International Journal of Agriculture and Nutrition

ISSN Print: 2664-6064
ISSN Online: 2664-6072
NAAS Rating (2026): 4.69
IJAN 2026; 8(7): 116-120
www.agriculturejournal.net
Received: 05-05-2026
Accepted: 10-06-2026

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Influence of planting density and fertilizer management on growth, productivity and quality parameters of upland cotton (*Gossypium hirsutum*) in Central U.P., India

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DOI: https://www.doi.org/10.33545/26646064.2026.v8.i7b.710

Abstract
Globally, cotton ranks among the most economically significant crops, making substantial contributions to the economies of numerous nations. Its cultivation extends across approximately 100 countries, with China, India, the United States, Pakistan, and Brazil collectively accounting for the largest share of world production; the crop underpins the textile sector by supplying raw fibrous lint. A field experiment was therefore conducted with hirsutum cotton genotype H-1300 during the Kharif season of 2024 at the Agriculture Farm of Swami Vivekanand Subharti University, Meerut, with the objective of evaluating the influence of plant spacing and fertilizer regimes on growth performance, yield attributes, total yield, fibre quality, and economic returns of hirsutum cotton. Seven treatment combinations were imposed, as follows: T_1 - control without fertilizer + normal spacing (67.5 × 30 cm); T_2 - 100% RDF + normal spacing; T_3 - 100% RDF + 25% less than normal spacing; T_4 - 125% RDF + 25% less than normal spacing; T_5 - 125% RDF + 25% less than normal spacing + soil application of ZnSO4; T_6 - 125% RDF + 25% less than normal spacing + foliar spray of 2% urea and 2% DAP; and T_7 - 125% RDF + 25% less than normal spacing + foliar spray of MgSO4 and ZnSO4. All treatments were laid out in a randomised block design replicated three times, with a standard inter-row spacing of 67.5 cm and an intra-row plant-to-plant distance of 30 cm. Treatment T_6 (125% RDF + 25% below standard spacing + foliar spray of 2% urea and 2% DAP) recorded the greatest improvements in all growth indices — plant height at 30, 60, 90, 120, and 150 DAS, monopodial and sympodial branch counts, and fresh as well as dry weight per plant — along with the highest yield attributes (boll number per plant, bolls per m², and individual boll weight), economic yields (seed cotton, lint, seed, and stick), and superior fibre quality scores (ginning out-turn and micronaire value). Fibre strength was highest under T_4 (125% RDF + 25% reduced spacing), while uniformity ratio did not differ significantly across treatments. The second-best performance was consistently delivered by T_7 (125% RDF + 25% below standard spacing + $MgSO_4$ + $ZnSO_4$ foliar spray). On the basis of these findings, it can be concluded that hirsutum cotton genotype H-1300 cultivated under an input combination of 125% RDF (60:30:20 kg NPK ha^{-1}), 25% reduced inter-plant spacing, and foliar application of 2% urea plus 2% DAP proved to be the most productive and economically rewarding option for cotton production in the Central Plain Zone of Uttar Pradesh.

Keywords: Cotton, planting density, fertilizer management, foliar nutrition, fibre quality, yield

Introduction
Among major field crops worldwide, cotton holds a position of outstanding economic relevance, supporting the livelihoods and trade balances of many developing and developed nations alike. The crop thrives in around 100 countries spanning tropical and subtropical belts; China, India, the United States, Pakistan, and Brazil are the dominant producers. As the primary source of natural textile fibre in the form of lint, cotton forms the backbone of the global textile and apparel industry; it is commercially cultivated across more than 80 countries. Domesticated cotton species used for commercial purposes fall into two broad categories — New World and Old World cotton — with the New World group further subdivided according to fibre characteristics.

Among the Old World diploid species, G. arboreum enjoys the widest cultivation, particularly in India, Pakistan, and several South-East Asian nations where it occupies the comparatively arid and less fertile tracts of Bangladesh, Myanmar, China, Sri Lanka, and Vietnam (Singh and Narayanan, 1991). Archaeological evidence from Mohenjo-daro indicates that cotton textile production in the Indian subcontinent has a history spanning approximately five millennia.

