x 10 cm + PBW-343	97.04	23.00	244.16
6.	25 cm x 10 cm + PBW-502	97.16	21.86	243.36
7.	30 cm x 10 cm + HD-2967	95.55	22.64	238.07
8.	30 cm x 10 cm + PBW-343	97.91	24.53	246.44
9.	30 cm x 10 cm + PBW-502	96.72	19.76	244.34
10.	Control (N:P:K) 120:80:60	100.64	20.56	240.46
	F test	NS	S	S
	SEm(±)	5.47	1.21	13.93
	CD (p=0.05)	-	3.59	41.38

Table 2: Effect of spacing and varieties on yield of wheat.

S. No.	Treatment Combinations	No. of Tillers/m^2	No. of spikes/m^2	No. of seeds/plant	Test weight (g)	Seed yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)
1.	20 cm x 10 cm + HD-2967	101.93	84.94	285.81	41.23	5.89	9.80	38.97
2.	20 cm x 10 cm + PBW-343	96.94	80.78	234.31	31.76	3.72	6.08	38.13
3.	20 cm x 10 cm + PBW-502	97.48	81.23	274.13	32.22	4.41	6.93	37.15
4.	25 cm x 10 cm + HD-2967	97.87	81.56	280.19	32.53	3.64	7.54	37.67
5.	25 cm x 10 cm + PBW-343	99.47	82.89	280.33	35.25	3.95	8.11	37.73
6.	25 cm x 10 cm + PBW-502	99.50	82.92	282.42	36.70	4.14	8.22	38.83
7.	30 cm x 10 cm + HD-2967	99.98	83.32	283.06	38.41	3.62	8.80	38.14
8.	30 cm x 10 cm + PBW-343	100.38	83.65	284.61	40.36	5.57	9.27	38.44
9.	30 cm x 10 cm + PBW-502	96.54	80.45	216.66	31.02	3.92	5.70	37.62
10.	Control (N:P:K) 120:80:60	96.11	80.09	210.47	30.95	2.24	5.80	35.74
	F test	S	S	S	S	S	S	NS
	SEm(±)	1.75	1.38	8.76	1.37	0.19	0.40	2.03
	CD (p=0.05)	5.26	4.09	26.02	4.08	0.56	1.20	-

Table 3: Effect of spacing and varieties on economics of wheat.

S. No.	Treatment Combinations	Cost of cultivation (INR/ha)	Gross return (INR/ha)	Net return (INR/ha)	B:C ratio
1.	20 cm x 10 cm + HD-2967	43147.95	162716.75	119568.80	2.77
2.	20 cm x 10 cm + PBW-343	43147.95	102258.34	59110.39	1.37
3.	20 cm x 10 cm + PBW-502	43147.95	120964.03	77816.08	1.80
4.	25 cm x 10 cm + HD-2967	43147.95	125570.39	82422.44	1.91
5.	25 cm x 10 cm + PBW-343	43147.95	135845.55	92697.60	2.15
6.	25 cm x 10 cm + PBW-502	43147.95	142095.09	98947.14	2.29
7.	30 cm x 10 cm + HD-2967	43147.95	149278.63	106130.68	2.46
8.	30 cm x 10 cm + PBW-343	43147.95	157736.74	114588.79	2.66
9.	30 cm x 10 cm + PBW-502	43147.95	93065.70	49917.75	1.16
10.	Control (N:P:K) 120:80:60	43147.95	89814.75	46666.80	1.08

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