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Research Paper

Optimizing cotton yield through macronutrient mixtures

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ABSTRACT

An incubation study, followed by a two-year field trial, was conducted at Tamil Nadu Agricultural University (TNAU), Coimbatore, to comprehensively assess the nutrient release and the effect of macronutrient fertilizer mixtures on nutrient uptake, nutrient use efficiency, cotton quality parameters, and crop yield during 2020 to 2021. The study aimed to identify the best fertilizer combinations of nitrogen (N), phosphorus (P), and potassium (K) sources to enhance cotton growth and productivity. The treatments, all involving 100% Recommended Dose of Fertilizers (RDF), comprised the following macronutrient mixtures: T_1 (Urea + DAP + MOP), T_2 (Urea + SSP + MOP), T_3 (Urea + DAP + SOP), T_4 (Urea + MAP + SOP), T_5 (CN + DAP + MOP), T_6 (CN + DAP + SOP), T_7 (Urea + CN + SSP + MOP), T_8 (CN + ASP + MOP), and T_9 (Absolute Control). The incubation study provided insights into the nutrient release pattern from the different fertilizer mixtures over time. The two-year field trial confirmed that the application of a fertilizer mixture containing CN, DAP, and MOP (T5) significantly increased nutrient uptake T_5 and agronomic use efficiency in cotton. The yield increase due to this particular treatment was 66.7% and 67.9% higher than the control during 2020 and 2021, respectively. Incorporation of sulfur-containing fertilizer mixtures, such as CN with DAP and SOP (T_6), and urea with DAP and SOP (T_3), markedly increased protein and oil content in cotton seed. Different fertilizer sources had no significant effect on lint quality parameters. Application of tailored macronutrient combinations to cotton plants improved nutrient uptake and yields, highlighting the practical benefits of strategic fertilizer application.

Key words: Cotton, Nutrient mixtures, Nutrient release, Nutrient uptake, Nutrient dynamics

Cotton (*Gossypium hirsutum*), often hailed as "white gold," has held an essential place in human civilization for centuries, serving as a multifaceted resource with significant socioeconomic implications. From being a staple in the textile industry to supporting livelihoods for millions, cotton remains an integral part of our lives. Amidst the rising global demand for cotton, nations such as India, renowned for their agricultural legacy, play a crucial role in addressing this growing demand. India holds the second position in cotton lint production, further emphasizing its significant contribution (FAO, 2021). Although India's role in meeting this escalating demand is pivotal, it is important to note that despite its importance to the Indian economy, the country's cotton yield per ha is lower than that of other major global cotton producers (PIB, 2022). The cotton cultivated area in Top of Form (Bhanderi *et al.,* 2024)

India is estimated to be 130.61 lakh ha of which Tamilnadu has an area of 1.62 lakh ha and a productivity of 373.58 kg/ha^{-1} (Indiastat, 2023). Factors such as environmental pressures, climatic uncertainties, and suboptimal nutrient management contribute to below-optimal cotton yields, impacting economies and livelihoods. To address this concern, research endeavors have become crucial, focusing on innovative approaches to sustainably enhance cotton productivity.

The lack of appropriate fertilizer management strategies has restricted the harmonious development of the cotton industry and environment (Wang *et al.,* 2021). Fertilizers containing ammonia, such as ammonium nitrate (AN), ammonium sulfate (AS), and urea, are highly prone to NH_3 volatilization. This process is a major pathway for N loss following fertilizer application, as highlighted by studies (Ma *et al.,* 2010; Jantalia *et al.,* 2012). Dari and

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Rogers (2021) further highlighted the impact of soil conditions, and the nature of nitrogen carriers on ammonia volatilization. The loss of N from fertilizer application may vary based on the form of N applied, soil type, and environmental conditions at the time of application (Watts *et al.,* 2017). Different P and K sources have also been proven to have significant impacts on cotton yield components and yield (Pervez *et al.,* 2005; Sepat *et al.,* 2012; Ananthakrishnan and Backiyavathy, 2020). However, few studies have compared the effects of different sources of fertilizers on cotton yield, particularly in the context of multiple nutrient mixtures.

