J. Cotton Res. Dev. **39**(1), 8-13 (January, 2025) **ISSN No. 0972-8619**

Enhancing *Bt* cotton production through optimal nutrient management in rainfed conditions

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Abstract : The field trial conducted to examine the influences of nutrient management on the seed cotton yield of *Bt.* Cotton and its economic implications under rainfed conditions at the Dry Farming Research Station, Junagadh Agricultural University, Vallabhipur, Gujarat, spanning the *kharif* season from 2012-13 to 2022-23. The trial was set up using a randomized block design, incorporating 9 distinct treatments comprising of T_1 - 80 kg N/ha, T_2 - 80 kg N/ha + 20 kg P_2O_5/ha + 40 kg K_2O/ha + 20 kg S/ha, T_3 - 80 kg N/ha + 20 kg P_2O_5/ha + 40 kg K_2O/ha + 40 kg S/ha, T_4 - 80 kg N/ha + 20 kg P_2O_5/ha + 80 kg K_2O/ha + 20 kg S/ha, T_5- 80 kg N/ha + 20 kg P_2O_5/ha + 80 kg K_2O/ha + 40 kg S/ha, T_6 - 80 kg N/ha + 40 kg P_2O_5/ha + 40 kg K2O/ha + 20 kg S/ha, T_7 - 80 kg N/ha + 40 kg P_2O_5/ha + 40 kg K_2O/ha + 40 kg S/ha, T_8 - 80 kg N/ha + 40 kg P_2O_5/ha + 80 kg K_2O/ha + 20 kg S/ha, T_9 - 80 kg N/ha + 40 kg P_2O_5/ha + 80 kg K_2O/ha + 40 kg S/ha, replicated thrice. On the basis of pooled results, maximum values of all the attributes like plant height, number of branches per plant and number of bolls per plant of cotton crop were recorded with treatment T_9 (80-40-80-40 NPKS kg/ha).The significantly higher seed cotton yield (1996 kg/ha) and stalk yield (2873 kg/ha) of cotton were recorded under treatment T_9 (80 kg N/ha + 40 kg P_2O_5/ha + 80 kg K_2O/ha + 40 kg S/ha). The highest total income (Rs. 95327/ha) was also obtained with application of 80-40-80-40 NPKS kg/ha (T_9). The pH, EC, and organic carbon content of the soil remained unaffected by various treatments. However, treatment T_9 (80-40-80-40 NPKS kg/ha) showed significantly higher values in the available status of phosphorus, potassium, and sulphur in the soil.

Keyword: *Bt* cotton, nutrient management, rainfed, seed cotton yield

Cotton (*Gossypium* spp.) stands as India's primary fibre cash crop, contributing to 85% of raw materials in the textile industry. India holds the position of the world's second largest cotton cultivator and producer, following China. Cotton is grown on 130.49 lakh hectares in India, with a production and productivity of 337.27 lakh bales and 439 kg/ha, respectively. In Gujarat state, it is grown on 25.49 lakh hectares with a production and productivity of 87.12 lakh bales and 581 kg/ha, respectively (DES, 2022).Productivity remains below global averages due to various factors including imbalanced nutrient management. Several factors contribute to the inadequate growth and productivity of *Bt.* cotton, such as unseasonable rainfall, fluctuations in monsoon timing, inadequate water management, improper planting schedules, and unbalanced fertilizer application (Ramasundaram and Gajbhiye, 2001). Balance nutrition with an optimum level of nutrients is essential for proper growth and development of the crop. The imbalanced nutrition leads to antagonistic effects and ultimately the crop suffers either because of excess or deficiency of essential elements. Nitrogen, phosphorus, and potassium are primary elements for enhancing agricultural crop production. Among these, Nitrogen (N) stands out as a crucial and costly input, exerting the quickest and most significant impact on plant growth. Being a component of protoplasm, it plays a vital role in photosynthesis and consequently, in the production of dry matter. Currently, issues such as cotton reddening are evident due to inadequate nutrient management practices (Das *et al.,* 2004). Phosphorus (P) is essential for plant growth and productivity, but

