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EDITED BY
Matteo Balderacchi,
Independent Researcher, Piacenza, Italy

REVIEWED BY
F. R. Echer,
University of Western São Paulo, Brazil
Abdul Rehman,
Zhengzhou University, China

*CORRESPONDENCE
Eliakira Kisetu Nassary
✉ keliakira@yahoo.com

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Effects of sowing dates and phosphorus levels on cotton growth and yield: soil analysis and implications

Jacob Shauri Tlatlaa[1], George Muhamba Tryphone[1] and Eliakira Kisetu Nassary[2]*

[1]Department of Crop Science and Horticulture, College of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania, [2]Department of Soil and Geological Sciences, College of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania

This study assessed the effects of sowing dates and phosphorus levels on cotton performance in Chato-Msilale village in Chato District, Tanzania. The soil analysis revealed that field exhibited slightly acidic soil with normal electrical conductivity but suffered from severe deficiencies in total nitrogen and organic carbon. The same field presents common issue of low cation exchange capacity, indicating limited nutrient-holding capacity. Furthermore, both fields displayed very low levels of total nitrogen (<0.1%), signaling a nitrogen deficiency. Available phosphorus was rated as medium (16.8 mg kg^{-1} soil). Trace elements fluctuated and could be managed based on specific crop requirements. The factors at different levels were: (1) sowing dates – (i) 25th November 2022, (ii) 15th December 2022, and (iii) 4th January 2023; and (2) Phosphorus levels – (i) control, (ii) 20 kg P ha^{-1}, (iii) 40 kg P ha^{-1}, and (iv) 60 kg P ha^{-1}. Regarding cotton growth and yield, sowing dates significantly ($p < 0.001$) influenced plant height, gin turnout, lint yield, number of bolls per plant, and boll weight while phosphorus levels did not exhibit significant effects. Earlier sowing dates resulted in higher yields, albeit with variations in yield components. Interactions showed that growth and yields were only numerically higher in the middle sowing date at higher levels of phosphorus applied. Overall, these insights offer valuable guidance for optimizing cotton cultivation in Chato District, emphasizing the importance of selecting appropriate sowing dates for improved yields.

KEYWORDS
crop improvement, improved livelihoods, smallholders, soil conservation, sustainable farming systems

1 Introduction

Cotton (*Gossypium hirsutum* L.) is a crucial fibre crop that serves as the backbone of the textile industry and contributes significantly to the economies of developing countries. Smallholder farmers predominantly cultivate cotton in these regions, with approximately 99% of the world's cotton farmers residing there. Asian countries (i.e., India, China, Pakistan, Uzbekistan, Turkmenistan, and Tajikistan) account for about 66% of cotton farmers, while West Africa, Egypt, South America (particularly Brazil), and other regions house the remaining 33% (EJF, 2007; Lin et al., 2023). These farmers typically work in rural settings and cultivate cotton

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on small plots, often less than 0.5 hectares, as a means of supplementing their income (EJF, 2007; Riello, 2022).

