PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol x(x): xx–xx
https://doi.org/10.14719/pst.6779

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RESEARCH ARTICLE

Effect of nutrient management practices on growth, yield attributes and yield of coloured cotton (*Gossypium hirsutum* L.)

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OPEN ACCESS

ARTICLE HISTORY
Received: 18 December 2024
Accepted: 07 February 2025
Available online
Version 1.0 : 05 March 2025

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
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CITE THIS ARTICLE
Selvakumar S, Ragavan T, Gurusamy A, Gunasekaran M, Sivakumar T, Prabhaharan J, Thiruppathi M, Subramanian E, Arthirani B, Rani S. Effect of nutrient management practices on growth, yield attributes and yield of coloured cotton (*Gossypium hirsutum* L.). Plant Science Today (Early Access). https:/doi.org/10.14719/pst.6779

Abstract

The field experiment was carried out at the Central Farm, AC &RI (Agricultural College and Research Institute), TNAU, Madurai, Tamil Nadu during *Kharif* season 2024. The study aimed to evaluate the effects of different nutrient management strategies on the growth, yield components and productivity of coloured cotton. The experiment followed a randomized block design (RBD) with nine treatments based on nitrogen equivalence, incorporating different organic manures in comparison to inorganic fertilizers, with each treatment replicated three times. The results revealed that growth parameters such as plant height, dry matter production, leaf area index, chlorophyll content, number of monopodial branches plant^{-1}, days to 50% flowering and days to 50% boll bursting were significantly enhanced by the application of 100% NPK based on site-specific recommendation (T_2), which statistically at par with 100% NPK through blanket recommendation (T_1). Yield attributes including number of fruiting branches plant^{-1}, number of fruiting points plant^{-1}, number of bolls plant^{-1}, number of bolls m^{-2}, boll setting percentage and boll weight, along with seed cotton yield, lint cotton yield, stalk yield and biological yield, which also showed a significant increase with the application of 100% NPK through site-specific recommendation (T_2). Organic treatments, including the complete organic package (T9), cover cropping with 75% N through vermicompost (T4) and cover cropping with 75% N through poultry manure (T5), exhibited comparable results to inorganic treatments. Future research should focus on optimizing organic nutrient management strategies and integrating cover crops to enhance soil health and ensure sustainable cotton production.

Keywords

coloured cotton; growth; manures; nutrient management; N equivalent; yield

Introduction

Cotton (*Gossypium sp*.), synonymously referred as "White Gold" and popularly hailed as "the King of Fibers," is one of the most significant cash crops both nationally and globally (1, 2). In India, cotton plays a crucial role in agriculture, industrial growth and job creation. It accounts for approximately 1.5% of the national Gross Domestic Product and 7.1% of agricultural value addition (3-5), while supporting the livelihoods of about 5.8 million farmers and sustaining approximately 50 million individuals through its production, processing and trade (6, 7). It is also affectionately referred as the "Friendly Fiber" due to its significant contributions to employment generation and foreign exchange (8).

Globally, cotton is cultivated across 31.01 million hectares, yiedling 41.41 million tonnes annually with an average productivity of 1.34 tonnes per hectare. India leads in cotton cultivation, accounting for approximately 40.95% of the global cotton-growing area. In India, cotton is grown on approximately 12.70 million hectares with an annual production of 10.83 million tonnes, contributing around 26.16% to global production. However, India's cotton productivity remains relatively low, with an average seed cotton yield of 850 kg/ha and lint cotton yield of 439 kg per hectare (9). In Tamil Nadu, cotton is grown on approximately 0.15 million hectares, producing 0.36 million bales annually with an average seed cotton yield of 753 kg per hectare and lint cotton yield of 388 kg per hectare (10).

The rising costs of fertilizers (N, P_2O_5 and K_2O) and the ongoing energy crisis have increased production costs and limited fertilizer availability in agriculture. While high-input technologies have boosted crop yields and efficiency, they raise concerns about soil health and environmental sustainability. In India, cotton farming accounts for over 55% of agrochemical use (11), contributing to soil degradation, water pollution and biodiversity loss. As a result, organic cotton cultivation is gaining attention as a sustainable alternative, emphasizing soil health, biodiversity and environmental conservation. Globally, organic cotton is cultivated on 0.62 million hectares of certified land and 0.29 million hectares of in-conversion land, producing 0.34 million tonnes each. It is grown in 21 countries, with eight countries (India-38%, Turkey-24%, China-10%, Kyrgyzstan-9%, Tanzania-6%, Kazakhstan-4%, Tajikistan-4% and the US-2%) accounting for 97% of the global organic cotton production. The remaining 13 countries contribute 3% (12).

Indian government in partnership with the textile industry, is promoting the cultivation of coloured cotton through ongoing research. Recent advancements show potential for improving its productivity, staple length and fiber strength to meet white cotton's textile standards. At present, colored cotton is cultivated on approximately 200 acres in areas such as Dharwad in Karnataka, Coimbatore in Tamil Nadu, Vidarbha in Maharashtra and Guntur in Andhra Pradesh, yielding around 330 quintals annually (13). In contrast, organic white cotton typically undergoes chemical dyeing, which leads to environmental concerns including water contamination, hazardous waste generation and adverse impacts on the well-being of farmers and nearby communities. Naturally coloured cotton offers a sustainable alternative by reducing dye use, minimizing pollution and lowering processing costs. It also requires less water and energy. However, naturally coloured cotton has shorter fibers and is less profitable than white cotton. If coloured cotton is priced higher than white cotton, it could offset the lower production costs of the fabric (14, 15).

