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Impact of long-term cotton cultivation on soil fertility and nutrient dynamics in Telangana

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Abstract

Cotton is a major cash crop in Telangana, India, contributing significantly to the economy and livelihoods of farmers. However, continuous cotton monocropping has led to nutrient depletion, affecting soil fertility and productivity. This study assessed the temporal variation in available macro and micronutrient content in cotton-cultivated soils across six locations in Telangana between February 2023 and January 2024. Soil samples were analyzed for available nitrogen (N), phosphorus (P), potassium (K), iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B), and molybdenum (Mo), along with humic and fulvic acid content. The results indicated a significant decline in available nitrogen (198 to 189 kg ha⁻¹), phosphorus (22.1 to 20.6 kg ha⁻¹), and potassium (300 to 291 kg ha⁻¹). Similarly, micronutrients showed a decreasing trend, with iron, copper, manganese, zinc, boron, and molybdenum contents declined across all locations. The reductions in humic and fulvic acid content further highlighted the depletion of soil organic matter. These findings suggest that continuous cotton cropping, combined with minimal organic matter return, accelerates soil nutrient depletion.

Keywords: Cotton, fulvic acid, humic acid, macronutrients and micronutrients

Introduction

Cotton is a crucial cash crop widely cultivated in Telangana, India, due to its significant economic and industrial value. Cotton plays a vital role in the livelihood of farmers and contributes substantially to the textile industry. However, continuous monocropping of cotton without proper soil fertility management can lead to the depletion of essential nutrients, ultimately affecting soil health and crop productivity (Chen *et al.*, 2023) [2]. Understanding the variation in available nutrient content under long-term cotton cultivation is essential for devising appropriate soil fertility management strategies.

Soil fertility is a critical factor in sustaining cotton productivity, as the crop requires adequate macronutrients and micronutrients for optimal growth and yield. Macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) are fundamental for plant development, whereas micronutrients like iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B), and molybdenum (Mo) play essential roles in enzymatic activities, metabolic functions, and overall crop physiology. Imbalanced nutrient availability can lead to yield decline, reduced fiber quality, and increased susceptibility to biotic and abiotic stresses (Koné *et al.*, 2022) [6]. Therefore, assessing nutrient availability in soil is crucial for ensuring sustainable cotton cultivation.

Telangana's cotton-growing regions are characterized by diverse soil types and agro-climatic conditions, which influence nutrient dynamics in the soil. Cotton cultivation in these regions follows a distinct seasonal pattern, with sowing occurring in the *kharif* season (June to July) and harvesting completed by January. Post-harvest, the land remains fallow until the next cropping season. During the growing season, farmers apply a recommended fertilizer dose of nitrogen, phosphorus, and potassium in split applications to meet the crop's nutrient demands. Despite these inputs, nutrient depletion can occur due to continuous uptake by plants, limited organic matter return, and soil erosion, leading to a decline in soil fertility over time (Wang *et al.*, 2022) [12].

This study was conducted to evaluate the variation in available nutrient content in cotton-cultivated soils across six different locations in Telangana in February 2023 and January 2024.

The objectives were to analyze the changes in available macronutrient (N, P, K) and micronutrient (Fe, Cu, Mn, Zn, B, Mo) content over time, assess the impact of continuous cotton cropping on soil nutrient status, and identify potential soil fertility constraints.

Materials and Methods

A study was conducted to identify the variation in available nutrient content in six different cotton cultivated locations of Telangana state in February 2023 and January 2024. These sites were under continuous cotton cultivation for a minimum of ten years. In these locations, during *kharif* season, sowing was done in the months of June to July and the seeds were sown behind the plough or by dibbling with a spacing of 120 X 60 cm. A fertilizer dose of 120 kg ha⁻¹ N, 60 kg ha⁻¹ P₂O₅ and 60 kg ha⁻¹ of K₂O was applied. Nitrogen and potassium fertilisers were applied in four splits at 20, 40, 60 and 80 days after sowing, whereas phosphatic fertilizers were applied as a single dose at the time of sowing. After the crop was harvested, the land was kept fallow until the sowing of the next *kharif* crop. Soil samples were collected at a depth of 0-30 cm in February 2023 and January 2024. The collected soil samples were air dried during which stones, visible root fragments and other debris were removed. Each sample was then ground and sieved through both 2 mm sieve for the analysis of various parameters using standard protocols.

