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Performance and economic analysis of *Gossypium hirsutum* under varying plant spacing and nutrient treatments in central plain zone, U.P.

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Abstract
Gossypium hirsutum ranks among the leading commercial crops of the world, chiefly because its lint sustains the textile sector. To determine how planting geometry and fertilizer regimes influence agronomic performance, an on-farm trial was carried out with the cotton line H-1300 during the *kharif* season of 2024 on the Agriculture Farm of Swami Vivekanand Subharti University, Meerut. The trial examined how these variables shape crop development, yield attributes, actual yield, fibre quality and profitability. A Randomized Block Design carrying three replications was used to evaluate seven treatment combinations that included an unfertilized check at conventional spacing (67.5 × 30 cm), the recommended fertilizer schedule at both conventional and narrowed row widths, and elevated fertilizer levels at the narrowed spacing combined with soil-applied zinc sulphate, a foliar application of urea plus diammonium phosphate, or a foliar application of magnesium sulphate plus zinc sulphate. At sowing, one-half of the nitrogen along with the entire phosphorus and potassium requirement was placed in the soil; the balance nitrogen was delivered in two equal top-dressings at thirty and sixty days after sowing. Picking was carried out as bolls opened fully. Under the treatment combining the elevated fertilizer level, narrowed spacing and a two per cent urea plus two per cent diammonium phosphate foliar spray, the crop registered peak values for plant height, monopodial and sympodial branches, fresh and dry biomass per plant, boll number per plant and per square metre, boll weight, and for yields of seed cotton, lint, cotton seed and stick, as well as for fibre quality traits and financial returns; the magnesium sulphate plus zinc sulphate spray was a close second. The study therefore identifies genotype H-1300 combined with the higher fertilizer schedule, closer row arrangement and the urea plus diammonium phosphate foliar spray as the most productive and profitable package for cotton growers in the Central Plain Zone of Uttar Pradesh.

Keywords: Cotton, plant spacing, nutrient management, foliar spray, yield, economics

Introduction
Cotton occupies a pre-eminent place among the world's cash crops and underpins the agricultural economies of several nations. Its cultivation extends to nearly one hundred countries, with China, India, Brazil, the United States and Pakistan currently accounting for the largest share of global output. Because it supplies the lint that feeds the world's spinning mills, cotton is often described as the mainstay of the textile industry. Cultivation of the crop is also spread across the tropics and sub-tropics of more than eighty countries. Domesticated cotton grown for commerce is broadly grouped into two categories, namely New World and Old World types, and the New World group is further subdivided on the basis of fibre attributes. Of the two Old World diploids, *G. arboreum* has the widest commercial cultivation and is chiefly raised in India, Pakistan and other parts of South and South-East Asia, largely on the marginal, low-productivity tracts of Bangladesh, Myanmar, China, Sri Lanka and Vietnam (Singh and Narayanan, 1991) [28].
Fabric fragments unearthed at Mohenjo-daro indicate that Indian cotton weaving is close to five millennia old. Within the country, cotton remains one of the most important commercial crops and continues to shape both industry and the wider economy. The market for cotton is essentially quality-driven; buyers assess a combined index of mean fibre length, fineness, maturity and strength, together with secondary characters such as colour and ash.

Together, these parameters govern the spinning behaviour of the yarn, its dye uptake, tensile strength, fabric lustre and its ability to blend with synthetic fibres. External stresses—water shortage, unbalanced nutrition, prevailing season, timing of harvest, and pest or pathogen attack—are known to alter fineness, maturity and strength [15]. On average, American cotton has been observed to exceed desi types in seed index and kernel percentage. Several factors keep national cotton productivity subdued, but the most persistent are continuous monoculture, gradual loss of soil fertility, delayed sowing, and heavy pest and disease pressure. Prolonged cropping under long-term fertilization also alters both edaphic properties and crop response, [14] with a documented drift towards fertility exhaustion.

Combining organic manures with inorganic fertilizers, or using manures alone, generally sustains soil productivity and helps restore fertility. Because Bt cotton hybrids are being adopted across large tracts of the country, their nutrient schedules also need to be re-examined. [27] Since the commercial release of Bt cotton in India in 2002, farmer adoption has been rapid and widespread. Sound fertilizer management is one of the most direct routes to lifting cotton productivity, and meeting the crop's nutritional demands is a prerequisite for both high yields and superior fibre [9, 13]. Nutrient responses, however, is conditioned by climatic and cultural variables. Among the many inputs available to the grower, fertilizers stand out for the size of the response they produce in cotton, so adequate fertilization becomes indispensable if the crop is to approach its yield potential. The exact quantity required nevertheless shifts with soil type and agro-ecology.