Nitrogen is the primary nutrient absorbed by cotton and plays a critical role in influencing the growth cycle, maturity, yield and fiber quality (16-18). Supplementing nitrogen enhances various physiological aspects of the plant such as chlorophyll and carotenoid levels, electron transport rate, free amino acids, soluble proteins, specific leaf nitrogen and stomatal conductance. These factors are strongly linked to the overall growth, yield and fiber quality characteristics of cotton (19). Organic nutrient management strategies including complete organic packages and the integration of cover crops with vermicompost, poultry manure and farmyard manure (based on N-equivalence) offer viable alternatives to inorganic treatments like site-specific and blanket recommendations. This study aims to assess the impact of different nutrient management strategies on the growth, yield characteristics and overall productivity of colored cotton.

Materials and Methods

Study location and Meteorological Parameters

The field trial was carried out during the *Kharif* season of 2024 at AC&RI (Agricultural College and Research Institute), TNAU, Madurai, Tamil Nadu. The site is situated in the SACZT (Southern Agroclimatic Zone of Tamil Nadu) at a latitude of 9°54'N and longitude of 78°54'E with an elevation of 147 meters above sea level. This region experiences a tropical climate with an average annual rainfall of 849 mm. During the cropping season (*Kharif* 2024), the average maximum and minimum temperatures were recorded at 35.26°C and 26.39°C, respectively. The relative humidity levels were 84.15% in the morning (07:22 hrs) and 61.22% in the afternoon (14:22 hrs) (Fig. 1).

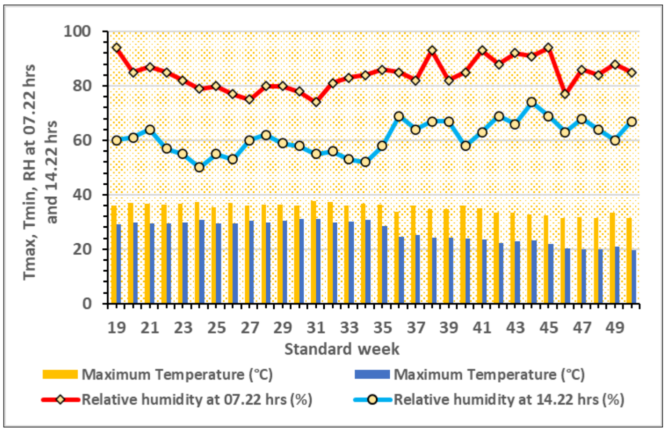

Fig. 1. Weather parameters prevailed during *Kharif* 2024.

Study Design and Treatment Specifications

The field trial was conducted using a RBD (Randomized Block Design) with 9 treatments and three replications during the *Kharif* season of 2024. Each plot had a total size of 5.4 × 4.5 m, with the net plot measuring 3.6 × 2.7 m. Treatments were randomly assigned within each replication to reduce experimental errors and ensure accurate results. Treatment details are shown in Table 1.

Preliminary Soil Analysis

Composite soil samples were randomly collected from the experimental field prior to the initiation of the study. These pre-sowing soil samples were air-dried, ground, sieved (2 mm) and processed for the analysis of primary physico-chemical properties (Table 1) including soil texture, pH, EC (Electrical conductivity), OC (Organic carbon), organic matter and available N (Nitrogen), P (Phosphorus) and K (Potassium). Standard analytical methods were employed for soil characterization including texture was determined

Table 1. Treatment details

	Treatments
T_1:	100% NPK (Blanket recommendation of inorganic nutrients)
T_2:	100% NPK (Based on site specific recommendation)
T_3:	Cover crop + 75% N through Farm yard manure (N equivalent)
T_4:	Cover crop + 75% N through Vermicompost (N equivalent)
T_5:	Cover crop + 75% N through Poultry manure (N equivalent)
T_6:	Green manure + 75% N through Farm yard manure (N equivalent)
T_7:	Green manure + 75% N through Vermicompost (N equivalent)
T_8:	Green manure + 75% N through Poultry manure (N equivalent)
T_9:	Complete organic package (Cover crop + Organic manure + Biofertilizers + Bio agents + Foliar spray)

*100% NPK (Blanket recommendation of inorganic nutrients) - (80: 40: 40 NPK kg ha^{-1})

100% NPK (Based on site specific recommendation) - (100: 40: 30 NPK kg ha^{-1})

Cover crop - Cowpea; Green manure - Sunhemp; Organic manure - Vermicompost; Biofertilizers - Azospirillum and Phosphobacteria

Bio agents - *Pseudomonas flurescens* and *Trichoderma viride;* Foliar spray - Pink pigmented facultative methylotrophs

using Robinson's International pipette method (20), pH was measured with an "ELICO" pH meter (21) and EC was assessed using an "ELICO" conductivity bridge (21). Available N was estimated by the alkaline $KMnO_4$ (alkaline permanganate method) (22), available P using the Olsen colorimetric method (23) and available K through extraction with neutral $NH_4C_2H_3O_2$ (normal ammonium acetate) (24). OCC (Organic carbon content) was determined by the H_2CrO_4 (Chromic acid) wet digestion method (25) and SOM (soil organic matter) was estimated by multiplying the organic carbon value by a factor of 1.724 (25).

Management of agronomic practices

The field was prepared to a fine tilth and the coloured cotton variety Vaidehi 1 (dark brown) was selected as the seed material. Cowpea (*Pusa 152*) was used as a cover crop, while Sunhemp (*ADT 1*) was grown as green manure, both of which were incorporated into the soil at the 50% flowering stage (45 days after sowing) by using power tiller. Cotton seeds were sown by dibbling to a depth of 3 cm and using a seeding rate of 6 kg per hectare with a spacing of 90 × 45 cm. Standard agronomic practices such as managing irrigation, performing intercultural operations and implementing plant protection measures were carried out based on the recommendations provided in (26).