Cotton occupies a pivotal position in India's agricultural and industrial economy. Fibre quality — the central determinant of market value — is a complex trait governed by the interplay of mean fibre length, fineness, maturity, and tensile strength, together with physical attributes such as colour and ash content. These parameters collectively dictate downstream processing characteristics including yarn spinnability, dye uptake, yarn tensile strength, fabric lustre, and suitability for blending with synthetic fibres. Environmental and management stresses — drought, nutritional imbalances, seasonal variation, harvest timing, and pest and disease pressure — are well-recognised modulators of fibre fineness, maturity, and strength (Nanjundayya, 1960) [14]. Cotton productivity in India remains constrained by a cluster of agronomic and edaphic factors, including the prevalence of monoculture systems, progressive soil-fertility decline, delayed planting, and the burden of pests and diseases. Long-term continuous cropping combined with imbalanced fertilisation accelerates soil-fertility depletion (Mathur, 1997) [13]. Integrated use of organic manures alongside inorganic fertilisers has been shown to arrest this decline and sustain productive capacity.

Bt cotton hybrids offer considerable potential for wider adoption in India, yet a reassessment of their fertilisation strategies is warranted to match their yield potential (Venugopal, 2004) [24]. Since its commercial introduction in 2002, Bt technology has been embraced across the country. Adequate nutritional management is a key lever for enhancing cotton productivity, since meeting the crop's nutritional demands is prerequisite to realising high yields and superior fibre quality (Kalaichelvi, 2009; Kumar *et al*., 2011) [8,12]. Cotton's response to applied nutrients is mediated by a combination of environmental conditions and cultural practices; of all production inputs, fertilisation has shown the most consistent positive impact on yield. However, the ideal fertiliser dose is not universal — it is shaped by local soil characteristics and the prevailing agro-climatic regime. Simultaneous deployment of improved high-yielding genotypes and sound agronomic management — optimal plant populations, appropriately calibrated fertiliser doses, timely pest management, and efficient water and weed control — collectively drive productivity gains. Micronutrient delivery through foliar application has been recognised as an efficient route to better nutrient use efficiency and enhanced crop performance (Rathinavel *et al*., 1999) [19]; such sprays also stimulate seed-level biochemical activity, contributing to higher yields (Chaudhary *et al*., 2001) [4]. The peak nutritional requirement of cotton occurs during squaring, blooming, and boll development, and supplementing nutrient supply through foliar sprays at these critical windows can translate directly into yield improvement (Bhatt and Nathu, 1986) [2]. Accordingly, the present investigation was undertaken to optimise plant spacing and nutrient management for growth, yield components, total yield, and fibre quality in upland cotton.

Materials and Methods

The experiment was carried out with hirsutum cotton genotype H-1300 during the Kharif 2024 cropping season at the Agriculture Farm, Swami Vivekanand Subharti University, Meerut. Total annual precipitation at the site amounted to 650.6 mm, predominantly received from mid-June through the second week of September via the south-west monsoon, with intermittent off-season showers. The experimental soil was characterised as sandy loam with moderate inherent fertility, a pH of 7.8, low organic carbon content (0.48%), and medium availability of both phosphorus (16 kg ha^{-1}) and potash (183 kg ha^{-1}).

The seven treatment combinations were T_1 - unfertilised control at standard spacing (67.5 × 30 cm); T_2 - 100% RDF + normal spacing; T_3 - 100% RDF + 25% less than normal spacing; T_4 - 125% RDF + 25% less than normal spacing; T_5 - 125% RDF + 25% less than normal spacing + soil application of ZnSO4; T_6 - 125% RDF + 25% less than normal spacing + foliar spray of 2% urea and 2% DAP; and T_7 - 125% RDF + 25% less than normal spacing + foliar spray of MgSO4 and ZnSO4. The treatments were evaluated in a randomised block design with three replications. The normal spacing was maintained at 67.5 cm (row to row) and 30 cm (plant to plant).