Cotton production covers roughly 2.5% of the world's arable land, equating to 30 million hectares, with a substantial portion involving crop rotation (Johnson et al., 2022; Voora et al., 2023). Around 30 million farmers depend on cotton in rotation with other crops, while approximately 20 million farmers rely solely on cotton production (Voora et al., 2023). Despite cotton's potential as an economic engine in developing rural areas, its cultivation faces various challenges related to farm inputs, influenced by environmental factors, cotton types, farmer socioeconomic conditions, and institutional policies (EJF, 2007). Conventional approaches have also contributed to the indiscriminate use of agricultural inputs, leading to environmental degradation (Iqbal et al., 2020). Furthermore, cotton yields are highly influenced by climate conditions and agronomic practices, including factors like plant density, sowing time, irrigation, and fertilization (Tuttolomondo et al., 2020). Sowing time is particularly crucial, impacting not only growth and yield but also fiber quality (Iqbal et al., 2020). It affects root penetration, vegetative growth, nutrient uptake, and solar energy utilization (Khan et al., 2017). However, selecting the optimal sowing time can be complex due to environmental variables such as air and soil temperatures and solar radiation (Iqbal et al., 2020; Tuttolomondo et al., 2020; Lin et al., 2023). Various crop husbandry challenges, such as improper plant population, water scarcity, inadequate seed rates, fertilizer mismanagement, weed infestations, insect pests, and diseases, contribute to low cotton yields (Lin et al., 2023). Phosphorus deficiency is particularly detrimental, reducing leaf expansion and photosynthesis rates. Phosphorus application enhances crop growth, nitrogen and potassium uptake, chlorophyll concentration, and dry matter yield (Jiaying et al., 2022; Khan et al., 2022). It is essential for cell division, flower bud and boll formation, and overall cotton plant development (Sun et al., 2023). Soil pH levels also influence phosphorus availability, with higher pH resulting in increased phosphorus fixation, particularly in moderately fertile soils (Johan et al., 2021; Solangi et al., 2023). Sustainable agricultural practices are critical for addressing global livelihood challenges (Ahmadzai et al., 2019; Muhie, 2022; Setsoafia et al., 2022). Understanding the intricate relationships between soil properties, sowing dates, and nutrient levels is fundamental to optimizing crop production and ensuring agricultural sustainability.

Tanzania's cotton production is substantial, with approximately 150,000 tons of seeds and 78,000 tons of lint produced each season (Baffes, 2004; Kabissa, 2016). This production spans across a variable land area ranging from 350,000 to 550,000 hectares (Kabissa, 2016). The majority of cotton cultivation, around 95%, is concentrated in the Western Cotton Growing Area (WCGA), which includes regions like Mwanza, Shinyanga, Simiyu, Geita, and others (Baffes, 2004; Kabissa, 2016). In contrast, the Eastern Cotton Growing Area (ECGA) accounts for the remaining 5% and includes regions like Morogoro, Kilimanjaro, Manyara, and others (Baffes, 2004). This geographical distribution highlights the significance of cotton cultivation in Tanzania's agriculture sector, particularly in the Western region (Kabissa, 2016). Cotton production in Western Tanzania faces challenges such as low yields and poor fiber quality, attributed to factors like displaced sowing dates, incorrect cultivar selection, soil fertility issues, weed infestations, diseases, and pests (Msigwa, 2019). Reports suggest that Tanzania's cotton lint yields are ~0.5 $t\,ha^{-1}$, which is far below their potential (1.5 $t\,ha^{-1}$) due to irregular sowing (Altenbuchner et al., 2016; Kabissa, 2016). Proper sowing timing and phosphorus application are crucial for improving cotton productivity, especially in the face of unpredictable rainfall patterns due to climate change. In the context of Chato District, representing WCGA, where cotton cultivation plays a significant role in the local economy, it is imperative to explore how these factors interplay and influence cotton growth and yield. Therefore, this study embarks on a comprehensive investigation of the physico-chemical properties of soils in Chato District, specifically in the Chato-Msilale fields. Soil characteristics, such as pH, electrical conductivity, nutrient content, and organic matter, are pivotal determinants of soil fertility and, subsequently, crop performance (Yang et al., 2020; Mazur et al., 2022; Mebrate et al., 2022). Evaluating these properties provides crucial insights into the potential challenges and opportunities for cotton cultivation in the district. Moreover, the study delves into the dynamic relationship between sowing dates and phosphorus levels—a critical aspect of cotton cultivation. Sowing dates directly impact the growth and development of cotton plants (Iqbal et al., 2020; Tuttolomondo et al., 2020; Sankaranarayanan et al., 2021), while phosphorus levels play a pivotal role in nutrient availability and overall crop yield (Beltrán and Bonilla, 2021; Nachimuthu et al., 2022; Kayoumu et al., 2023). Unraveling the main and interaction effects of these variables is essential for optimizing cotton production in Chato District. By elucidating the intricate connections between soil properties, sowing dates, and phosphorus levels, this research seeks to provide evidence-based recommendations for cotton farmers in Chato District. These recommendations aim to enhance agricultural practices, maximize cotton yield, and contribute to the sustainable development of the local agricultural sector.