Implementation of Treatments

***Application of inorganic fertilizers*:** Inorganic fertilizers were applied according to the recommended schedule 80:40:40 kg of N, P_2O_5 and K_2O ha^{-1} equivalent to 100% NPK. N, P and K were provided using urea (46% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O), respectively. The complete application of N, P_2O_5 and K_2O was made as a basal as a basal dose before sowing the crop. The nutrient status of the experimental soil was assessed before the initiation of experiment field and the soil showed low available nitrogen, medium available phosphorus and high available potassium. Under the site-specific nutrient management approach, adjustments were made to standardize the nutrient availability to medium levels across all nutrients. Nitrogen was increased by 25%, while potassium was reduced by 25%, resulting in a revised site-specific recommendation of 100:40:30 kg ha^{-1} for N, P and K. The quantity of both blanket and site-specific recommendations of inorganic nutrients are detailed in Table 2.

***Application of organic manures*:** Required quantities of well decomposed organic manures like FYM (Farm yard manure), VC (Vermicompost) and PM (Poultry manure) were applied and mixed into the soil at one day before sowing as per recommended treatment plots on the basis of 75% of N equivalent to that of recommended dose of nitrogen (RDN) on dry weight basis. The quantity of organic manures prevailed in Table 3. Biofertilizers including *Azospirillum* and *Phosphobacteria* (2 kg ha^{-1}) along with biocontrol agents (*Trichoderma viride* and *Pseudomonas fluorescens* @ 2.5 kg ha^{-1}) were applied to the soil at the basal level. During the FL and BD (Flowering and Boll development) stages, a foliar spray of PPFM (1%) was applied at a rate of 5 liters per hectare.

Data recorded

***Growth parameters*:** From each treatment plot, five tagged plants were randomly chosen to assess growth characteristics including PH (plant height), DMP (dry matter production), LAI (leaf area index) at flowering (LAI at FL), Chlorophyll content at flowering, NMB/P (number of monopodial branches per plant) and the number of days required for 50% FL (50% flowering) and 50% BB (50% boll bursting).

The plant height was recorded from the cotyledonary node to the tip of the last fully opened leaf using a linear meter scale. Leaf area including leaf length and width was documented from 5 tagged plants and the average was presented in cm. The collected plant samples were first dried in the air and then oven-dried at 80 ± 5°C until they attained a constant weight. DMP (Dry matter production)

Table 2. The primary physico-chemical properties of the experimental soil during *kharif* 2024

Season	pH	EC (dS m^{-1})	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	OC (%)	OM	Textural class
Kharif 2024	8.1	0.18	235.12	17.01	330.52	0.62	1.07	Sandy clay loam

(*EC- Electrical conductivity/ N- Nitrogen/ P-Phosphorus/ K- Potassium/ OC- Organic carbon/ OM- Organic matter)

Table 3. Quantity of blanket and site-specific recommendation of inorganic nutrients - (100% RDF: 80: 40: 40 NPK kg ha^{-1})

Treatments	Inorganic nutrients (kg ha^{-1})		
	N (Urea)	P_2O_5 (SSP)	K_2O (MOP)
T_1 - 100% NPK (Blanket recommendation) (80: 40: 40 NPK kg ha^{-1})	173.91	250.00	66.66
T_2 - 100% NPK (Based on site specific recommendation) (100: 40: 30 NPK kg ha^{-1})	217.39	250.00	50.00

was quantified using an electronic top pan balance and the average value was recorded in kilogram per hectare. Chlorophyll content (SPAD value) was evaluated using a Chlorophyll meter (SPAD-502) from the lower, middle and upper leaves of five randomly chosen tagged plants at the flowering stage and the mean SPAD value was determined (27). The D 50% FL (Days to 50% flowering) denote the duration from sowing to when half of the plants have bloomed, while the D 50% FL (Days to 50% boll bursting) indicate the time from sowing until 50% of the plants show boll bursting. The LAI (Leaf area index) was calculated using the formula provided by (28).

$$\text{LAI} = \frac{\text{L x W x CF x NL x NP}}{\text{Ground Area}} \quad \text{(Eqn. 1)}$$

Where,

[*LA- Leaf area (cm^2), L- Length of the leaf (cm), W- Width of the leaf (cm), CF- Correction factor (0.78), NL- Number of leaves per plant, NP- Number of plants per unit area].

***Yield attributes and yield*:** The NFP/P (Number of fruiting points per plant) was recorded at 30 days intervals, beginning from the square formation stage (30 Days after sowing) until harvest (150 Days after sowing). Similarly, the cumulative counts of NB/P (Number of bolls per plant) and NB/m^2 (Number of bolls per square meter) were recorded for tagged plants in each treatment from the BF (boll formation stage) (60 Days after sowing) to harvest (150 Days after sowing) at 30 days intervals. The averages were calculated and recorded as numerical values.

***Boll weight*:** During the first harvest, 10 mature and open bolls (seed cotton) were randomly selected from the five tagged plants in each treatment plot to estimate boll weight. The average weight per boll was calculated by dividing the total seed cotton weight from the 10 bolls by 10, with the result presented in grams.

***Boll setting percentage*:** The boll setting percentage (BS %) represents the ratio of bolls formed to total fruiting points and expressed as a percentage. The calculation of boll setting percentage was done using the formula

$$\text{BS \%} = \frac{\text{Number of bolls plant}^{-1}}{\text{Number of squares (fruiting points) plant}^{-1}} \times 100 \quad \text{(Eqn. 2)}$$

***Seed cotton yield*:** Seed cotton yield was computed from each net plot area wise at each picking. The picked seed cotton was shade dried for 4 hours and weighed. The total yield was computed and expressed as kg ha^{-1}.

***Stalk yield*:** Following the final harvest, cotton stalks were cut at ground level, gathered from each plot and air-dried in the field to reduce moisture content. Once dried, the stalks were weighed and the stalk yield was computed and expressed in kg ha^{-1}.

***Biological yield*:** Biological yield represents the total biomass of the crop obtained by adding seed cotton yield and stalk yield and is expressed in kg ha^{-1}.