its availability in soil is often limited due to fixation. Phosphorus is importance in various plant processes like germination, root and shoot development, photosynthesis, and nitrogen fixation at cellular and conversing and transferring energy within cell metabolism (Malhotra *et al.*, 2018). Potassium (K) holds a significant role in osmotic regulation, exerting a crucial influence on water uptake in plant roots. Potassium deficient plants are not able to withstand water stress effectively, mostly because of their inability to make full use of available water. Potassium can affect the rate of transpiration and water uptake through regulation of stomata opening (Tisdale *et al.,* 1995).Sulphur (S) improved yield and quality parameters of seed cotton (Mamatha *et al.,* 2009). Sulphur is an important factor influencing cotton yield, the plant growth and development (Najafian and Zahedifar, 2015). Considering the aim, the experiment was designed to investigate how nutrient management affects *Bt.* cotton in rain-fed conditions, conducted at the Dry Farming Research Station of Junagadh Agricultural University in Vallabhipur, Gujarat. This research aims to address this gap by examining the impact of nutrient management on *Bt.* Cotton under rainfed conditions.

MATERIALS AND METHODS

A field experiment was conducted during *kharif* 2012-2013 to 2022-2023 at Dry Farming Research Station, Junagadh Agricultural University, Vallabhipur under Bhal and Coastal area, Agro-climatic zone VIII. The soil of the experimental field was medium black with clayey texture and alkaline in reaction (pH 8.09, EC 0.38 dSm^{-1}). The soil was medium in Organic carbon (0.58 %), low in available nitrogen (230.3 kg/ha), medium in available phosphorus (42.36 kg/ha), high in available potassium (516 kg/ha) and medium in available sulphur (10.10 ppm), respectively. The experiment comprised total 9 treatments *i.e.* T_1 - 80 kg N/ha, T_2 - 80 kg N/ha + 20 kg P_2O_5/ha + 40 kg K_2O/ha + 20 kg S/ha, T_3 - 80 kg N/ha + 20 kg P_2O_5/ha + 40 kg K_2O/ha + 40 kg S/ha, T_4 - 80 kg N/ha + 20 kg P_2O_5/ha + 80 kg K_2O/ha + 20 kg S/ha, T_5- 80 kg N/ha + 20 kg P_2O_5/ha + 80 kg K_2O/ha + 40 kg S/ha, T_6 - 80 kg N/ha + 40 kg P_2O_5/ha + 40 kg K_2O/ha + 20 kg S/ha, T_7 - 80 kg N/ha + 40 kg P_2O_5/ha + 40 kg K_2O/ha + 40 kg S/ha, T_8 - 80 kg N/ha + 40 kg P_2O_5/ha + 80 kg K_2O/ha + 20 kg S/ha, T_9 - 80 kg N/ha + 40 kg P_2O_5/ha + 80 kg K_2O/ha + 40 kg S/ha in randomized block design, replicated thrice. *Bt.* cotton variety G.Cot. Hy. 8 BG-II was sown, the 80 kg nitrogen/ha was applied in three splits *i.e.* 25 per cent as basal, 50 per cent as top dressing at 35-40 days and 25 per cent as top dressing at 60-65 days and all necessary agronomic practices were implemented according to the crop's requirements. The growth and yield parameters, including seed cotton and stalk yield of the cotton, were measured. After harvest of crop soil samples were collected and analysed for EC, pH, OC, available N, P_2O_5, K_2O and S status in soil using standard methods (Jackson, 1973). Experimental data were analysed by adopting standard statistical methods of analysis of variance as given (Gomez and Gomez, 1982).

RESULTS AND DISCUSSION

Yield attributes

The findings presented in Table 1 regarding the yield attributes *i.e.* plant height, branches/plant and bolls/plant of cotton crop were significantly affected due to different nutritional treatments during all the years of experimentation and in pooled results also. On the basis of pooled results, maximum values of all the yield attributing characters were recorded with treatment T_9 (80-40-80-40 NPKS kg/ha). This could be attributed to the application of N, P, K and S fertilizers at a higher dosage, which is evidently beneficial for the plants. Similar results were also observed by Gadhiya *et al.*, (2009), Sakarvadia *et al.*, (2009) and Vora *et al.,* (2015).