The rationale of this study originates from the reality that there is no single documentation in Tanzania showing a clear conventional agriculture-based practices in the cotton industry (Altenbuchner et al., 2016; Kabissa, 2016; Msigwa, 2019). In the vast landscape of agriculture, where each decision made by smallholder farmers can significantly impact crop yield and overall productivity, the nuanced interplay of variables often remains a subject of intricate exploration (Sheahan and Barrett, 2017; Pawlak and Kołodziejczak, 2019). Among the myriad factors influencing crop growth, the strategic selection of sowing dates for cotton stands out as a pivotal determinant (Tuttolomondo et al., 2020; Sankaranarayanan et al., 2021). Concurrently, the application of phosphorus-containing fertilizers adds another layer of complexity to the agricultural equation (Johan et al., 2021). Surprisingly, in the realm of smallholder farming settings, these critical aspects—sowing dates for cotton and the judicious use of phosphorus-containing fertilizers—have not received the depth of evaluation they undeniably warrant in Tanzania. The cultivation of cotton, a cornerstone of many smallholder farming communities, hinges on the delicate balance between environmental conditions and agronomic practices (Altenbuchner et al., 2016). The timing of sowing dates emerges as a critical factor, as it directly interfaces with the intricate dance between climatic patterns and the specific requirements of the cotton crop (Tuttolomondo et al., 2020). The significance of identifying optimal sowing dates is further underscored by the potential repercussions on crop establishment, development, and, ultimately, yields. Yet, within the context of smallholder farming, where resource constraints and diverse agroecological settings prevail, the tailored evaluation of these sowing dates remains conspicuously absent (Akanmu et al., 2023).

Simultaneously, the application of phosphorus-containing fertilizers introduces another layer of agricultural intricacy.

Smallholder farmers, often operating with limited resources, must navigate the delicate balance of providing adequate phosphorus without incurring excessive costs. The relationship between phosphorus-containing fertilizers, cotton crops, and the specific contexts of smallholder farming settings demands a meticulous examination that is notably absent from the current body of research in Tanzanian cotton sector. Therefore, against this backdrop of unexplored intricacies, this research endeavors to bridge the existing knowledge gap by comprehensively evaluating the impact of sowing dates on cotton cultivation in smallholder farming settings. Moreover, it seeks to unravel the intricate dynamics of phosphorus-containing fertilizers, investigating their application in a manner that aligns with the unique challenges and opportunities presented by small-scale agriculture in the country. Through this inquiry, we aspire to unearth insights that not only enrich our understanding of cotton farming intricacies but also offer practical, context-specific recommendations for smallholder farmers navigating the complexities of sowing dates and phosphorus management. In doing so, this research aims to contribute substantively to the sustainable enhancement of agricultural practices within the realm of smallholder farming communities.

2 Materials and methods

2.1 Description of the study area

The study took place in Chato District, Tanzania, situated between 2°15′ and 3°15′ S latitude and 31° to 32° E longitude (Figure 1). The district's elevation ranges from 1,135 m to 1,141 m above sea level. Chato experiences two rainy seasons: short rains from September to December and long rains from February to May. The average annual rainfall is 850 mm, and temperatures vary between 24°C and 30°C (Msigwa, 2019).

Before starting the experiment, soil samples were collected at a depth of 0–30 cm from the fields in Chato-Msilale village. These fields were chosen based on their historical potential in cotton production, although the specific soil conditions related to available phosphorus and other potential parameters were not clear initially (Msigwa, 2019). Chato-Msilale was selected for the study due to its slightly acidic pH, which could be suitable for cotton. Available phosphorus was medium (~ 16 mg kg^{-1} soil), which could offer crop response to external application of phosphorus. Therefore, the decision to choose Chato-Msilale was informed by a comprehensive assessment of soil conditions, focusing on the limitation of available phosphorus. Factors considered for site selection included a feasibility study (not presented in the provided text), water availability for supplemental irrigation, and guidance from local agricultural officers. It is worth noting that this study represents the first field trial in Chato district involving the use of fertilizers and manipulation of sowing dates. The primary objective is to assess cotton performance under local conditions before considering scaling up production using a conventional approach in the area and in similar areas.