***HI (Harvest index)*:** The HI (Harvest index) was computed as the ratio of economic yield (seed cotton yield) to biological yield (the sum of seed cotton yield and stalk yield), following the formula outlined by (29).

$$\text{HI (Harvest index)} = \frac{\text{Economic yield (kg ha}^{-1})}{\text{Biological yield (kg ha}^{-1})} \times 100 \quad \text{(Eqn. 3)}$$

***Lint percentage*:** The L% (Lint percentage) was computed as the proportion of LCY (lint cotton yield) to the total SCY (Seed cotton yield) with the result recorded as a percentage.

$$\text{L \% (Lint percentage)} = \frac{\text{Lint cotton yield (kg ha}^{-1})}{\text{Seed cotton yield (kg ha}^{-1})} \times 100 \quad \text{(Eqn. 4)}$$

Statistical analysis

All evaluated traits were subjected to analysis of variance (ANOVA) using R Studio (version 4.2.1) on a Windows (30). Significant differences between means were assessed using Fisher's LSD (Least Significant Difference) test at a 5% level with non-significant results marked as 'NS' (31). Boxplots were used to depict the effect of diverse nutrient management strategies on coloured cotton yield, while trait relationships were analyzed using Pearson correlation coefficients. The boxplots were generated with KAU GRAPES (v.1.1.0) (General R-based Analysis Platform Empowered by Statistics).

Results

Growth parameters

The growth parameters of colored cotton including PH (Plant height), DMP (Dry matter production), LAI at FL (Leaf area index at flowering), Chlorophyll content at flowering, NMB/P (Number of monopodial branches per plant) and the number of days required for 50% flowering (D 50% FL) and 50% boll bursting (D 50% BB) were significantly influenced by various nutrient management practices (Table 5).

Significant differences in plant height at the harvest stage (150 DAS) were observed across various nutrient management practices (Table 4). The site-specific application of 100% NPK (100:40:30 kg ha^{-1}) (T_2) achieved the maximum plant height of 147.39 cm during the *Kharif* 2024. This was statistically on par with the application of 100 % NPK through blanket recommendation (80:40:40 kg ha^{-1}) (T_1). These were followed by the complete organic package (131.21 cm) along with other organic treatments during the same season.

The DMP (Dry matter production) of coloured cotton at the harvest stage (150 days after sowing) was significantly affected by various nutrient management strategies (Table 4). During the *Kharif* 2024 season, the highest dry matter production (DMP) values were recorded under the application of 100% NPK based on site-specific (T_2) and blanket (T_1) recommendations achieving 4191 and 4142 kg ha^{-1}, respectively. These were followed by the complete organic

Table 4. Quantity of different organic manures - (100% RDF: 80: 40: 40 NPK kg ha^{-1})

Organic manures	Quantity (kg ha^{-1})		
	N content (%)	100% N	75% N
Farm yard manure	0.39	20513	15385
Vermicompost	1.85	4324	3243
Poultry manure	2.55	3137	2353

Table 5. Effect of nutrient management practices on growth parameters (PH, DMP, LAI, SPAD value, MB/P, D 50% FL and D 50% BB) of coloured cotton during *Kharif* 2024

Treatments	PH (cm)	DMP (kg ha^{-1})	LAI at FL	Chl. C at FL	NMB/P	D 50% FL	D 50% BB
T_1	143.97	4142	0.559	50.72	2.08	53.94	121.61
T_2	147.39	4191	0.591	51.52	2.13	54.04	122.84
T_3	124.12	3344	0.485	46.72	1.71	50.00	114.89
T_4	129.04	3520	0.502	48.32	1.78	50.97	115.22
T_5	126.79	3380	0.49	47.22	1.75	50.28	114.99
T_6	106.23	2795	0.408	43.72	1.36	46.21	108.22
T_7	111.25	2919	0.427	44.52	1.48	47.20	108.58
T_8	109.55	2840	0.42	44.32	1.41	46.66	108.31
T_9	131.21	3599	0.504	48.52	1.82	51.11	115.28
SEd	5.65	199.88	0.025	0.99	0.10	1.07	2.93
CD (P=0.05)	11.97	423.72	0.053	2.10	0.22	2.28	6.21
Mean	110.93	3014.56	0.43	41.90	1.52	44.37	101.63
CV	5.51	7.16	6.31	2.56	7.36	3.50	3.13

(*PH- Plant height/ DMP- Dry matter production/ LAI at FL- Leaf area index at flowering/ Chl. C at FL- Chlorophyll content at flowering/ NMB/P- Number of monopodial branches per plant/ D 50% FL- Days to 50% flowering/ D 50% BB- Days to 50% Boll bursting)

package (T_9) and along with other organic treatments during the same season.

The nutrient management practices exhibited significant differences in the LAI (Leaf Area Index) and Chlorophyll content during the FL (Flowering stage) (Table 4). Among the treatments, the application of 100% NPK through site-specific recommendation (T_2) recorded the highest LAI of 0.591 and Chlorophyll content of 51.52 at the flowering stage during *Kharif* 2024. This was statistically comparable to the application of 100% NPK through blanket recommendation (80:40:40 kg ha^{-1}) (T_1). These were followed by the complete organic package (T_9) registered LAI of 0.504 and Chlorophyll content of 48.52 at the flowering stage and along with other organic treatments during the respective season.

The NMB/P (Number of monopodial branches per plant) was significantly influenced by the different nutrient management practices of coloured cotton (Table 4). The highest number of monopodial branches per plant (NMB/P) was recorded with the application of 100% NPK through site -specific (100:40:30 kg ha^{-1}) (T_2) and blanket (80:40:40 kg ha^{-1}) (T_1) recommendations at rates of 2.13 and 2.08 branches plant^{-1}, respectively. These were closely followed by the complete organic package (T_9) with 1.82 branches plant^{-1} and all other organic treatments recorded comparatively lower values during the *Kharif* 2024.