The present study aimed to contribute to this endeavor by investigating the role of macronutrient fertilizer mixtures in augmenting cotton yield and quality. Through the exploration of different macronutrient combinations, including N, P and K sources, we aimed to identify the optimal fertilizer mixture that enhances cotton agronomic efficiency and nutrient use efficiency. Furthermore, we aimed to examine the nutrient release patterns of these mixtures, providing insights into how they cater to plant needs throughout various growth stages. The implications of this research extend beyond mere productivity enhancement. A comprehensive understanding of nutrient uptake and crop yield response to specific fertilizer combinations can foster sustainable agricultural practices worldwide. By developing targeted fertilization strategies, farmers can optimize yields while minimizing environmental impacts.

The quest to enhance cotton productivity transcends meeting global demands; it aligns with sustainable development and prosperity for cotton farmers and communities globally. Through our research, we aspire to make a positive contribution to this endeavor, inspiring further exploration into sustainable agricultural practices for a brighter and more prosperous future in the cotton industry and beyond.

MATERIALS AND METHODS

Experimental design and treatments

An incubation experiment was conducted to assess the nutrient release from macronutrient mixtures, which was followed by a two years field experiment on cotton crop. The experiment consisted of nine different macronutrient fertilizer mixture combinations (T_1 to T_9), each replicated thrice. These treatments provided the same recommended dose of NPK, but with varying fertilizer sources, including urea, calcium nitrate (CN), single superphosphate (SSP), muriate of potash (MoP), sulfate of potash (MoP), diammonium phosphate (DAP), ammonium sulfate phosphate (ASP), and mono ammonium phosphate (MAP). The detailed treatment information and nutrient concentration is presented in Table 1 and 2, respectively with T_1 representing general farmer practices followed in the study area and T_9 assigned as the absolute control. The macronutrient fertilizer mixtures were prepared by combining individual fertilizers based on soil test-based recommendations (60:30:30 kg N, P_2O_5, and K_2O /ha) just before application in the field. The total recommended fertilizer was applied in two splits: the first half of the N, K_2O and full dose of P_2O_5 were applied at sowing, and the remaining half of the nitrogen and potassium doses were applied 40-45 days after sowing.

Incubation study

To investigate the nutrient release patterns from various macronutrient mixtures, an incubation experiment was conducted for 150 days. Bulk surface soil samples were collected from a farmer's field in Dheenampalayam, Coimbatore. The experimental soil underwent a systematic process, including air drying and gentle fragmentation to pass through a 2 mm sieve, ensuring uniformity. A total of 216 plastic cups, each with a capacity of 250 g and di-

Table 1. Treatment details for the experiment

Treatment number	Treatment details
T_1	100% RDF through Urea + DAP + MOP
T_2	100% RDF through Urea + SSP + MOP
T_3	100% RDF through Urea + DAP + SOP
T_4	100% RDF through Urea + MAP + SOP
T_5	100% RDF through CN + DAP + MOP
T_6	100% RDF through CN + DAP + SOP
T_7	100% RDF through Urea + DAP + CN + SSP +MOP
T_8	100% RDF through CN + ASP + MOP
T_9	Absolute Control

Table 2. Nutrient concentration in fertilizer used

Fertilizers	Nutrient concentration (%)			
	N	P_2O_5	K_2O	Others
Urea	46	-	-	-
CN	16	-	-	Ca – 20
DAP	18	46	-	-
SSP	-	16	-	S - 12 and Ca - 21
MAP	11	52	-	-
ASP	20	20	-	S - 13
MOP	-	-	60	-
SOP	-	-	50	S - 18