This study examined soil properties through various methods. Soil pH was measured using the electrometric technique in 1:2.5 soil:water suspensions, following Thomas (1996). Organic carbon was determined using the wet-oxidation method by Walkley and Black (Nelson and Sommers, 1982) and expressed as organic matter using Vant Hoff's factor (1.72). Total nitrogen was quantified using the Semi-Micro Kjeldahl method (Bremner and Mulvaney, 1982). Phosphorus extraction involved dilute NH_4F-HCl, with spectrophotometric measurement (Shio, 1996). Cation exchange capacity (CEC) and exchangeable bases, calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) were assessed by saturating soil with neutral 1 M ammonium acetate (CH_3COONH_4) and displacing adsorbed NH_4^+ with K^+ using 1 M KCl. Then, CEC was determined by the Kjeldahl distillation method. Exchangeable bases Ca, Mg, K, and Na displaced by NH_4^+ were measured via atomic absorption spectrophotometry (Sumner and Miller, 1996). Particle-size distribution was analyzed using the Bouyoucos hydrometer method (Gee and Bauder, 1986). The determination of available micronutrients, iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) involved diethylene triamine pentacetic acid (DTPA) as per the procedure by Lindsay and Norvell (1978). Measurement of these micronutrients was performed using an atomic absorption spectrophotometer. Electrical conductivity (EC1:2.5) was potentiometrically measured in a 1:2.5 soil-to-water ratio according to Okalebo et al. (2002).

2.2 Experimental design and treatments

The study was laid down as a factorial experiment arranged in a randomized complete block design (RCBD) replicated three times. There were two factors at different levels: (1) sowing dates – (i) 25th November 2022 (D1), (ii) 15th December 2022 (D2), and (iii) 4th January 2023 (D3); and (2) phosphorus levels – (i) control (P0), (ii) 20 kg P ha^{-1} (P1), (iii) 40 kg P ha^{-1} (P2), and (iv) 60 kg P ha^{-1} (P3). Given that the treatments (i.e., sowing dates × phosphorus levels) were in three replicates in each sowing date (i.e., 12 plots per sowing date), there were a total of 36 experimental plots. Phosphorus from diammonium phosphate (DAP, 46% P_2O_5) was applied during seed sowing. Based on routine soil characterization nitrogen deficiency was managed at 21 days after sowing. Since DAP contains 21% N, the equivalent rate of N applied to all plots from urea (46% N) was 70 kg N ha^{-1}, falling within the recommendations compiled by Savoy and Joines (2009). Two seeds of cotton variety UKM-08 were sown per hole at the spacing of 0.6 m between rows and 0.3 m between holes. The variety is adapted and commonly used by farmers in the area. Plot size was 2.4 m × 2.7 m (6.48 m^2) with 5 rows and 10 holes per row, making a total of 100 plants per experimental per plot (equivalent to 154,321 plants per hectare). The spacing between plots within a replicate was 0.5 m and that between replicate blocks was 1 m. During drought periods when rains were not well distributed, frequent irrigation was conducted along with the application of mulching materials to improve the water-holding capacity of the soil in the study area. Local weather station was established 2 months before setting of an experiment for which data on rainfall and temperature was collected for before, during, and after experimentation (Figure 2). However, the data coinciding with the period during when the plants were in the field is of months November 2022 to June 2023. Harvesting months were May and June 2023.

2.3 Data collection

During data collection, 30 representative plants were selected randomly in each plot and tagged with colored string. The data