The D 50% FL (Days to 50% flowering) and D 50% BB (Days to 50% boll bursting) were significantly influenced by different nutrient management practices of coloured cotton (Table 4). The application of 100% NPK based on site-specific recommendation (100:40:30 kg ha^{-1}) (T_2) recorded the maximum days to 50% flowering of 54.04 days and days to 50% boll bursting of 122.84 days during the *Kharif* 2024. These results were statistically similar to those obtained with the application of 100% NPK based on blanket recommendation (80:40:40 kg ha^{-1}) (T_1). Both inorganic treatments showed comparable results and significantly outperforming of complete organic package (T_9) and other organic nutrient management treatments in the respective growing

Yield attributes

The yield attributes of coloured cotton such as the NSB/P (Number of sympodial branches per plant), NFP/P (Number of fruiting points per plant), NB/P (Number of bolls per plant), NB/m² (Number of bolls per square meter), BS% (Boll setting percentage) and BW (Boll weight) were significantly influenced by the various nutrient management practices (Table 6).

Sympodial branches are key structures that support the reproductive organs of the cotton crop and their development is affected by agronomic practices including nutrient management strategies. The NSB/P (Number of sympodial branches per plant) in coloured cotton showed significant variation under different nutrient management practices (Table 5). The coloured cotton crop treated with 100% NPK based on site-specific recommendation (22.61 SB plant^{-1}) and blanket recommendation (22.49 SB plant^{-1}) practices recorded the highest number of sympodial branches per plant (NFB plant^{-1}) followed by the complete organic package (T_9) (20.31 SB plant^{-1}), cover crop with vermicompost on an N-equivalent basis (T_4) (20.17 SB plant^{-1}) and other organic nutrient management treatments during the *Kharif* 2024.

The NFP/P (Number of fruiting points per plant) in coloured cotton was significantly affected by the different nutrient management practices (Table 5). Among these practices, the highest number of fruiting points was recorded with the application of 100% NPK based on site-specific recommendation (T_2) with 70.31 FP plant^{-1} and blanket recommendation (T_1) with 69.87 FP plant^{-1} during the *Kharif* 2024. These were followed by the complete organic package (T_9) (64.36 FP plant^{-1}), cover crop with vermicompost on an N-equivalent basis (T_4) (64.19 FP plant^{-1}) and other organic nutrient management treatments during the same season.

Boll characteristics play a vital role in determining seed cotton yield. Different nutrient management practices significantly influenced boll traits, such as the NB/P (Number of bolls per plant), NB/m² (Number of bolls per square meter),

Table 6. Effect of nutrient management practices on yield attributes (SB/P, FP/P, Bolls/P, Bolls/m², BS % and BW) of coloured cotton during *Kharif* 2024

Treatments	NSB/P	NFP/P	NB/P	NB/m²	BS %	BW (g)
T_1	22.49	69.87	28.31	69.93	40.51	3.44
T_2	22.61	70.31	28.52	70.44	40.56	3.49
T_3	19.17	63.87	24.08	59.48	37.70	3.07
T_4	20.17	64.19	24.52	60.56	38.20	3.13
T_5	19.49	63.92	24.19	59.75	37.84	3.1
T_6	16.59	60.03	21.04	51.97	35.05	2.69
T_7	17.10	60.15	21.20	52.36	35.25	2.77
T_8	16.84	60.09	21.12	52.17	35.14	2.72
T_9	20.31	64.36	24.59	60.74	38.21	3.15
SEd	0.97	1.62	1.32	3.30	1.08	0.12
CD (P=0.05)	2.05	3.44	2.79	7.00	2.29	0.26
Mean	17.16	56.94	21.44	52.96	33.36	2.71
CV	6.10	3.10	6.66	6.78	3.51	5.02

(*NSB/P- Number of sympodial branches per plant/ NFP/P- Number fruiting points per plant/ NB/P- Number of bolls per plant/ NB/ m²- Number of bolls per square meter/ BS %- Boll setting percentage/ BW- Boll weight)

BS% (Boll setting percentage) and BW (Boll weight) in coloured cotton (Table 5). The application of 100% NPK based on site-specific recommendation (100:40:30 kg ha^{-1}) (T_2) resulted in the highest values for boll traits during *Kharif* 2024 including the number of bolls per plant (28.52 B plant^{-1}), bolls per square meter (70.44 B plant^{-1}), boll setting percentage (40.56%) and an average boll weight of 3.49 g. This performance was on par with 100% NPK applied through blanket recommendation (80:40:40 kg ha^{-1}) (T_1). Both inorganic treatments demonstrated comparable results and significantly outperformed the complete organic package (T_9) as well as other organic nutrient management treatments during the respective growing season.

Yield

SCY (Seed cotton yield), LCY (Lint cotton yield), SY (Stalk yield) and BY (Biological yield) of coloured cotton were significantly influenced by various nutrient management strategies (Table 7 and Fig. 2-4).

The SCY (Seed cotton yield) and LCY (Lint cotton yield) of coloured cotton were significantly influenced by the nutrient management practices (Table 6 and Fig. 2, 3). The highest SCY (Seed cotton yield) of 2099 kg ha^{-1} and lint cotton yield of 770.54 kg ha^{-1} were recorded with the application of 100% NPK based on site-specific recommendation (100:40:30 kg ha^{-1}) (T_2) during the *Kharif* 2024. This performance was statistically comparable to the application of 100% NPK through blanket recommendation (80:40:40 kg ha^{-1}) (T_1). These were followed by the complete organic package (T_9) achieved the SCY (Seed cotton yield) of 632.43 kg ha^{-1} and LCY (Lint cotton yield) of 625.13 kg ha^{-1} was outperforming to other organic treatments in the same season.