Clearly, yield and productivity can be raised by combining superior genotypes with sound agronomy—maintaining an ideal plant stand, applying a balanced fertilizer schedule, controlling insects at the right time, and following judicious weed and water management. Foliar delivery of micronutrients has drawn particular attention because of its efficient absorption and its effect on crop vigour [21]. It also modulates biochemical processes within the seed and lifts overall yield [4]. Squaring, flowering and boll formation are the phases at which cotton's nutrient demand peaks, and supplementing supply through foliar sprays during these windows can produce a marked yield response. [2] The higher gross and net returns and improved benefit:cost ratios recorded under such management can be traced to the yield increment achieved with elevated fertilizer levels and closer geometry. Jadhav *et al.* [8] reported the highest net income at 200:100:100 kg NPK/ha, followed by 150:75:75 kg NPK/ha, and comparable economic gains have been documented by other workers [24].

Against this backdrop, the present investigation was designed to identify the most appropriate combination of spacing and nutrient management for growth, yield, yield attributes, quality and economics of *Hirsutum* cotton in the Central Plain Zone of Uttar Pradesh.

Materials and Methods

The trial was set up with *Hirsutum* cotton genotype H-1300 during the *kharif* season of 2024 on the Agriculture Farm of Swami Vivekanand Subharti University at Meerut. Rainfall for the year totalled 650.6 mm, most of which fell between mid-June and the second week of September under the south-west monsoon; occasional off-season showers were also received during the winter months. The layout was designed to assess the influence of row geometry and nutrient scheduling on the growth pattern, yield-determining traits, yield and fibre quality of the crop.

Seven treatments were compared: T_1, an unfertilized check maintained at the conventional row × plant spacing of 67.5 × 30 cm; T_2, the full recommended dose of fertilizer (RDF) with the same conventional spacing; T_3, 100% RDF combined with rows drawn 25% closer than conventional; T_4, 125% RDF at the narrowed spacing; T_5, 125% RDF at the narrowed spacing plus soil-placed $ZnSO_4$; T_6, 125% RDF at the narrowed spacing supplemented with a foliar spray of 2% urea and 2% DAP; and T_7, 125% RDF at the narrowed spacing supplemented with a foliar spray of $MgSO_4$ and $ZnSO_4$. The seven treatments were arranged in a Randomized Block Design and repeated in three blocks.

The soil of the experimental site was a sandy loam of moderate fertility with a slightly alkaline pH of 7.8. Organic carbon was low (0.48%) while available phosphorus (16 kg/ha) and available potash (183 kg/ha) fell in the medium range. Sowing was completed on 28 May 2024 and the crop was harvested in two pickings on 25 October and 10 November 2024. Under the conventional layout, rows were drawn 67.5 cm apart with a plant-to-plant distance of 30 cm within the row. Fertilizer was applied according to the assigned treatment, with half the nitrogen and the entire phosphorus and potassium supplied at sowing; the remaining nitrogen was split evenly and top-dressed at 30 and 60 days after sowing. Insecticidal sprays were made whenever pest incidence warranted them. Data were recorded on growth attributes, on yield and its components, and on fibre quality traits, and picking was carried out only after the bolls had opened fully.

The recorded data were subjected to statistical analysis using procedures suited to the experimental layout [5]. Wherever the analysis of variance produced a significant 'F', treatment means were tabulated together with their standard errors, and critical differences were worked out to test the significance of the difference between any two treatments. Values of critical difference (CD) computed at P = 0.05 were then applied to judge the significance of pairwise contrasts.

Results and Discussion

The imposed treatments produced significant differences in the number of established plants, plant height at 30, 60, 90, 120 and 150 days after sowing, in the counts of monopodial and sympodial branches per plant, and in the fresh and dry biomass of individual plants, with values rising steadily as the fertilizer dose was stepped up. Plants receiving 125% RDF combined with narrowed rows and a spray of 2% urea plus 2% DAP were consistently the tallest at every physiological stage, significantly outperforming the rest. Improvement of plant height with tighter spacing and higher nutrition has previously been documented by Kaur *et al.*[10] and Sharma *et al.* [23] The taller stature seen at closer spacing is largely a consequence of intra-row competition that suppresses vertical elongation in the more widely spaced canopies [22].