Sowing was completed on 28 May 2024, and the crop was harvested in two picking operations on 25 October 2024 and 10 November 2024. Fertiliser application followed the treatment schedule: at sowing, 50% of the nitrogen dose together with the full complement of phosphorus and potassium was incorporated into the soil; the remaining nitrogen was split equally and top-dressed at 30 and 60 DAS. Appropriate crop-protection measures were enforced, with insecticide applications timed to actual pest pressure. Data on growth parameters, yield components, economic yield, and fibre quality traits were systematically recorded throughout the crop season, and bolls were picked selectively at full maturity.

The data were analysed statistically using the methods and tests of significance appropriate to the design (Cochran and Cox, 1950) [5]. Wherever the ‘F’ test in the analysis of variance revealed significant effects, summary tables giving treatment means with their standard errors were prepared, and appropriate critical differences (CD) were computed to test the significance between two treatments. Critical difference values at P = 0.05 were used to determine the significance of differences between means.

Results and Discussion

All measured vegetative parameters — plant stand count, plant height at 30, 60, 90, 120, and 150 DAS, monopodial and sympodial branch number per plant, and biomass (fresh and dry weight) — responded significantly to the imposed spacing and nutrient management regimes, with values trending upward as fertiliser rates increased (Table 1A). Among all treatments, T_6 (125% RDF + 25% reduced spacing + foliar 2% urea + 2% DAP) produced the tallest plants across every measurement date, surpassing all other treatments at each crop growth stage. A positive association between plant height and combined spacing-nutrition management has been similarly documented by Kaur *et al.* (2010) [9] and Sharma *et al.* (2004) [21]. The comparatively taller stature observed under closer plant spacing is attributed to inter-plant competition, which promotes upward elongation; conversely, wider spacing allows lateral spread and curtails vertical extension (Reddy and Kumar, 2010) [20].

The maximum monopodial branch count per plant was recorded under T_5 (125% RDF + 25% reduced spacing + soil $ZnSO_4$ application), which differed significantly from all other treatments (Table 1B). T_6 and T_7 ranked second and third, respectively, for monopodia per plant. An upward trend in sympodial branch number accompanied rising fertiliser doses at reduced spacing, with T_6 recording the highest sympodial count (13.47), though differences between treatments were not always statistically significant. The enhancement in both monopodia and sympodia under optimum nutritional conditions is likely attributable to the stimulatory effect of adequate mineral nutrition on meristematic activity, promoting cell division and elongation and, consequently, greater lateral branching. These observations align with earlier findings reported by Ram and Giri (2006) [16] and Kaur *et al*. (2010) [9].

Biomass accumulation per plant, both in terms of fresh and dry weight, was markedly influenced by fertiliser level in combination with plant spacing. The highest fresh and dry weight was registered under T_6, followed closely by T_7 ($MgSO_4$ + $ZnSO_4$ foliar spray). The observed biomass gains are attributable to heightened meristematic activity driven by optimal nutritional supply. Comparable trends have been documented by Jadhav *et al*. (2012) [7].

Treatment T_6 (125% RDF + 25% reduced spacing + foliar 2% urea + 2% DAP) registered significantly higher boll number per plant, boll density per m², and individual boll weight relative to treatments receiving lower fertiliser doses or standard spacing (Table 2). The second-highest yield attributes were associated with T_7 ($MgSO_4$ + $ZnSO_4$ foliar spray). The improvement in these yield components is a downstream consequence of the superior vegetative growth — enhanced plant height, greater branch production, and higher biomass — achieved under T_6. These findings are consistent with the results reported by Jadhav *et al*. (2012) [7].