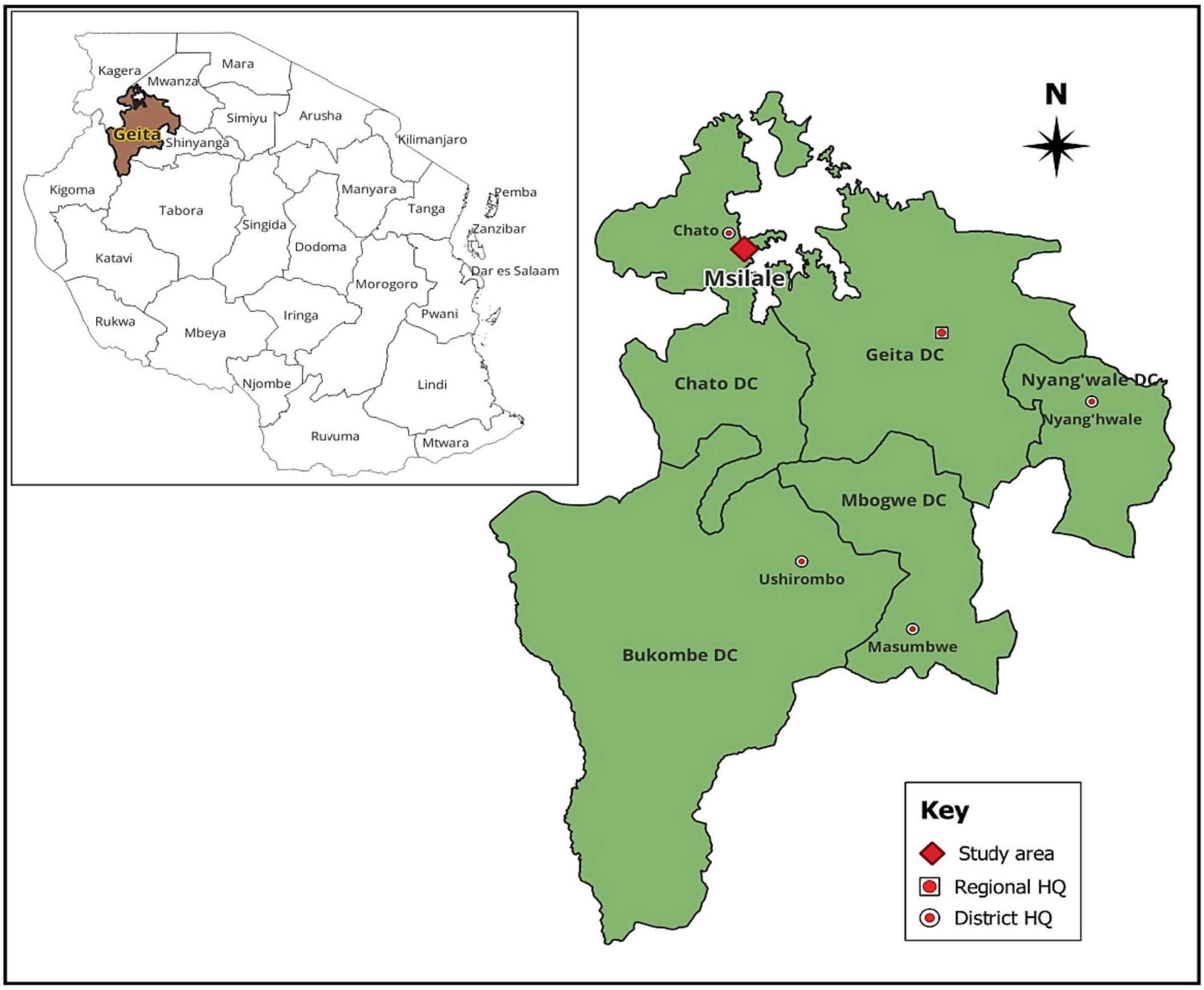

FIGURE 1
Map of Geita region showing Chato with Msilale study area where field experiment was established.

collected on growth was plant height (cm). On the other hand, the data collected on yield parameters were boll number per cotton plant, individual boll weight, gin turnout, and lint yield. Boll weight was calculated as shown in Equation 1.

$$Boll\ weight\left(g\right)=\frac{Total\ weight}{Boll\ number} \quad (1)$$

During harvest, all plants in a plot were included except the plants in the border rows and at the edges of the inner rows. Cottonseeds from the plots with different levels of phosphorus and sowing dates were weighed and equivalent yields (tons) per hectare were computed from each plot as total yield (Equation 2).

$$Y=\frac{A\times 10}{6.48} \quad (2)$$

Where Y is total yield ($t\,ha^{-1}$) and A is the quantity of cotton seed + fibre (kg) harvested in a plot.