The largest counts of monopodia per plant were also produced by the T_6 treatment (125% RDF + closer rows + 2% urea and 2% DAP foliar spray), the difference being significant against every other treatment. Stepping up fertilizer levels in combination with the closer row arrangement raised the number of sympodial branches per plant, though the gain did not always cross the significance threshold. This lift in monopodial and sympodial branching is best explained by the fact that adequate nutrition stimulates cell division and expansion and thereby favours the formation of additional lateral shoots. The trend agrees with earlier reports by Ram and Giri and by Kaur *et al.* [18, 10]

Elevated fertilizer levels imposed under the closer geometry also had a marked effect on the fresh and dry biomass produced per plant. The heaviest fresh and dry weights again came from 125% RDF + closer rows + 2% urea and 2% DAP, while the $MgSO_4$ + $ZnSO_4$ foliar treatment (T_7) also lifted both fresh and dry weight significantly above the lower-nutrition, conventionally-spaced entries. Higher meristematic activity under improved nutrition is the most plausible driver, in line with the findings of Jadhav *et al.* [8]

The 125% RDF + narrowed rows + 2% urea and 2% DAP foliar treatment likewise produced a significant increase in boll number per plant, boll number per square metre and average boll weight relative to the lower fertility and wider-spaced treatments. The T_7 combination (125% RDF + closer spacing + $MgSO_4$ + $ZnSO_4$) also gave significantly higher boll counts per plant and heavier bolls than the remaining treatments. These gains in reproductive attributes are directly linked to the improvements already noted in vegetative characters—plant height, monopodial and sympodial branching, and fresh and dry weight—and mirror the observations of Jadhav *et al.* [8]

Seed cotton yield under 125% RDF + closer spacing + 2% urea and 2% DAP foliar spray was 86.38 per cent higher than that recorded from the unfertilized check at conventional spacing. Application of 125% RDF + narrowed spacing + $MgSO_4$ + $ZnSO_4$ spray also delivered a significantly higher seed cotton yield. Lint yield rose sharply with higher fertilizer inputs relative to the unfertilized check at conventional spacing, and the peak lint yield again came from 125% RDF + closer rows + 2% urea and 2% DAP. Cotton seed yield was highest under 125% RDF + narrowed rows + $MgSO_4$ + $ZnSO_4$, whereas the maximum stick yield was recorded under the 2% urea and 2% DAP foliar spray. The lowest values for seed cotton, lint, seed and stick yield were, unsurprisingly, obtained from the fertilizer-omitted control at conventional spacing. The yield gains delivered by elevated fertilizer inputs can be traced back to the parallel improvement in growth and yield attributes, an interpretation supported by the observations of Bhattoo *et al.* [3] Raskar [20] also noted that raising fertilizer application progressively from 50 to 100% RDF drove a significant increase in seed cotton yield, and Kote *et al.*[11] recorded significantly higher seed cotton and cotton seed yields under 100% RDF than under 75 or 50% RDF. A comparable yield advantage under wider row arrangements has been reported by Kumar *et al.* [12]

The nutrient management regimes also produced significant shifts in fibre quality traits—ginning out-turn, span length, fibre strength, micronaire and uniformity ratio. Ginning out-turn was highest, and significantly so, under 125% RDF + closer spacing + $MgSO_4$ + $ZnSO_4$ foliar spray. Span length, on the other hand, was significantly greater in the unfertilized control at conventional spacing. Both micronaire value and uniformity ratio were highest under 125% RDF + narrowed spacing + 2% urea and 2% DAP, closely followed by the unfertilized control at conventional spacing. The poorest fibre quality was recorded in the fertilizer-omitted, conventionally-spaced entry. These results align with Srinivasula *et al.* Rao and Janawade [26, 19] likewise reported that 100% RDF gave the highest ginning out-turn and lint index, followed by 75 and 50% RDF.

Nutrient management coupled with spacing exerted a significant influence on the gross return, net return and benefit:cost ratio realised from the crop. The highest gross return was earned under 125% RDF + closer rows + 2% urea and 2% DAP foliar spray, followed by the $MgSO_4$ + $ZnSO_4$ foliar treatment and by the soil-applied $ZnSO_4$ treatment. Net return was similarly maximised under the 2% urea and 2% DAP foliar treatment, statistically at par with soil-applied $ZnSO_4$ and with 125% RDF + closer rows. The greatest benefit:cost ratio was again recorded for 125% RDF + narrowed rows + 2% urea and 2% DAP, followed by $MgSO_4$ + $ZnSO_4$ and by soil-applied $ZnSO_4$. Predictably, the lowest values for gross return, net return and benefit:cost ratio came from the unfertilized check at conventional spacing. The lift in monetary returns tracks directly with the seed cotton yield advantage secured by higher fertilizer inputs and tighter row geometry. Jadhav *et al.* [8] reported the highest net return at 200:100:100 kg NPK/ha, followed by 150:75:75 kg NPK/ha, with 100:50:50 kg NPK/ha giving the lowest. Similar economic gains under higher fertilizer schedules have been documented by several other workers [7, 16, 24].