Table 1. Effect of nutrient management on growth and yield attributes of cotton (Pooled result of six years)

Treatments	Plant height (cm)	Monopodia/ plant	Sympodia/ plant	bolls/ plant	Boll weight (g)
T1- N_{80}	87.93	1.52	12.25	24.11	3.66
T2- $N_{80}P_{20}K_{40}S_{20}$	95.62	1.57	13.76	27.93	3.60
T3- $N_{80}P_{20}K_{40}S_{40}$	96.07	1.63	12.68	27.97	3.69
T4- $N_{80}P_{20}K_{80}S_{20}$	100.50	1.72	14.60	28.00	3.74
T5- $N_{80}P_{20}K_{80}S_{40}$	97.22	1.68	14.08	28.84	3.79
T6- $N_{80}P_{40}K_{40}S_{20}$	102.59	1.77	15.16	32.60	3.95
T7- $N_{80}P_{40}K_{40}S_{40}$	104.65	1.81	15.87	33.21	3.88
T8- $N_{80}P_{40}K_{80}S_{20}$	105.07	1.85	15.92	35.33	3.70
T9- $N_{80}P_{40}K80S_{40}$	108.82	1.96	16.76	36.37	4.10
S.Em.±	1.77	0.06	0.37	1.05	0.13
C.D. (p=0.05)	4.98	0.16	1.04	2.95	NS
C.V. (%)	6.87	12.70	9.84	13.32	12.81
Y					
S.Em.±	1.32	0.04	0.28	0.78	0.09
C.D. (p=0.05)	3.71	0.12	0.78	2.20	0.26
YXT					
S.Em.± 3.96	0.13	0.83	2.34	0.28	
C.D. (p=0.05)	NS	NS	NS	NS	NS

Table 2. Effect of nutrient management on seed cotton yield of cotton (kg/ha)

Treatments	2016-2017	2018-2019	2019-2020	2020-2021	2021-2022	2022-2023	**Pooled**
T1- N_{80}	921	802	1551	1510	1723	2027	**1422**
T2- $N_{80}P_{20}K_{40}S_{20}$	975	815	1651	1669	1878	2148	**1523**
T3- $N_{80}P_{20}K_{40}S_{40}$	995	864	1698	1716	1813	2181	**1544**
T4- $N_{80}P_{20}K_{80}S_{20}$	967	972	1582	1600	1916	2289	**1554**
T5- $N_{80}P_{20}K_{80}S_{40}$	985	983	1705	1687	1834	2312	**1584**
T6- $N_{80}P4_0K_40S_{20}$	1011	985	2034	1731	1965	2505	**1705**
T7- $N_{80}P_{40}K_{40}S_{40}$	1039	1138	2073	1739	1916	2737	**1774**
T8- $N_80P_40K_{80}S_{20}$	1057	1109	2037	1770	1957	3092	**1837**
T9- $N_{80}P_{40}K_{80}S_{40}$	1083	1139	2554	1800	2058	3341	**1996**
S.Em.±	79	76	175	109	115	227	**58**
C.D. (p=0.05)	NS	228	525	NS	NS	681	**162**
C.V. (%)	13.67	13.43	16.18	11.16	10.48	15.63	**14.71**
Y							
S.Em.±	47						
C.D. (p=0.05)	132						
YXT							
S.Em.±	141						
C.D. (p=0.05)	NS						

Yield

Seed cotton yield:

The data presented in Table 2 indicated that the effect of different treatments on seed cotton yield of cotton was found significant during the years of 2018-2019, 2019-2020 and 2022-2023 as well as in pooled result. Application of 80 kg N/ha+40 kg P_2O_5/ha+80 kg K_2O/ha+40kg S/ha (T_9) recorded significantly higher seed cotton yield of 1139, 2554, 3341 and 1996 kg/ha during the years of 2018-2019, 2019-2020, 2022-2023 and in pooled result, respectively, but it was remained at par with treatments T_4, T_5, T_6, T_7 and T_8 in the year of 2018-2019, treatments T_6, T_7 and T_8 in the year of 2019-2020, treatments T_7 and T_8 in the year of 2022-2023 and treatment T_8 (80 kg N/ha+40 kg P_2O_5/ha+80 kg K_2O/ha+20 kg S/ha) in pooled result. The results are in concurrence with those