Table 1A: Effect of spacing and nutrient management on growth parameters in *hirsutum* cotton

Treatments	No. of plants/plot	Plant population/ha	Plant height (cm)				
			30 DAS	60 DAS	90 DAS	120 DAS	150 DAS
T_1 - Control (no fertilizer) + normal spacing	62.33	38476.7	25.00	47.67	68.20	93.80	109.93
T_2 - 100% RDF + normal spacing	73.33	45308.7	27.47	50.00	73.87	97.93	117.53
T_3 - 100% RDF + 25% less than normal spacing	65.33	39683.3	28.00	51.13	72.40	96.53	114.80
T_4 - 125% RDF + 25% less than normal spacing	76.33	41285.0	29.80	51.80	74.20	99.40	118.13
T_5 - 125% RDF + 25% less than normal spacing + soil $ZnSO_4$ (20 kg/ha)	77.33	45285.0	30.20	52.73	75.13	101.13	120.23
T_6 - 125% RDF + 25% less than normal spacing + foliar 2% urea + 2% DAP	80.00	50724.3	31.60	56.00	77.47	105.20	124.60
T_7 - 125% RDF + 25% less than normal spacing + foliar MgSO4 (1%) + ZnSO4 (0.5%)	78.00	48504.3	30.26	55.27	76.13	102.33	122.13
S.E (d)	0.74	363.57	0.62	1.14	0.83	0.63	1.62
C.D. at 5%	1.61	792.15	1.34	2.48	1.82	1.37	3.52

Table 1B: Effect of spacing and nutrient management on growth parameters in *hirsutum* cotton

Treatments	Monopodia/plant	Sympodia/plant	Fresh weight/plant (g)	Dry weight/plant (g)
T_1 - Control (no fertilizer) + normal spacing	0.87	12.00	274.33	136.33
T_2 - 100% RDF + normal spacing	1.07	12.67	335.67	150.00
T_3 - 100% RDF + 25% less than normal spacing	0.93	13.00	333.33	145.33
T_4 - 125% RDF + 25% less than normal spacing	1.00	13.10	337.33	152.00
T_5 - 125% RDF + 25% less than normal spacing + soil $ZnSO_4$ (20 kg/ha)	1.40	13.20	346.67	153.00
T_6 - 125% RDF + 25% less than normal spacing + foliar 2% urea + 2% DAP	1.13	13.47	388.67	158.33
T_7 - 125% RDF + 25% less than normal spacing + foliar MgSO4 (1%) + ZnSO4 (0.5%)	1.23	13.27	349.00	155.67
S.E (d)	0.08	0.11	3.56	2.25
C.D. at 5%	0.17	0.24	7.76	4.89

Table 2: 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 (no fertilizer) + normal spacing	13.93	66.06	3.13
T_2 - 100% RDF + normal spacing	17.80	89.33	3.25
T_3 - 100% RDF + 25% less than normal spacing	15.87	80.76	3.25
T_4 - 125% RDF + 25% less than normal spacing	19.53	95.13	3.26
T_5 - 125% RDF + 25% less than normal spacing + soil $ZnSO_4$ (20 kg/ha)	21.13	98.52	3.33
T_6 - 125% RDF + 25% less than normal spacing + foliar 2% urea + 2% DAP	25.40	117.88	3.43
T_7 - 125% RDF + 25% less than normal spacing + foliar MgSO4 (1%) + ZnSO4 (0.5%)	23.47	102.29	3.39
S.E (d)	0.62	1.74	0.08
C.D. at 5%	1.35	3.80	0.17

Table 3: 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 25% (mm)	Micronaire value	Uniformity ratio (%)	Fibre strength (g/tex)
T_1 - Control (no fertilizer) + normal spacing	746.67	261.8	485.33	4384.0	35.02	26.7	4.77	80.0	25.47
T_2 - 100% RDF + normal spacing	1199.33	422.9	777.67	5142.7	35.20	25.6	4.30	80.0	26.23
T_3 - 100% RDF + 25% less than normal spacing	1144.00	404.2	740.33	4483.3	35.33	26.2	4.60	80.3	27.30
T_4 - 125% RDF + 25% less than normal spacing	1250.00	430.9	819.67	5504.3	34.47	25.4	4.63	80.0	28.30
T_5 - 125% RDF + 25% less than normal spacing + soil $ZnSO_4$ (20 kg/ha)	1257.00	429.9	827.67	5733.0	34.20	26.1	4.47	79.7	27.50
T_6 - 125% RDF + 25% less than normal spacing + foliar 2% urea + 2% DAP	1391.62	487.5	902.60	6388.7	35.63	26.2	4.83	80.0	26.37
T_7 - 125% RDF + 25% less than normal spacing + foliar MgSO4 (1%) + ZnSO4 (0.5%)	1259.33	448.0	811.67	5818.7	35.60	25.5	4.43	80.0	27.70
S.E (d)	58.65	19.80	39.10	46.22	0.18	0.13	0.78	0.78	0.14
C.D. at 5%	127.79	43.14	85.20	100.70	0.39	0.27	NS	NS	0.30