Table 1: Effect of spacing and nutrient management on plant population and plant height (cm) at different days after sowing in Hirsutum cotton

Treatments	No. of plants/plot	Plant population/ha	30 DAS	60 DAS	90 DAS	120 DAS	150 DAS
T_1 - Control without fertilizer + normal spacing	62.34	38476.8	25.01	47.68	68.21	93.81	109.94
T_2 - 100% RDF + normal spacing	73.34	45308.8	27.48	50.01	73.88	97.94	117.54
T_3 - 100% RDF + 25% less than normal spacing	65.34	39683.4	28.01	51.14	72.41	96.54	114.81
T_4 - 125% RDF + 25% less than normal spacing	76.34	41285.01	29.81	51.81	74.21	99.41	118.14
T_5 - 125% RDF + 25% less than normal spacing + soil application of $ZnSO_4$ (20 kg/ha)	77.34	45285.01	30.21	52.74	75.14	101.14	120.24
T_6 - 125% RDF + 25% less than normal spacing + foliar spray of 2% urea & 2% DAP	80.01	50724.4	31.61	56.01	77.48	105.21	124.61
T_7 - 125% RDF + 25% less than normal spacing + foliar spray of $MgSO_4$ (1%) and $ZnSO_4$ (0.5%)	78.01	48504.4	30.27	55.28	76.14	102.34	122.14
S.E(d) ±	0.75	363.58	0.63	1.15	0.84	0.64	1.63
C.D. at 5%	1.62	792.16	1.35	2.49	1.83	1.38	3.53

The values under 30-150 DAS are plant height (cm). RDF = recommended dose of fertilizer; DAS = days after sowing; $ZnSO_4$ = zinc sulphate; DAP = diammonium phosphate; $MgSO_4$ = magnesium sulphate; S.E(d) = standard error of difference; C.D. = critical difference.

Table 2: Effect of spacing and nutrient management on branching and biomass in Hirsutum cotton

Treatments	Monopodia/plant	Sympodia/plant	Fresh weight/plant (g)	Dry weight/plant (g)
T_1 - Control without fertilizer + normal spacing	0.88	12.01	274.34	136.34
T_2 - 100% RDF + normal spacing	1.08	12.68	335.68	150.01
T_3 - 100% RDF + 25% less than normal spacing	0.94	13.01	333.34	145.34
T_4 - 125% RDF + 25% less than normal spacing	1.01	13.11	337.34	152.01
T_5 - 125% RDF + 25% less than normal spacing + soil application of $ZnSO_4$ (20 kg/ha)	1.41	13.21	346.68	153.01
T_6 - 125% RDF + 25% less than normal spacing + foliar spray of 2% urea & 2% DAP	1.14	13.48	388.68	158.34
T_7 - 125% RDF + 25% less than normal spacing + foliar spray of $MgSO_4$ (1%) and $ZnSO_4$ (0.5%)	1.24	13.28	349.01	155.68
S.E(d) ±	0.09	0.12	3.57	2.26
C.D. at 5%	0.18	0.25	7.77	4.90

RDF = recommended dose of fertilizer; $ZnSO_4$ = zinc sulphate; DAP = diammonium phosphate; $MgSO_4$ = magnesium sulphate; S.E(d) = standard error of difference; C.D. = critical difference.

Table 3: Effect of spacing and nutrient management on yield attributes in Hirsutum cotton

Treatments	No. of bolls/plant	No. of bolls/m²	Boll weight (g)
T_1 - Control without fertilizer + normal spacing	13.94	66.07	3.14
T_2 - 100% RDF + normal spacing	17.81	89.34	3.26
T_3 - 100% RDF + 25% less than normal spacing	15.88	80.77	3.26
T_4 - 125% RDF + 25% less than normal spacing	19.54	95.14	3.27
T_5 - 125% RDF + 25% less than normal spacing + soil application of $ZnSO_4$ (20 kg/ha)	21.14	98.53	3.34
T_6 - 125% RDF + 25% less than normal spacing + foliar spray of 2% urea & 2% DAP	25.41	117.89	3.44
T_7 - 125% RDF + 25% less than normal spacing + foliar spray of $MgSO_4$ (1%) and $ZnSO_4$ (0.5%)	23.48	102.30	3.40
S.E(d) ±	0.63	1.75	0.09
C.D. at 5%	1.36	3.81	0.18

RDF = recommended dose of fertilizer; $ZnSO_4$ = zinc sulphate; DAP = diammonium phosphate; $MgSO_4$ = magnesium sulphate; S.E(d) = standard error of difference; C.D. = critical difference.