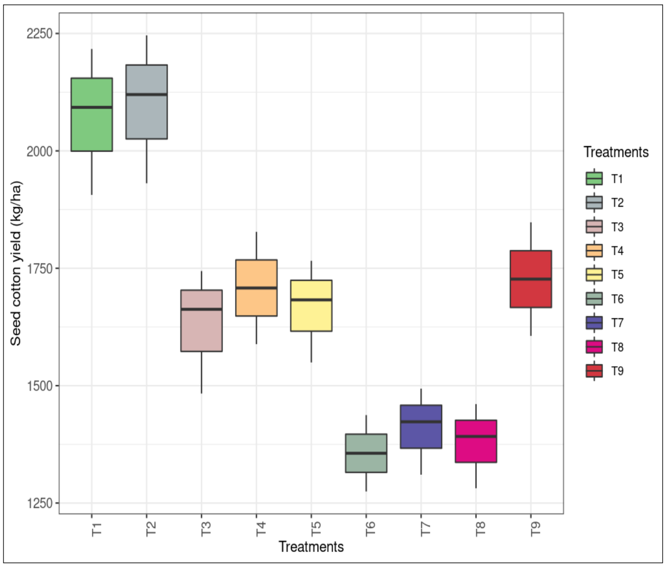

Fig. 2. Effect of nutrient management practices on seed cotton yield (kg ha^{-1}) of coloured cotton during *Kharif* 2024.

The SY (Stalk yield) was significantly influenced by the different nutrient management strategies (Table 6 and Fig. 4). The highest stalk yields of 5504 kg ha^{-1} and 5442 kg ha^{-1} were recorded with the inorganic treatments including 100% NPK based on site-specific (100:40:30 kg ha^{-1}) (T_2) and blanket (80:40:40 kg ha^{-1}) (T_1) recommendations, respectively during

Table 7. Effect of nutrient management practices on yield (SCY, LCY, SY, BY and HI) of coloured cotton during *Kharif* 2024

Treatments	SCY (kg ha^{-1})	LCY (kg ha^{-1})	SY (kg ha^{-1})	BY (kg ha^{-1})	HI	Lint %
T_1	2072	758.97	5442	7514	0.276	36.63
T_2	2099	770.54	5504	7603	0.276	36.71
T_3	1630	595.93	4511	6141	0.265	36.56
T_4	1708	625.13	4645	6353	0.269	36.60
T_5	1666	609.59	4585	6251	0.267	36.59
T_6	1356	494.26	3821	5177	0.262	36.45
T_7	1409	514.29	3927	5336	0.264	36.50
T_8	1378	502.69	3850	5228	0.264	36.48
T_9	1727	632.43	4677	6404	0.270	36.62
SEd	102.41	37.68	269.31	367.72	0.012	1.6
CD (P=0.05)	217.10	79.88	570.92	779.53	NS	NS
Mean	1479.78	541.27	4031.67	5511.44	0.24	32.50
CV	7.50	7.54	7.24	7.23	5.35	5.3

(*SCY- Seed cotton yield/ LCY- Lint cotton yield/ SY- Stalk yield/ BY- Biological yield/ HI- Harvest index)

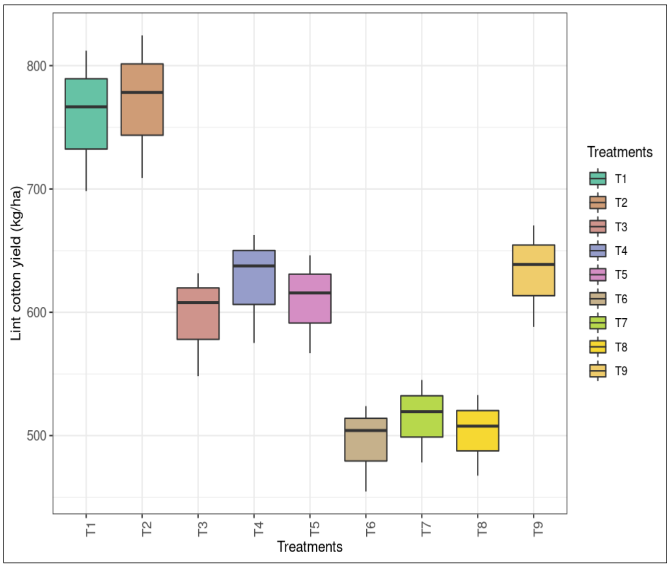

Fig. 3. Effect of nutrient management practices on lint cotton yield (kg ha^{-1}) of coloured cotton during *Kharif* 2024.

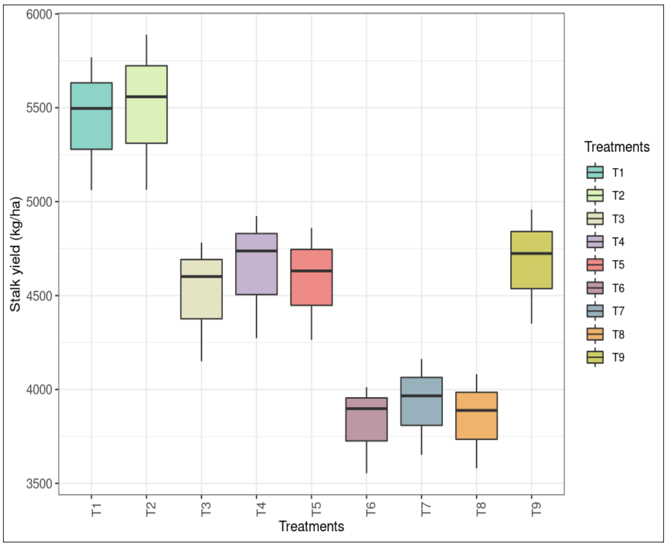

Fig. 4. Effect of nutrient management practices on stalk yield (kg ha^{-1}) of coloured cotton during *Kharif* 2024.

the *kharif* 2024. These were followed by the complete organic package (T_9) (4677 kg ha^{-1}), cover crop incorporation with vermicompost on an N-equivalent basis (T_4) (4645 kg ha^{-1}) and along with all other organic treatments throughout the *Kharif* 2024.