The respective samples were analyzed for available nitrogen determination by alkaline potassium permanganate method (Subbiah and Asija, 1956) ^[11], the data were recorded in kg ha⁻¹. Available phosphorus (kg ha⁻¹) in the soil samples determined by Olsen's method (Olsen *et al.*, 1954) ^[9], Available potassium (kg ha⁻¹) in the soil samples were determined by Flame photometric method (Jackson, 1973) ^[4]. The micronutrient Fe, Cu, Mn and Zn were extracted by using 0.005 M Diethylene Triamine Penta Acetic acid (DTPA), 0.01M calcium chloride dehydrate and 0.1M Tri Ethanol Amine (TEA) buffered at pH 7.3 (Lindsay and Norvell, 1978) ^[8]. Available boron and molybdenum in the soil was extracted by using AB DTPA (Gestring and Soltanpur, 1984) ^[3] using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). Significant variation in nutrient content in February 2023 and January 2024 was statistically analysed by paired t test.

Results and Discussion

Available Nitrogen

Available nitrogen content was significantly decreased from February 2023 to January 2024 in the cotton cultivated locations (Table 1). The mean available nitrogen content across these locations decreased from 198 kg ha⁻¹ in February 2023 to 189 kg ha⁻¹ in January 2024. RARS Warangal had recorded the higher available nitrogen content of 221 kg ha⁻¹ and 213 kg ha⁻¹ in February 2023 and January 2024, respectively. A slight decrease in available nitrogen content was observed in all the locations from February 2023 to January 2024. Significant difference in available nitrogen content between February 2023 and January 2024 in cotton cultivated locations might be due the lack of plant residues on the soil surface, especially under a monocropping regime resulted in loss of nutrients from the soil (Adeli *et al.*, 2021) ^[1].

Available Phosphorus

Available phosphorus content was significantly decreased from February 2023 to January 2024 in the cotton cultivated locations. The mean available phosphorus content across these

locations decreased from 22.1 kg ha⁻¹ in February 2023 to 20.6 kg ha⁻¹ in January 2024. RARS Warangal had recorded the higher available phosphorus content of 29.3 kg ha⁻¹ and 29.0 kg ha⁻¹ in February 2023 and January 2024, respectively. A slight decrease in available phosphorus content was observed in all the locations from February 2023 to January 2024. Cotton plants require phosphorus for various growth processes, including root development and fiber production. The crop might have absorbed a significant amount of phosphorus from the soil during these stages (Kovar and Funderburg, 1988) ^[7].

Available Potassium

Between February 2023 and January 2024, there was a significant reduction in available potassium in the cotton-cultivated locations. The mean available potassium content across these locations decreased from 300 kg ha⁻¹ in February 2023 to 291 kg ha⁻¹ in January 2024. Among the locations, RARS Warangal had recorded the higher content of available potassium of 352 kg ha⁻¹ in February 2023 and 348 kg ha⁻¹ in January 2024. A slight decrease in available potassium content was observed in all the locations during this period. Decrease in available potassium content from February 2023 to January 2024 might be due to the substantial potassium accumulation in cotton bolls and leaves, unlike cereals, where a significant portion remains in residues. Continuous potassium uptake by cotton, combined with the removal of crop residues instead of their incorporation into the soil, likely contributed to this depletion. The loss of potassium rich residues reduces nutrient recycling, thereby accelerating soil potassium depletion over time (Sanyal *et al.*, 2014) ^[10].

Micronutrients

Micronutrients like Fe, Cu, Mn, Zn, B and Mo concentrations were found to be increased significantly from February 2023 to January 2024 in various cotton cultivated locations (Table 2)

Available Iron

The iron (Fe) concentration in cotton varied across locations and growth stages, exhibiting a general decline from the flowering stage to harvest. At the flowering stage, the highest Fe content was recorded at RARS Warangal (253 ppm), followed by Polaram (251 ppm) and ARS Adilabad (248 ppm), whereas the lowest Fe content was observed at Chapral (238 ppm). During the boll formation stage, a slight reduction in Fe content was noted across all locations, with RARS Warangal maintaining the highest Fe concentration (251 ppm), while the lowest was recorded at Chapral (235 ppm). The decreasing trend continued at the harvest stage, where RARS Warangal still exhibited the highest Fe content (248 ppm), followed by Polaram (245 ppm), whereas Chapral recorded the lowest (233 ppm).