RDF = recommended dose of fertilizers; DAS = days after sowing; S.E (d) = standard error of the difference; C.D. = critical difference; NS = non-significant.

Seed cotton yield under T_6 (125% RDF + 25% reduced spacing + foliar 2% urea + 2% DAP) was significantly the highest, representing an 86.38% advantage over the unfertilised control at standard spacing (Table 3). The $MgSO_4$ + $ZnSO_4$ foliar treatment (T_7) also produced a significantly elevated seed cotton yield. Lint yield followed the same pattern, with the highest value recorded under the urea + DAP foliar spray. Cotton-seed and stick yields were likewise augmented by elevated fertiliser doses, while all yield fractions were at their nadir in the unfertilised control. The yield increments with higher fertilisation levels are largely a reflection of improved vegetative vigour and better-expressed yield components. Consistent results have been reported by Bhattoo *et al*. (2012) [3]. Raskar (2004) [18] documented that escalating fertilisation from 50% to 100% RDF produced progressively greater seed cotton yields, with 100% RDF outperforming 50% and 75% RDF by 31.71% and 10.16%, respectively. The superiority of 100% RDF over reduced rates (75% and 50%) for seed cotton and cotton-seed yield was further corroborated by Kote *et al.* (2005) [10], in agreement with Bhaskar (1993) [1]. At the spacing management level, significantly higher seed cotton output under wider inter-plant distances has also been noted by Kumar *et al*. (2010) [11].

Fibre and processing quality traits — ginning out-turn, span length, fibre strength, micronaire value, and uniformity ratio — were all significantly modulated by the fertilisation and spacing regimes evaluated (Table 3). Among treatments, T_6 (125% RDF + 25% reduced spacing + foliar 2% urea + 2% DAP) achieved the highest ginning out-turn (35.63%), closely followed by T_7 (35.60%), with T_3, T_2, and T_1 occupying the intermediate positions and T_4 and T_5 recording the lowest values (34.47% and 34.20%, respectively). In contrast, span length was greatest under the unfertilised control at standard spacing, declining with increasing fertilisation. Micronaire value was highest under T_6 (4.83), followed by the control T_1 (4.77). Uniformity ratio did not differ significantly across treatments (CD = NS), with values ranging narrowly from 79.7% (T_5) to 80.3% (T_3). The lowest overall fibre quality expression, particularly for micronaire and fibre strength, was associated with the unfertilised control. Fibre strength was highest under T_4 (28.30 g/tex), followed by T_7 (27.70 g/tex) and T_5 (27.50 g/tex); T_6 ranked fifth (26.37 g/tex), suggesting that very high fertiliser doses with foliar nitrogen supplementation do not necessarily optimise fibre tensile properties. These outcomes concur with observations reported by Srinivasula *et al*. (2007) [23]. Rao and Janawade (2009) [17] similarly recorded progressive increases in ginning out-turn and lint index as RDF application rose from 50% through 75% to 100%.

Conclusion

The results of the present study collectively demonstrate that hirsutum cotton genotype H-1300, when grown under an input regime comprising 125% RDF (60:30:20 kg NPK ha^{-1}) combined with 25% below-standard plant spacing and foliar supplementation of 2% urea plus 2% DAP, consistently delivered the highest productivity and the best economic returns among all treatment combinations evaluated in the Central Plain Zone of Uttar Pradesh. This treatment combination is therefore recommended for adoption by cotton growers in this agro-climatic region.

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