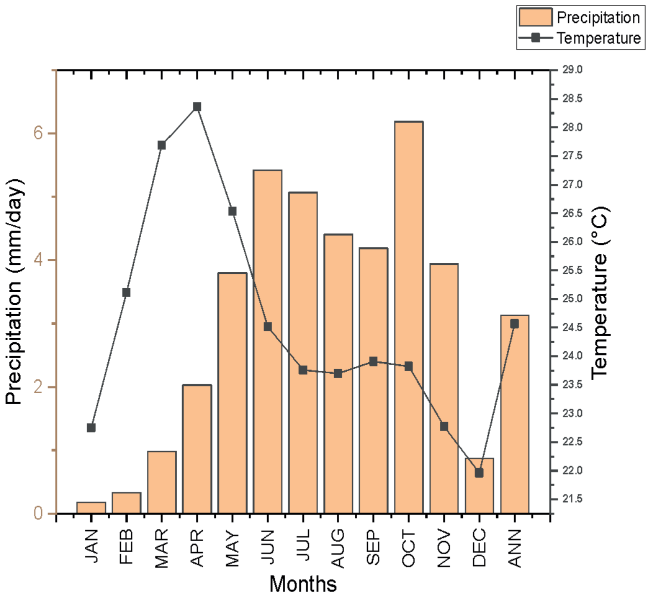

Fig. 1. Average climatological temperature and precipitation for the study area

mensions of 6 × 4 cm (L × B), served as controlled containers for this study. Cups were filled with 250 g soil and then calculated quantities of fertilizer mixtures were added according to the treatments, with three replications. The soil samples were periodically analysed to observe the gradual release of nutrients over specific intervals (0, 7, 15, 30, 60, 90, 120 and 150 DAI) following standard procedures (Stanford and English, 1949; Olsen, 1954; Subbiah and Asija, 1956), and the values were recorded in kg ha^{-1}. Following the incubation study for 150 days, a field trial was conducted in the field under cotton to observe the effect of clear-cut differences in nutrient release patterns that had been established during the incubation period.

Experimental site

Two year experiment with cotton crop was conducted in a farmer's plot located at Dheenampalayam near Coimbatore, with geographical coordinates of 10°59'16.8"N, 76°51'43.2"E. The average annual weather details of the study area are presented in Figure 1. The soil in the experimental area was slightly alkaline (*p*H - 7.8), non-saline (EC – 0.20 dS/m^{-1}), and non-calcareous ($CaCO_3$ - 1.27%). It had a sandy clay loam texture, with a bulk density of 1.34 Mg/m^{-3}. The soil was found to be low in available N, medium in P, and high in K, with a ratio of 150:10:612 kg/ha^{-1}. Contents of DTPA extractable Zn, Cu, Fe and Mn were found to be 0.82, 1.2, 5.3 and 3.4 ppm, respectively.

Crop management and data collection

The field experiment was carried out using the CO-14 variety (parentage: (MCU 5 × TCH 92-7) × MCU 5-1) for 150 days during the winter season (August to January) in 2020 and 2021 under irrigated conditions. The plots measured 4 × 3 m^2, and planting was carried out following a spacing of 90 × 45 cm. Five random plants from each plot were tagged for data collection. Standard irrigation and cultivation practices were followed (TNAU, 2020), including necessary crop protection measures and need-based pesticide applications. Four pickings were conducted at the harvest stage, and the seed cotton was shade-dried and sent for ginning.

The nutrient content analysis was conducted on the cotton stalk, which includes the main stem, branches, and leaves of the cotton plant. Samples were collected from the stalks at different physiological growth stages (The growth stages of the cotton plants were divided as follows: vegetative (1-50 days after planting), flowering (51-90 days after planting), boll formation (91-120 days after planting), and boll bursting (121-150 days after planting). to ensure a consistent basis for nutrient uptake measurement. After harvesting, the samples were oven-dried to a constant weight. The dried material was then ground and mixed thoroughly to obtain a representative sample. This representative sample was analyzed for nutrient content, and the results were used to calculate the nutrient uptake per hectare using the formula provided and is expressed in kg/ha^{-1}.

$$\text{Uptake of Nutrient (kg/ha)} = \frac{\text{Nutrient content (\%) x Dry matter (kg/ha)}}{100}$$

The agronomic nutrient use efficiency was computed using the following formula and is expressed in kg/kg^{-1} (Fagera Baligar, 2005):

$$\text{Nutrient use efficiency (kg/ha)} = \frac{\text{Yield in fertilizer plot - Yield in control plot}}{\text{Dose of fertilizer applied}}$$

Four pickings were made and the total yield was recorded separately for each treatment. The mean yield was expressed in kg/ha. The quality properties of the lint, such as fiber length, strength, and fineness, were assessed using facilities at the Department of Cotton, TNAU, Coimbatore, with the help of the STATEX compact high-volume instrument.