BY (Biological yield) was significantly influenced by the various nutrient management practices (Table 6). Among the nutrient management practices, the application of 100% NPK based on site-specific (T_2) (7603 kg ha^{-1}) and blanket (T_1) (7514 kg ha^{-1}) recommendations showed superior performance in terms of the biological yield (BY) during the *Kharif* 2024. These were followed by the complete organic package (T_9) (6404 kg ha^{-1}), cover crop with vermicompost on an N-equivalent basis (T_4) (6353 kg ha^{-1}) and along with all other organic treatments throughout the respective season. However, no significant differences were observed in the HI (Harvest index) and L% (lint percentage) among the different nutrient management practices for coloured cotton (Table 6).

Correlation between yield traits of coloured cotton

Positive correlation was observed among the yield traits of coloured cotton evaluated under different nutrient management practices (Fig. 5). Strong positive

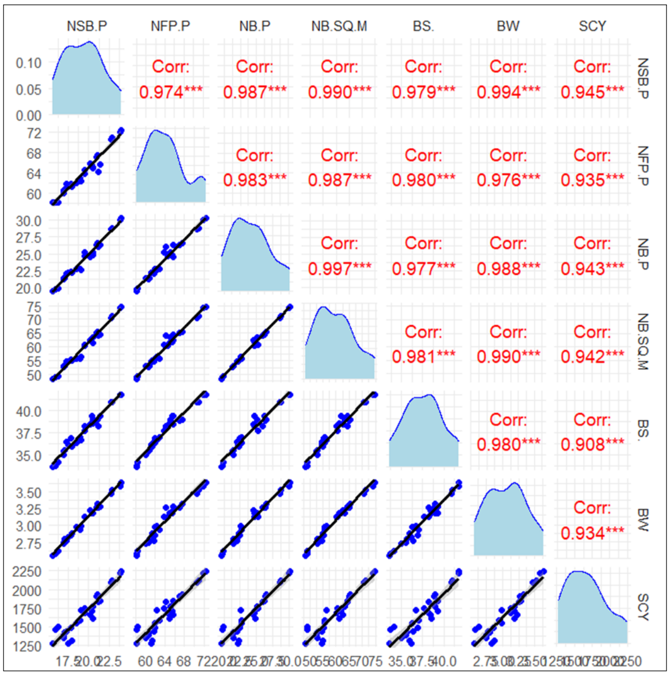

Fig. 5. Pearson's correlation coefficients illustrating the relationships among 7 yield attributes of coloured cotton under various nutrient management practices during *Kharif* 2024. NSB.P- Number of sympodial branches plant^{-1}/ NFP.P- Number of fruiting points plant^{-1}/ NB. P- Number of bolls plant^{-1}/ NB.SQ.M- Number of bolls m^{-2}/ BS%- Boll setting percentage/ BW- Boll weight/ SCY- Seed cotton yield. Positive correlation is shown by red.

interrelationships were recorded among NSB.P (Number of sympodial branches plant^{-1}), NFP.P (Number of fruiting points plant^{-1}), NB. P (Number of bolls plant^{-1}), NB.SQ.M (Number of bolls m^{-2}), BS% (Boll setting percentage), BW (Boll weight) and SCY (Seed cotton yield) under different nutrient management practices. The seed cotton yield of coloured cotton exhibited a strong positive correlation and a highly significant association with yield traits such as NSB.P (0.945), NB. P (0.943), NB.SQ.M (0.942), NFP.P (0.935), BW (0.934) and BS% (0.908) under diverse nutrient management approaches. Similar results were reported by (4).

Discussion

Growth parameters

Inorganic nutrient treatments, such as 100% NPK applied through site-specific (T_2) and blanket (T_1) recommendations significantly enhanced growth parameters including plant height (PH), dry matter production (DMP), leaf area index at flowering (LAI at FL), chlorophyll content at flowering (Chl. C at FL), number of monopodial branches per plant (NMB/P) and the number of days required for 50% flowering (D 50% FL) and 50% boll bursting (D 50% BB) (Table 4).

The application of inorganic nutrients such as 100% NPK through site-specific (T_2) and blanket (T_1) recommendations resulted in significantly taller coloured cotton plants compared to those under organic nutrient treatments. These organic treatments included the complete organic package (T_9), cover crop combined with 75% N through vermicompost on an N-equivalent basis (T_4), cover crop with poultry manure on an N-equivalent basis (T_5), cover crop with farmyard manure on an N-equivalent basis (T_3) and other organic treatments. This enhancement might be due to the immediate and balanced supply of nutrients, where nitrogen stimulates vegetative growth, phosphorus aids in root and branch development and potassium promotes cell elongation and overall plant vigour. These results are similar to those reported by previous studies (32-35)

In contrast, the nutrient availability from organic sources and the favorable conditions for nutrient uptake (36) might have contributed to improved plant growth. Enhanced nitrogen availability might have supported chlorophyll formation, boosted photosynthesis and promoted greater plant height through its role in cell elongation. These findings align with previous studies (37, 38). Organic management practices such as the complete organic package (cover crop + vermicompost + biofertilizers + biocontrol agents + PPFM) and cover crop incorporation with vermicompost on an N-equivalent basis exhibited a slower but consistent improvement in growth parameters including plant height, dry matter production, leaf area index at flowering, chlorophyll content at flowering, number of monopodial branches per plant and the number of days required for 50% flowering and 50% boll bursting compared to inorganic nutrient treatments. This could be attributed to the enhanced nitrogen availability provided by this treatment, which promoted an increase in leaf size, ultimately leading to higher LAI, improved light interception and greater dry matter accumulation. This gradual enhancement might be due to the slow nutrient release from organic inputs, which improved soil organic matter, microbial activity and overall soil health. Vermicompost ensured a steady nutrient supply, biofertilizers facilitated nitrogen fixation and phosphorus solubilisation and PPFM supported plant metabolism and stress resilience. Although initial growth under organic treatments was slower, the cumulative benefits promoted sustainable and balanced plant growth over time (39, 40).