Table 3. Effect of nutrient management on stalk yield of cotton (kg/ha)

Treatments	2016-2017	2018-2019	2019-2020	2020-2021	2021-2022	2022-2023	Pooled
T1- N_{80} 12_{35}	1157	2083	2212	1955	3038	1947	
T2- $N_{80}P20K_{40}S_{20}$	1312	1183	2212	2341	2083	3935	**2178**
T3- $N_{80}P20K_{40}S_{40}$	1415	1389	2418	2469	2829	4102	**2437**
T4- $N_{80}P20K_{80}S_{20}$	1389	1260	2289	2521	2418	4005	**2314**
T5- $N_{80}P20K_{80}S_{40}$	1415	1415	2572	2443	2984	4223	**2509**
T6- $N_{80}P40K_{40}S_{20}$	1440	1440	2649	2495	3112	4244	**2563**
T7- $N_{80}P40K_{40}S_{40}$	1492	1543	2752	2546	3061	4555	**2658**
T8- $N_{80}P40K_{80}S_{20}$	1492	1620	2803	2572	3318	5095	**2817**
T9- $N_{80}P40K_{80}S_{40}$	1517	1646	2829	2623	3421	5198	**2873**
S.Em.±	123	77	156	185	190	398	**87**
C.D. (p=0.05)	NS	231	468	NS	569	1193	**245**
C.V. (%)	15.05	9.48	10.77	12.97	11.74	16.15	**14.94**
Y							
S.Em.±				71			
C.D. (p=0.05)				200			
YXT							
S.Em.±				214			
C.D. (p=0.05)				NS			

Table 4. Effect of nutrient management on post harvest soil fertility of cotton.

Treatments	pH (1:2.5)	EC (dS/m) (1:2.5)	OC (%)	Avail. P_2O_5 (kg/ha)	Avail. K2O (kg/ha)	Avail. S (ppm)
Initial	8.09	0.38	0.58	42.36	516	10.10
T1- N_{80}	7.79	0.47	0.47	33.22	465	9.35
T2- $N_{80}P_{20}K_{40}S_{20}$	7.91	0.49	0.44	43.08	507	16.28
T3- $N_{80}P_{20}K_{40}S_{40}$	7.89	0.51	0.40	46.50	504	21.17
T4- $N_{80}P_{20}K_{80}S_{20}$	7.82	0.53	0.42	45.48	579	15.95
T5- $N_{80}P_{20}K_{80}S_{40}$	7.86	0.50	0.41	48.29	585	21.45
T6- $N_{80}P_{40}K_{40}S_{20}$	7.84	0.53	0.43	53.26	513	16.22
T7- $N_{80}P_{40}K_{40}S_{40}$	7.91	0.55	0.44	55.78	514	22.38
T8- $N_{80}P_{40}K_{80}S_{20}$	7.80	0.57	0.45	54.05	592	15.95
T9- $N_{80}P_{40}K_{80}S_{40}$	7.54	0.58	0.43	58.92	595	23.04
S.Em.±	0.23	0.02	0.03	2.32	27	1.08
C.D. (p=0.05)	NS	NS	NS	6.96	80	3.24
C.V. (%)	5.07	7.72	10.92	8.25	8.58	10.43

reported by Gadhiya *et al.,* (2009), Khambalkar *et al.,* (2017), Sakarvadia *et al.,* (2009) and Vora *et al.,* (2019).