Data analysis and visualization

Data from field and laboratory experiments were analysed by following the RBD and CRD, respectively using standard methods (Panse and Sukhatme, 1978). Differences between treatment means were compared using the least significant difference at the 0.05 probability level. OriginPro (Learning Edition) and RStudio (Ver: 2023.12.1+402) was used for data visualization.

RESULTS AND DISCUSSION

Incubation study

Nutrient release

Significant variations were observed in the N release patterns among the treatments from the 7th to the 150th day of incubation (Fig. 2). The treatments involving CN displayed a concomitant increase in N release. On the 0th day, N release was not pronounced and ranged from 150.40 to 152.78 kg/ha. However, from the 7th to the 90th day, the release increased, with the maximum value recorded on the 90th day (177.92 kg/ha). Thereafter, a gradual and slight decrease was observed. Among the different treatments, those with calcium nitrate (T_5, T_6, T_7, and T_8) applied consistently had the highest values on all days of incubation, except on the 0th day. T_5 displayed the maximum N release, ranging from 152.78 to 177.92 kg/ha, which was on par with that of T_7 (152.59 to 177 kg/ha) and T_6 (152.12 to 176.53 kg/ha) throughout the 150-day incubation period. The increase in N release from the 7th to 90th days is in line with the findings of previous research (Geng *et al.,* 2015). The progressive increase in N release until the 90th DAI establishes a consistent N supply during the critical growth stages of cotton. The period from the 90th to the 120th DAI corresponds to the flowering and boll formation stages of cotton growth, necessitating a well-maintained nutrient provision. The slight decrease from the 120th DAI could be attributed to the loss of N through volatilization as time advanced.

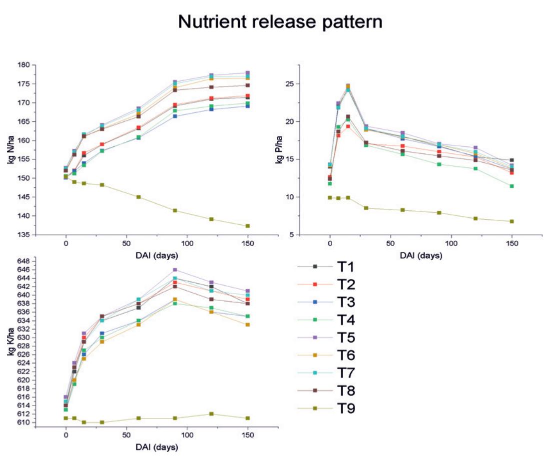

Fig. 2. Effect of macronutrient mixtures on NPK release pattern from different macronutrient mixtures (kg ha^{-1}) on corresponding days after incubation

For P release, the highest value was observed in treatment T_5 on the 15th day of incubation. The release of P from T_5 ranged from 14.21 to 24.75 kg/ha, which was on par with that from T_6 (13.80 to 24.66 kg/ha), T_3 (13.70 to 24.66 kg/ha), T_1 (14.01 to 24.32 kg/ha), and T_7 (14.01 to 24.15 kg/ha$'$) throughout the 150-day incubation period. The available P content in the soil increased during the early stages of incubation, followed by a gradual decrease, possibly due to the conversion of P into insoluble complexes (Mehta *et al.,* 2015). Phosphatic fertilizers initially increased the available soil P for the first two weeks of incubation, followed by a gradual decrease, with DAP-treated soil maintaining the highest level of extractable P throughout the experiment. Phosphorus plays a vital role in enhancing initial root development, increasing yield, facilitating earlier boll set, and promoting timely maturity in cotton (Ahmad and Abdin, 2000). During the incubation study, DAP exhibited a consistent and greater release of P, even though this release diminished after the 15 DAI. Nonetheless, DAP ensured a higher P supply compared to the initial P status of the soil.

The data on K release patterns from different macronutrient mixtures indicated that there were no significant differences among the treatments. However, it is worth noting that the treatment with MOP had a comparatively greater effect, ranging from 614 to 641 kg/ha, than did the treatment with SOP, which ranged from 613 to 635 kg/ha. The non-significant differences among the treatments, might be due to the already high available K status in the soil.