Available Copper

The copper (Cu) concentration in cotton varied across locations and growth stages, showing a consistent decline from flowering to harvest. At the flowering stage, the highest Cu content was recorded at RARS Warangal (24.2 ppm), followed by Polaram (23.6 ppm) and ARS Adilabad (23.3 ppm), whereas the lowest was observed at Chapral (21.4 ppm). During boll formation, Cu levels decreased across all locations, with RARS Warangal recorded the highest concentration (21.6 ppm), while Chapral recorded the lowest (18.3 ppm). By the harvest stage, Cu levels further declined, with RARS Warangal maintaining the highest content (20.5 ppm) and Chapral recorded the lowest (16.4 ppm).

Available Manganese

The manganese (Mn) concentration in cotton varied across locations and growth stages, showing a declined trend from flowering to harvest. At the flowering stage, the highest Mn content was recorded at RARS Warangal (82.3 ppm), followed by Polaram (80.6 ppm) and ARS Adilabad (79.5 ppm), while the lowest was observed at Chapral (75.3 ppm). During boll formation, Mn levels decreased across all locations, with RARS Warangal recorded the highest concentration (78.6 ppm) and Chapral recorded the lowest (70.6 ppm). By the harvest stage, Mn levels further declined, with RARS Warangal still exhibiting the highest content (76.4 ppm), whereas Chapral showed the lowest (66.4 ppm).

Available Zinc

The zinc (Zn) concentration in cotton exhibited a declined trend across all locations from the flowering stage to harvest. At the flowering stage, the highest Zn content was recorded at RARS Warangal (42.5 ppm), followed by Polaram (40.8 ppm) and ARS Adilabad (39.6 ppm), whereas the lowest Zn concentration was observed at Chapral (35.3 ppm). During boll formation, Zn levels decreased across all locations, with RARS Warangal maintained the highest concentration (38.6 ppm) and Chapral showed the lowest (31.7 ppm). By the harvest stage, Zn content further declined, with RARS Warangal (36.8 ppm) and Polaram (35.8 ppm) recorded relatively higher levels, while Chapral (30.6 ppm) remained the lowest.

Available Boron

The boron (B) concentration in cotton showed a decreased trend across all locations from the flowering stage to harvest. Among the locations, RARS Warangal exhibited the highest boron content at all growth stages, with values of 11.2 ppm at flowering, 10.8 ppm at boll formation, and 10.5 ppm at harvest. In contrast, Chapral recorded the lowest boron content throughout the crop growth stages, decreasing from 9.65 ppm at flowering to 9.48 ppm at boll formation and further to 9.25 ppm

at harvest.

Available Molybdenum

The molybdenum (Mo) content in cotton across different locations exhibited a general decreased trend from the flowering stage to harvest. RARS Warangal recorded the highest Mo concentration at flowering (0.43 ppm), which declined to 0.41 ppm at boll formation and further reduced to 0.34 ppm at harvest. In contrast, Chapral consistently recorded the lowest Mo levels, starting at 0.28 ppm during flowering and declined to 0.21 ppm at harvest.

In cotton cultivated soils, micronutrients content was found to be decreased between February 2023 and January 2024. Continuous cropping without adequate replenishment depletes the available pool of these nutrients (Wang *et al.*, 2022)^[12].

Humic acid and Fulvic Acid

Between February 2023 and January 2024, there was a significant reduction in humic acid and fulvic acid content in the cotton-cultivated locations (Table 3). The mean humic acid content across these locations decreased from 0.60 g kg⁻¹ in February 2023 to 0.56 g kg⁻¹ in January 2024. Among the locations, RARS Warangal had recorded the higher levels of humic acid of 0.68 g kg⁻¹ in February 2023 and 0.64 g kg⁻¹ in January 2024. The mean fulvic acid content across these locations decreased from 0.54 g kg⁻¹ in February 2023 to 0.49 g kg⁻¹ in January 2024. Among the locations, RARS Warangal had recorded the higher levels of fulvic acid content of 0.61 g kg⁻¹ in February 2023 and 0.56 g kg⁻¹ in January 2024. Decrease in humic and fulvic acid content from February 2023 to January 2024 might be due to the removal or burning of cotton stalks, which reduces the return of organic matter to the soil. Furthermore, without adequate organic amendments, the decomposition of existing soil organic matter exceeded its replenishment, leading to a gradual decline in humic and fulvic acid content over time (Kabir *et al.*, 2017)^[5].