Cotton stalk yield:

The data presented in Table 3 indicated that the effect of different treatments on stalk yield of cotton was found significant during the years of 2018-2019, 2019-2020, 2021-2022 and 2022-2023 as well as in pooled result. Application of 80 kg N/ha+40 kg P_2O_5/ha+80 kg K_2O/ha+40kg S/ha (T_9) recorded significantly higher stalk yield of cotton during the years of 2018-2019, 2019-2020, 2021-2022, 2022-2023 and in pooled result, but it was remained at par with treatments T_5, T_6, T_7 and T_8 in the year of 2018-2019, treatments T_3, T_5, T_6, T_7 and T_8 in the year of 2019-2020, treatments T_5, T_6, T_7 and T_8 in the year of 2021-2022, treatments T_3, T_4, T_5, T_6, T_7 and T_8 in the year of 2022-23 and treatments T_7 and T_8 in pooled result. The increase in cotton stalk yield with N, P, K and S fertilization was ascribed to their impact on plant height and also on branching as supported by Gadhiya *et al.,* (2009), Sakarvadia *et al.,* (2009) and Vora *et al.,* (2019).

Post harvest soil fertility

The data presented in Table 4 revealed

Table 5. Economics of cotton as influenced by different nutrient management practices.

Treatments	Seed cotton yield (kg/ha)	Cotton stalk yield (kg/ha)	Gross return (Rs./ha)	Total cost of cultivation (Rs./ha)	Net return (Rs./ha)	B:C ratio
T1- N_{80}	1422	1947	121871	56577	65295	2.15
T2- $N_{80}P_{20}K_{40}S_{20}$	1523	2178	130513	63770	66743	2.05
T3- $N_{80}P_{20}K_{40}S_{40}$	1544	2437	132501	64439	68062	2.06
T4- $N_{80}P_{20}K_{80}S_{20}$	1554	2314	133277	66692	66585	2.00
T5- $N_{80}P_{20}K_{80}S_{40}$	1584	2509	135925	67605	68320	2.01
T6- $N_{80}P_{40}K_{40}S_{20}$	1705	2563	146227	68020	78207	2.15
T7- $N_{80}P_{40}K_{40}S_{40}$	1774	2658	152105	69360	82744	2.19
T8- $N_{80}P_{40}K_{80}S_{20}$	1837	2817	157541	72918	84622	2.16
T9- $N_{80}P_{40}K_{80}S_{40}$	1996	2873	171087	75760	95327	2.26

that the effect of different treatments on post-harvest soil fertility like pH, EC and organic carbon were found non-significant, while available phosphorus, potash and sulphur were significantly affected due to different treatments. Significantly higher available phosphorus (58.92 kg/ha) was recorded under application of 80 kg N/ha+40 kg P_2O_5/ha+80 kg K_2O/ha+40kg S/ha (T_9), but it was at par with treatments T_6, T_7 and T_8 and significantly higher available potash (595 kg/ha) was recorded under application of 80 kg N/ha+40 kg P_2O_5/ha+80 kg K_2O/ha+40kg S/ha (T_9), but it was *at par* with treatments T_4, T_5 and T_8.Whereas, available sulphur (23.04 ppm) was also recorded significantly higher under application of 80 kg N/ha+40 kg P_2O_5/ha+80 kg K_2O/ha+40kg S/ha (T_9), but it was remained at par with treatments T_3, T_5 and T_7. The result is similar to Ravi kiran and Halepyati (2013), Sujatha and Vijayalakshmi (2013) and Vora *et al.,* (2015).

Economics

The economics of different treatments was worked out on the basis of pooled results and presented in Table 5. The data indicated that the maximum net returns Rs. 95327/ha and B:C ratio 2.26 were recorded under application of 80 kg N/ha+40 kg P_2O_5/ha+80 kg K_2O/ha+40kg S/ha (T_9), followed by application of 80 kg N/ha+40 kg P_2O_5/ha+80kg S/ha+20 kg S/ha (T_8) in net return (Rs. 84622/ha) and application of 80 kg N/ha+40 kg P_2O_5/ha+40 kg S/ha+40 kg S/ha (T_7) in B:C ratio (2.19).

CONCLUSION

Optimizing nutrient management with 80-40-80-40 kg/ha NPKS fertilization enhances *Bt.* Cotton yield, net returns and post-harvest soil fertility under rainfed conditions. This underscores the importance of balanced fertilization in improving crop productivity and sustainability. Further research and adoption of such practices are warranted to enhance cotton production in rainfed regions.

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Received for publication : September 20, 2024
Accepted for publication : October 26, 2024