Field Study

Nutrient uptake

The research findings on nutrient uptake by cotton stalks at various growth stages are summarized in Table 3. Nutrient uptake is closely related to dry matter production and the concentration of nutrients in plants. The treatments had a significant effect on nutrient uptake in cotton. Treatment T_5 consistently demonstrated the highest nutrient uptake across all growth stages. During the vegetative stage, T_5 showed the highest uptake of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) at 4.60 kg/ha, 1.57 kg/ha, and 4.60 kg ha, respectively, followed closely by treatments T_7 and T_8 for N, and T_1 and T_8 for P_2O_5. This trend continued in the flowering stage, with T_5 showing maximum uptakes of 39.21 kg/ha for N, 26.00 kg/ha for PO, and 18.60 kg/ha for KO. In the boll formation stage, T_5 again exhibited the highest uptake with values of 61.84 kg/ha for N, 30.98 kg/ha for PO, and 37.16 kg/ha for KO. Finally, during the boll bursting stage, T_5 maintained the highest nutrient uptake levels at 75.50 kg/ha for N, 33.31 kg/ha for PO, and 43.35 kg/ha for KO.

Table 3. Effect of macronutrient mixtures on NPK uptake (kg/ha) by cotton stalk at physiological growth stages during the year 2020 and 2021 (pooled values are given). (T_1 (Urea + DAP + MOP), T_2 (Urea + SSP + MOP), T_3 (Urea + DAP + SOP), T_4 (Urea + MAP + SOP), T_5 (CN + DAP + MOP), T_6 (CN + DAP + SOP), T_7 (Urea + CN + SSP + MOP), T_8 (CN + ASP + MOP), and T_9 (Absolute Control))

Treatment number	Vegetative			Flowering			Boll formation			Boll bursting		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
T_1	4.64	1.52	4.23	28.76	19.72	15.60	45.38	25.06	30.04	65.48	26.49	41.17
T_2	4.65	1.48	4.27	32.20	20.09	16.21	49.57	23.53	31.08	66.55	26.98	39.67
T_3	4.33	1.37	3.92	25.14	19.10	14.78	40.63	23.45	28.82	61.72	25.82	38.70
T_4	4.29	1.38	3.97	23.34	18.26	13.65	41.27	21.56	28.61	55.62	25.73	38.52
T_5	5.20	1.57	4.60	39.21	26.00	18.60	61.84	30.98	37.16	75.50	33.31	43.35
T_6	4.99	1.35	4.23	32.24	21.04	16.89	55.04	24.68	31.68	70.77	28.60	39.61
T_7	5.26	1.48	4.35	34.81	22.03	17.65	58.63	28.14	34.83	73.30	30.90	40.86
T_8	5.05	1.53	4.02	33.68	20.05	16.94	55.74	23.59	33.91	70.87	28.03	41.62
T_9	3.82	0.97	3.32	10.34	8.89	12.86	18.6	11.64	26.73	30.34	9.43	36.94
SEm±	0.07	0.01	0.07	0.51	0.31	0.24	0.82	0.45	0.45	1.02	0.35	0.60
CD (P=0.05)	0.26	0.06	0.32	1.75	0.84	0.53	0.64	1.53	0.80	2.13	1.00	0.58

Among the two K sources, treatments containing MOP showed greater uptake than those with SOP. Overall, T_5's superior performance across all growth stages underscores its effectiveness in enhancing nutrient absorption in cotton plants.

The highest N uptake of T_5, reflects its effectiveness in promoting N assimilation at different critical growth stages. The treatment T_5 provided N in two available forms (nitrate and ammonium), which likely contributed to better N accumulation in the plants and hence increased photosynthesis. These findings also align with the previous incubation study. Furthermore, the presence of calcium in the treatment played a crucial role in carbohydrate translocation. Calcium deficiency can lead to the accumulation of carbohydrates in cotton leaves, resulting in poor absorption and assimilation of nitrates (Joham, 1957). However, with calcium supplied along with nitrate in the form of CN, N use efficiency was improved, leading to maximum N uptake. Significantly highest P uptake of T_5 during flowering, boll formation, and boll bursting stages, indicate its role in enhancing P assimilation at various crop development phases. Phosphorus uptake was higher during the initial growth stages, as it is essential for root growth, which occurs in the early stages of the crop. Compared with the other treatments, the treatments containing DAP resulted in greater P uptake, which is consistent with the findings of previous studies (Siddiqui and Oad, 2007; Luo *et al*., 2023). The non-significant differences observed in case of K uptake may be attributed to the initially high K status of the soil (612 kg/ha), which was readily available for immediate uptake by the crop. Later, applied K might have been taken up by the plants, resulting in similar K uptake values among the treatments. Higher uptake of MoP compared to SOP, is consistent with results reported by Surendran (2005) in rice. This correlates with the higher release of MOP observed during incubation study.