Yield attributes

The yield attributes of coloured cotton such as the number of sympodial branches per plant (NSB/P), the number of fruiting points per plant (NFP/P), the number of bolls per plant (NB/P), the number of bolls per square meter (NB/m^2), boll setting percentage (BS%) and boll weight (BW) are crucial factors influencing seed cotton yield (Table 5).

The application of 100% NPK through site-specific and blanket recommendations might have contributed to the enhancement of these attributes likely due to the prompt and balanced supply of essential nutrients necessary for optimal growth and reproductive development. Adequate nitrogen availability in the inorganic nutrient treatments might have supported both vegetative and reproductive growth, encouraging the development of sympodial branches, fruiting points and providing more sites for boll formation. A well-balanced supply of phosphorus might have been essential for boll initiation and retention by aiding energy transfer within the plant and minimizing boll shedding. This might have contributed to an increased number of bolls, thereby boosting seed cotton yield. Additionally, potassium might have played a key role in carbohydrate translocation, promoting the development of larger and heavier bolls, which ultimately enhanced yield per plant and overall crop productivity. These findings are found to be similar to (41, 42).

On the other hand, organic nutrient management treatments such as the complete organic package (cover crop + vermicompost + biofertilizers + biocontrol agents + PPFM) and cover crop combined with vermicompost showed positive Impacts on yield attributes including the number of sympodial branches, number of fruiting points per plant, bolls per plant, boll weight and boll setting percentage. The integration of organic manures, biofertilizers and biocontrol agents might have contributed to a balanced nutrient supply while improving the soil physical and biological properties. This combination might have enhanced pest and disease resistance as well as improved nutrient uptake efficiency, leading to an increase in fruiting points and better boll retention (43). The inclusion of PPFM (pink pigmented facultative methylotrophs) might have improved plant physiological functions and aiding boll development under stressful conditions (39). Similarly, the combination of cover crops with vermicompost might have enriched soil organic matter and stimulated microbial activity, which enhanced root development and the gradual formation of fruiting points. Over a period, this strategy might have contributed to increased boll weight by maintaining a consistent supply of essential nutrients and improving soil moisture retention. Similar findings have been reported in previous studies (44, 45).

Yield

In this study, the higher seed cotton yield and lint cotton yield were observed with inorganic treatments such as the application of 100% NPK through site-specific and blanket recommendations. This increase might have resulted from their rapid nutrient release, which promoted immediate crop growth and increased yield. In contrast, organic manures release nutrients more gradually, leading to progressive improvements in soil health, nutrient cycling and sustainability offering long-term benefits for productivity (46).

In a similar manner, the application of inorganic nutrients significantly improved lint yield, lint percentage, stalk yield and biological yield. This may be attributed to the rapid and steady availability of essential nutrients needed for fiber development and biomass growth. The availability of key nutrients during critical stages of fiber elongation and thickening might have improved both the quality and quantity of lint. Additionally, the higher stalk and biological yields might be due to the efficient nutrient uptake from inorganic sources, which supported healthy vegetative and reproductive growth. In contrast, organic amendments including cover crops, vermicompost and poultry manure release nutrients gradually, which leads to lower initial yields. However, organic nutrients improve soil structure, stimulate microbial activity, enhance nutrient cycling and boost water retention, thereby contributing to long-term soil fertility and sustainable cotton production with gradually increasing yields over successive growing seasons. These findings are consistent with previous studies (32, 37, 38, 47).

Conclusion

This study indicated that different nutrient management practices significantly influenced the growth parameters, yield attributes and overall productivity of coloured cotton. During *Kharif* 2024, inorganic nutrient treatments, particularly 100% NPK applied through site-specific (T_2) and blanket (T_1) recommendations, resulted in superior growth parameters, yield attributes and seed cotton yield in the short term. Conversely, organic treatments such as the complete organic package (T_9) and cover crop incorporation with 75% N through vermicompost on an N-equivalent basis (T_4), contributed to improved soil fertility, enhanced water conservation and reduced reliance on chemical inputs, thereby promoting long-term sustainability and minimizing environmental impacts. Although organic approaches initially resulted in slightly lower yields, their long-term benefits closely aligned with those of inorganic treatments, highlighting the potential of the complete organic package (T9) and cover crop incorporation with 75% N through vermicompost (T4) as viable strategies for sustainable coloured cotton production.

Future research should prioritize the optimization of organic nutrient management practices, with a particular focus on refining the complete organic package and integrating cover crops with vermicompost on an N-equivalent basis Investigating the long-term effects of these practices on soil health, nutrient cycling and the overall agronomic performance of coloured cotton is crucial, particularly regarding soil fertility restoration, microbial dynamics and sustainable nutrient availability. Moreover, detailed studies are needed to assess the synergistic effects of these organic approaches in diverse agro-climatic environments, enabling the development of region-specific strategies. Such research is essential for enhancing the scalability of these practices, fostering a transition toward ecologically sustainable cotton production and mitigating the environmental consequences associated with conventional agriculture.

Acknowledgements

We would like to express our heartfelt gratitude to the advisory committee members and the teaching and non-teaching staff of the Department of Agronomy for their invaluable assistance during this study. We also extend our sincere appreciation to the DST-FIST scheme for providing the essential infrastructural support that contributed to the successful completion of this work.

Authors' contributions

SS conducted the experiment, collected observations, and performed data analysis. TR guided the formulation of the research concept and methodology, supervised the study, facilitated research funding and approved the final manuscript. AG contributed to developing the research ideas, reviewing the manuscript and securing research grants. MG implemented the experiment and provided guidance throughout the research. TS conceptualized the study and participated in its design and coordination. JP provided guidance on soil and crop management, assisted in developing the methodology and contributed to the manuscript review and editing. MT supported resource acquisition and data visualization. ES conceptualized the study and contributed to the manuscript review and editing. BA assisted with the overall research work and summarized the weather and experimental data. SR reviewed and edited the manuscript. All authors have read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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