Thereafter, gin turnout was computed (Equation 3).

$$GT=\frac{Lint\ yield}{Total\ yield}\times 100 \quad (3)$$

Where GT is the gin turnout (%).

2.4 Statistical analysis

The data was subjected to the two-way analysis of variance (ANOVA) with the sowing dates and phosphorus levels forming the main fixed effects (two factors) and replicate blocks treated as random factors. The significant treatment means were compared using standard errors of differences of means (s.e.d.) at a 5% threshold by Tukey's post-hoc multiple comparisons.

3 Results

3.1 Physico-chemical properties of the soils from the study areas

Table 1 provides information on various soil properties for the field reference in Chato-Msilale. The soil of the study area has a pH of 6.1, which is slightly acidic. This pH level indicates that the soil is somewhat acidic but still within an acceptable range for many crops. Furthermore, the electrical conductivity is 150 µs cm^{-1}, which is considered normal. This value indicates the soil's ability to conduct electrical current and can be related to its salinity. The total nitrogen content is 0.05%, which is very low. This indicates a deficiency of nitrogen in the soil, which is an essential nutrient for plant growth. The organic carbon content in the soil is 0.5%, which is low. Organic carbon is important for soil fertility, so this value suggests a need for organic matter improvement. Organic carbon content can affect soil structure and nutrient retention. In addition, the organic matter content in the soil is 0.8%, which is considered high. This indicates good organic matter content, which is beneficial for soil health and fertility. The available phosphorus in the soil is 16.8 mg kg^{-1}, which is considered medium. Adequate phosphorus levels are essential for plant growth. The levels of trace elements (i.e., Cu, Zn, Mn, and Fe) are highly variable and can be managed based on specific crop requirements.

The results show that the CEC is 2.92 cmol$_{(+)}$ kg^{-1} soil, which is relatively low. CEC measures the soil's ability to retain and exchange cations (positively charged ions), which is important for nutrient availability to plants. A low CEC suggests that the soil may have limited nutrient-holding capacity. The concentrations of calcium,

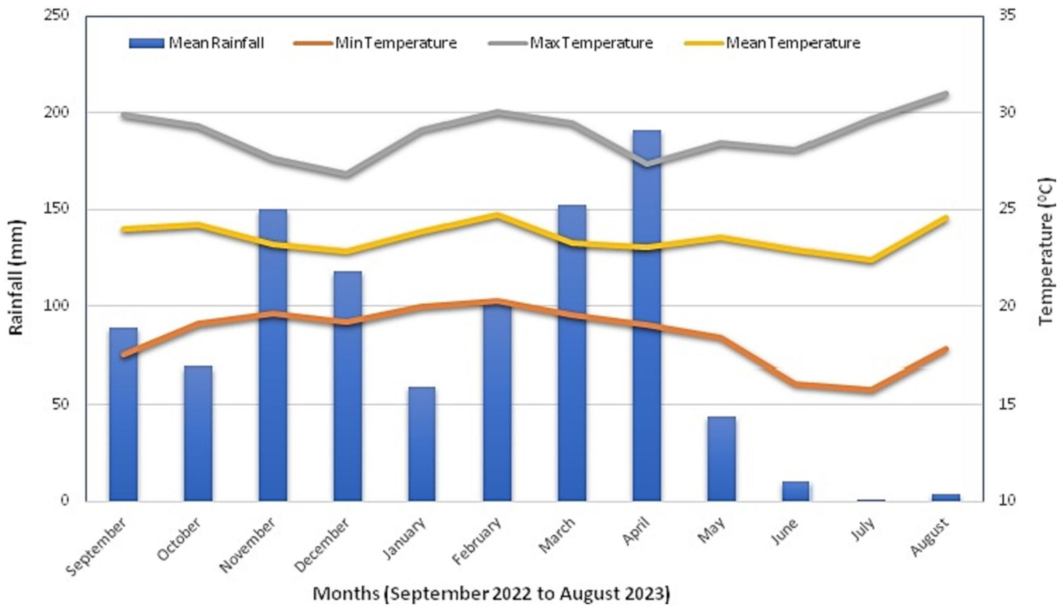

FIGURE 2
Weather (rainfall and temperature) information of the study area during the period of experimentation in Chato-Msilale site.