Lint quality assessment

The results indicate that there were variations observed in the mean fibre length, fibre strength, fibre fineness, and uniformity index of the cotton lint across the different treatments. However, upon conducting statistical analysis, it was found that these variations were not significant among the treatments. In other words, despite the observed differences, the differences in mean fibre length, strength, fineness, and uniformity index between the treatment groups were not large enough to be considered statistically significant. This implies that the choice of fertilizer combination did not have a substantial impact on these particular fibre characteristics. The details of these results can be found in Table 4. This limited influence of treatments on fibre quality can be attributed to the genetic nature of this characteristic. Nutrient sources had minimal effect on micronaire, fibre strength, fiber length and uniformity (Watts *et al.,* 2017). It was also reported that P played an insignificant role in affecting fibre properties (Tewolde and Fernandez, 2003), which aligns with our present study's results. Overall, the observations emphasize that fibre quality is primarily governed by genetic factors, and the treatments in this study had limited discernible effects on these attributes.

Table 4. Effect of macronutrient mixtures on fibre quality of cotton (pooled values are given)

Treatment number	Fibre length (mm)	Fibre strength (g/tex)	Uniformity Index (%)	Fibre fineness (Micronaire)
T_1	35.8	21.8	84.5	4.3
T_2	35.5	21.9	85.2	4.3
T_3	35.4	21.7	83.6	4.4
T_4	35.8	22.6	83.6	4.4
T_5	36.2	22.0	83.1	4.3
T_6	36.0	22.1	84.2	4.3
T_7	36.5	22.5	84.9	4.3
T_8	35.5	22.0	82.5	4.4
T_9	34.3	21.6	84.9	4.2
SEm±	0.75	0.51	1.75	0.10
CD (P=0.05)	NS	NS	NS	NS

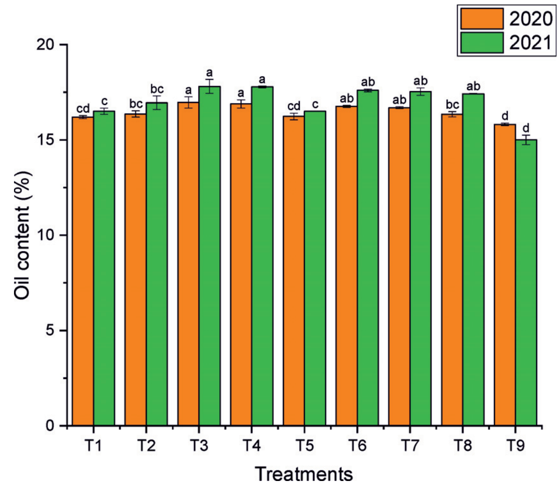

Fig. 3. Effect of macronutrient mixtures on cotton seed oil content (%) in the year 2020 and 2021. Different letters for treatments indicate significant difference at p d" 0.05 by DMRT

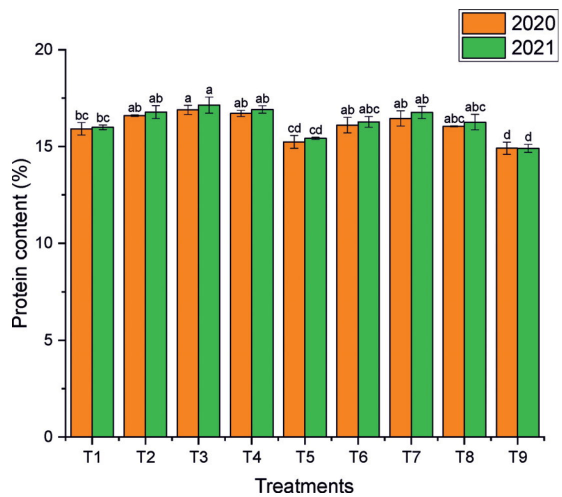

Fig. 4. Effect of macronutrient mixtures on cotton seed protein content (%) in 2020 and 2021. Different letters for treatments indicate significant difference at p d" 0.05 by DMRT