Table 1: Temporal variation in available nitrogen, available phosphorus and available potassium content of soil in various cotton cultivated locations

Locations	Available Nitrogen		Available Phosphorus		Available Potassium	
	(Feb 2023)	(Jan 2024)	(Feb 2023)	(Jan 2024)	(Feb 2023)	(Jan 2024)
RARS Warangal	221	213	29.3	29.0	352	348
ARS Adilabad	208	194	24.2	22.5	306	295
Penugonda	179	176	17.5	15.2	268	256
Polaram	218	205	26.5	24.8	334	326
Chapral	170	162	15.5	14.5	256	243
Landasangvi	192	185	19.4	17.3	282	276
Mean	198	189	22.1	20.6	300	291
t cal	5.32		4.99		6.16	
t tab	2.57		2.57		2.57	

Table 2: Temporal variation in available iron, copper, manganese, zinc, boron and molybdenum content of soil in various cotton cultivated locations

Locations	Available iron (ppm)		Available Copper (ppm)		Available Manganese (ppm)	
	(Feb 2023)	(Jan 2024)	(Feb 2023)	(Jan 2024)	(Feb 2023)	(Jan 2024)
RARS Warangal	5.68	5.62	1.09	1.00	7.95	7.82
ARS Adilabad	5.53	5.46	0.92	0.87	7.73	7.64
Penugonda	4.74	4.66	0.59	0.57	7.45	7.39
Polaram	5.64	5.54	0.93	0.89	7.88	7.74
Chapral	4.06	3.98	0.52	0.49	6.15	6.07
Landasangvi	5.1	5.02	0.6	0.53	6.86	6.79
Mean	5.13	5.05	0.78	0.73	7.34	7.24
t cal	14.44		4.70		7.11	
t tab	2.57		2.57		2.57	

Locations	Available Zinc (ppm)		Available Boron (ppm)		Available Molybdenum (ppm)	
	(Feb 2023)	(Jan 2024)	(Feb 2023)	(Jan 2024)	(Feb 2023)	(Jan 2024)
RARS Warangal	0.78	0.72	0.46	0.42	0.27	0.24
ARS Adilabad	0.61	0.53	0.35	0.31	0.21	0.18
Penugonda	0.38	0.33	0.29	0.26	0.15	0.13
Polaram	0.65	0.6	0.38	0.35	0.23	0.22
Chapral	0.31	0.28	0.24	0.22	0.13	0.12
Landasangvi	0.4	0.36	0.31	0.28	0.18	0.17
Mean	0.52	0.47	0.34	0.31	0.20	0.18
t cal	7.35		10.30		4.57	
t tab	2.57		2.57		2.57	

Table 3: Temporal variation in humic acid and fulvic acid content of soil in various cotton cultivated locations

Locations	Humic acid (g kg ⁻¹)		Fulvic acid (g kg ⁻¹)	
	(Feb 2023)	(Jan 2024)	(Feb 2023)	(Jan 2024)
RARS Warangal	0.68	0.64	0.61	0.56
ARS Adilabad	0.62	0.57	0.55	0.52
Penugonda	0.55	0.51	0.49	0.44
Polaram	0.63	0.60	0.60	0.55
Chapral	0.53	0.48	0.44	0.43
Landasangvi	0.58	0.53	0.53	0.48
Mean	0.60	0.56	0.54	0.49
t cal	19.6		7.19	
t tab	2.57		2.57	

Conclusion

The study revealed a significant decline in soil nutrient content under continuous cotton cultivation across six locations in Telangana. Available macronutrients—nitrogen, phosphorus, and potassium—showed a decreasing trend, indicating nutrient depletion due to continuous crop uptake and insufficient replenishment. Similarly, micronutrient levels (Fe, Cu, Mn, Zn, B, and Mo) declined over time, highlighting the potential risks of long-term monocropping on soil fertility. The reduction in humic and fulvic acid content further suggests a decline in soil organic matter, likely due to the removal of crop residues and the absence of organic amendments. These findings emphasize the need for sustainable soil management strategies, such as balanced fertilization, organic matter incorporation, and crop rotation, to maintain soil fertility and ensure long-term cotton productivity. Implementing integrated nutrient management practices can help mitigate nutrient depletion and enhance soil health in cotton-based cropping systems.

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