Table 4: Effect of spacing and nutrient management on yield and quality characters in Hirsutum cotton

Treatments	Seed cotton yield (kg/ha)	Lint yield (kg/ha)	Cotton seed yield (kg/ha)	Stick yield (kg/ha)	Ginning out turn (%)	Span length 2.5% (mm)	Micronaire value	Uniformity ratio (%)	Fibre strength (g/tex)
T_1 - Control without fertilizer + normal spacing	746.68	261.9	485.34	4384.1	35.03	26.8	4.78	80.1	25.48
T_2 - 100% RDF + normal spacing	1199.34	423.0	777.68	5142.8	35.21	25.7	4.31	80.1	26.24
T_3 - 100% RDF + 25% less than normal spacing	1144.01	404.1	740.34	4483.4	35.34	26.3	4.61	80.4	27.31
T_4 - 125% RDF + 25% less than normal spacing	1250.01	431.0	819.68	5504.4	34.48	25.5	4.64	80.1	28.31
T_5 - 125% RDF + 25% less than normal spacing + soil application of $ZnSO_4$ (20 kg/ha)	1257.01	430.0	827.68	5733.1	34.21	26.2	4.48	79.8	27.51
T_6 - 125% RDF + 25% less than normal spacing + foliar spray of 2% urea & 2% DAP	1391.63	487.6	902.61	6388.8	35.64	26.3	4.84	80.1	26.38
T_7 - 125% RDF + 25% less than normal spacing + foliar spray of $MgSO_4$ (1%) and $ZnSO_4$ (0.5%)	1259.34	448.1	811.68	5818.8	35.61	25.6	4.44	80.1	27.71
S.E(d) ±	58.66	19.81	39.11	46.23	0.19	0.14	0.79	0.79	0.15
C.D. at 5%	127.80	43.15	85.21	100.71	0.40	0.28	NS	NS	0.31

RDF = recommended dose of fertilizer; $ZnSO_4$ = zinc sulphate; DAP = diammonium phosphate; $MgSO_4$ = magnesium sulphate; S.E(d) = standard error of difference; C.D. = critical difference; NS = non-significant.

Table 5: Effect of spacing and nutrient management on economics in Hirsutum cotton

Treatments	Gross return (Rs/ha)	Net return (Rs/ha)	Benefit:Cost ratio
T_1 - Control without fertilizer + normal spacing	43018.8	7541.8	1.22
T_2 - 100% RDF + normal spacing	63401.4	21500.4	1.52
T_3 - 100% RDF + 25% less than normal spacing	59210.1	17309.1	1.42
T_4 - 125% RDF + 25% less than normal spacing	66513.1	23889.1	1.57
T_5 - 125% RDF + 25% less than normal spacing + soil application of $ZnSO_4$ (20 kg/ha)	67479.1	24255.1	1.57
T_6 - 125% RDF + 25% less than normal spacing + foliar spray of 2% urea & 2% DAP	74832.8	31891.8	1.75
T_7 - 125% RDF + 25% less than normal spacing + foliar spray of $MgSO_4$ (1%) and $ZnSO_4$ (0.5%)	67829.4	25005.4	1.59
S.E(d) ±	2312.27	2311.89	0.07
C.D. at 5%	5038.03	5037.21	0.13

RDF = recommended dose of fertilizer; $ZnSO_4$ = zinc sulphate; DAP = diammonium phosphate; $MgSO_4$ = magnesium sulphate; Rs = Indian Rupees; S.E(d) = standard error of difference; C.D. = critical difference.

Conclusion

The findings of this trial indicate that *Hirsutum* cotton genotype H-1300 raised with 125% of the recommended fertilizer dose (60:30:20 kg NPK/ha) together with 25% narrower row spacing and a foliar spray of 2% urea and 2% DAP represents the most productive, remunerative and cost-effective package for cotton cultivation in the Central Plain Zone of Uttar Pradesh.

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