Seed quality

Figures 3 and 4 present the oil and protein contents of the cotton seeds, respectively. During 2020 and 2021, the oil content ranged from 15.82% to 16.97% and 15.00 to 17.81%, respectively, with the maximum oil percentage recorded under T_3 (16.97 and 17.81%, respectively), which was found to be on par with that recorded under T_4 (16.89 and 17.81%, respectively). The protein content (%) in cotton seeds varied, ranging from 14.91% to 16.89% during the year 2020. The T3 treatment had the highest protein content (16.89%), followed by the T_4 treatment (16.71%). Similarly, T_2 and T_7 exhibited comparable protein contents of 16.60% and 16.45%, respectively. In contrast, the control treatment (T_9) displayed the lowest protein content of 14.91%. Similar trends were observed during 2021, with 17.14% for T_3.. Combined application of N and S led to increased oil and protein content in rapeseed (Ahmad and Abdin, 2000). Similarly, in canola, the application of sulfur resulted in higher oil content (Ahmad *et al.,* 2007). These findings suggest that S plays a significant role in enhancing protein and oil content, which is also, be applicable to cotton as observed in our study. Consequently, the treatment supplied with SOP recorded higher oil content. Seed protein content slightly decreased with the application of calcium. This could be due the role of Ca in nutrient balance, plant physiology, plant growth and development Sawan *et al.,* (2001). However, despite the reduction in protein content, protein yield increased because the application of calcium led to a corresponding increase in seed yield.

Agronomic use efficiency

Table 5 presents the agronomic use efficiency data for the different treatments. The highest agronomic N, P, and K use efficiencies were 14.13 kg/kg, 28.27 kg/kg, and 28.27 kg/kg, respectively, in T_5 during 2020 and 14.32 kg/kg, 28.63 kg/kg, and 28.63 kg/kg, respectively, during 2021. It was observed that at the end of second year of trial (2021) NPK use efficiency under treatment T_5 increased by 76 %, compared to the conventional fertilization strategy (T_1) followed by the farmers of the study area. Agronomic efficiency is a measure of the productivity improvement achieved through the use of nutrient inputs (Fixen *et al.,* 2015). Our finding suggests that this specific treatment combination (T_5) was particularly effective in optimizing nutrient utilization and enhancing crop productivity in terms of these essential nutrients. In a separate investigation conducted by Otto *et al.* (2023)

Table 5. Effect of macronutrient mixtures on agronomic nutrient use efficiency (kg/kg) of cotton

Treatment number	Agronomic nutrient use efficiency					
	Nitrogen		Phosphorus		Potassium	
	2020	2021	2020	2021	2020	2021
T_1	7.95	8.12	15.90	16.23	15.90	16.23
T_2	8.50	8.72	17.00	17.43	17.00	17.43
T_3	6.20	6.37	12.40	12.73	12.40	12.73
T_4	5.73	5.93	11.47	11.87	11.47	11.87
T_5	14.13	14.32	28.27	28.63	28.27	28.63
T_6	10.98	11.17	21.97	22.33	21.97	22.33
T_7	11.45	11.67	22.90	23.33	22.90	23.33
T_8	11.30	11.52	22.60	23.03	22.60	23.03
T_9	-	-	-	-	-	-

comparable outcomes were observed, with CN application yielding an agronomic N use efficiency of 10.3 kg kg[1], outperforming urea which exhibited 8.3 kg/kg.

Kapas yield

The kapas yield results for cotton (Fig. 5) showed diverse responses to the various combinations of nutrient mixtures. Particularly the performance of treatment T_5, which exhibited the highest kapas yield of 2118 kg/ha in 2020 and 2123 kg/ha in 2021. This yield was 66.7% and 67.9% higher, respectively, compared to the absolute control (T_9). These findings underscore the significant impact of nutrient management strategies on cotton yield, with treatment T_5 demonstrating particularly promising results. Higher yield obtained in cotton plants treated with CN over urea aligns with the findings of Otto *et al.,* (2023). Cotton

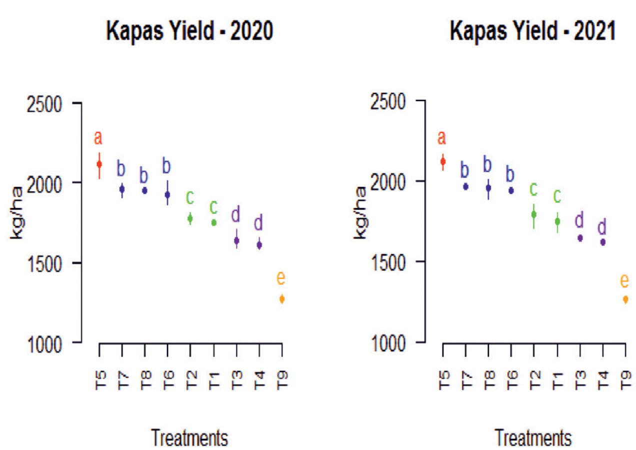

Fig. 5. Effect of macronutrient mixtures on kapas yield (kg/ha) of cotton in 2020 and 2021. Different letters for treatments indicate significant difference at p d" 0.05 by DMRT

roots can uptake both nitrate and ammonium ions for physiological processes that drive crop development and yield (Rot, 1994). Blending nitrate and ammonium forms proves advantageous for plant growth when compared to the individual application of nitrate or ammonium (Hachiya and Sakakibara, 2017). The application of CN, providing N in the nitrate form, and DAP, providing N in the ammoniacal form, offers two plant-available forms of N. This combination helps to maintain a healthy soil *p*H, as ammonium ions tend to decrease pH, while nitrate ions tend to increase it. In line with our findings, Luo *et al.,* (2023) reported that applying DAP significantly improved wheat yield in non-calcareous soil. Another study conducted by Sabir *et al.,* (2021) reported a similar finding, indicating that DAP demonstrates relatively greater effectiveness and contributes to increased plant growth in non-saline, typical soil conditions.

Calcium is the third most required nutrient in terms of uptake after K and N (Rochester *et al.,* 2012). Potassium may be positively affected the activity of cytochrome oxidase and nitrate reductase, leading to improved stomatal conductance and decreased transpiration rates—these are the physiological effects of K. Potassium application also increased lint yield and net profit (Geng *et al.,* 2020). Furthermore, K improved N absorption by promoting vegetative growth (Ali and Tatla, 2007). Plots fertilized with MOP recorded higher yield compared to those fertilized with SOP, confirming the results of Keshavarz *et al.*, (2004), who found that the maximum cotton yield in non-saline conditions was achieved with MoP. Kaviani *et al.,* (2004) also reported higher yields with MoP application in tomato compared to SOP.

In conclusion, the findings of this research study demonstrate the significant influence of various macronutrient mixtures on the growth, nutrient uptake, and yield of cotton. The incubation study provided valuable insights into the nutrient release pattern, with treatments containing CN showing increased N release. Additionally, the application of DAP in combination with MoP was beneficial for P release. In the field, application of CN + DAP + MOP (T_5) emerged as the most effective treatment, resulting in the improved growth, highest kapas yield and agronomic nutrient use efficiency. This study also revealed that fertilizer sources improved seed quality but had a non-significant effect on lint quality. Application of treatments containing CN improved primary growth indices. These findings emphasize the significance of selecting macronutrients and their effective combinations for enhancing cotton productivity. By understanding nutrient release patterns and nutrient uptake processes, farmers can make informed decisions on nutrient management practices to optimize crop yield and quality. The findings of this study have the potential to empower cotton farmers in India and other cotton-producing regions, enabling informed decisions on nutrient management for increased productivity and economic stability. Additionally, the outcomes may serve as a valuable resource for policymakers and researchers, fostering advancements in cotton cultivation practices and contributing to global food security. As cotton continues to play a crucial role in various industries, these findings hold immense potential for advancing agricultural practices and meeting the ever-growing demand for this vital crop.

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