TABLE 1 Physico-chemical properties of the soils of the study area.

Parameter	pH (1:2.5)	EC		Total N	OC	OM		Cu	Zn	Mn	Fe	Avail. P
		µs cm^{-1}		%				mg kg^{-1}				
Value	6.1	150		0.05	0.5	0.8		0.09	0.3	5	37.3	16.8
Rating	Slightly acid	Normal		Very low				Deficient		High		Medium

Parameter	Texture (%)			CEC	Ca	Mg	Na	K
	Clay	Silt	Sand	cmol$_{(+)}$ kg^{-1}				
Value	22.84	2.92	74.24	1.71	0.27	0.13	0.52	0.71
Rating	Textural class: Sandy clay loam			Very low	Low	Very low	Medium	High

EC, electrical conductivity; N, nitrogen, OC, organic carbon; OM, organic matter; Cu, copper; Zn, zinc; Mn, manganese; Fe, iron; P, phosphorus; CEC, cation exchange capacity; Ca, calcium; Mg, magnesium; Na, sodium; K, potassium.

magnesium, sodium, and potassium are 1.71, 0.27, 0.13, and 0.52 $cmol_{(+)}$ kg^{-1} soil, respectively. These values are generally within acceptable ranges, with calcium being the highest. Calcium is important for soil structure and plant growth. However, the magnesium and potassium levels are medium and high, respectively. The field has sandy clay loam soil, which is generally suitable for agriculture. However, the low CEC indicates limited nutrient-holding capacity and slightly different nutrient profiles. Adjustments may be necessary to optimize nutrient availability for specific crops in the field, such as adding organic matter or fertilizers based on the specific nutrient deficiencies and crop requirements.

3.2 Effects of sowing dates and phosphorus on cotton growth and yield parameters

The results of the main effects of sowing dates and phosphorus levels and their interactions on growth and yield parameters of cotton are presented in Table 2. Sowing dates have a significant effect on plant height ($p = 0.001$). Phosphorus levels do not have a significant effect on plant height ($p = 0.15$). Conversely, the interaction between sowing dates and phosphorus levels is not significant for plant height ($p = 0.863$).

With yield parameters, sowing dates have a highly significant effect on boll number per cotton plant ($p = 0.023$), gin turnout ($p = 0.004$), individual boll weight, and lint yield ($p < 0.001$), indicating that different sowing dates significantly impact these variables. Phosphorus levels do not have a significant effect on plant height, boll number per cotton plant, individual boll weight, gin turnout, and lint yield ($p > 0.05$). The interaction between sowing dates and phosphorus levels is not significant for these measured variables ($p > 0.05$), as shown in Figure 3.

The results in Table 3 shows the means for various growth and yield parameters of cotton as affected by different sowing dates and phosphorus levels. Sowing date D3 results in significantly ($p < 0.001$) taller plants compared to D1 and D2. Sowing dates D1 and D2 result in significantly higher gin turnout compared to D3. Sowing dates D1 and D2 result in significantly higher lint yields compared to D3 ($p < 0.001$). There is a significant difference in the number of bolls per plant and weight of an individual boll between sowing dates, with D1 and D2 having significantly higher values of these variables compared to D3.

The provided results in Table 3 also show the impact of different phosphorus levels on various growth and yield parameters of cotton. None of the evaluated parameters differed significantly among the different phosphorus levels.

4 Discussion

4.1 Soil characteristics of Chato-Msilale village

In the context of the studied soil properties for Chato-Msilale, several key points and implications can be discussed based on cotton production. Cotton plants typically thrive in slightly acidic to neutral soils (Agegnehu et al., 2021; Gilbert and Renner, 2021). The soil has pH level within this range, which is slightly acid and displays crop response to external phosphorus input. This is generally favorable for cotton production, as extreme pH levels can limit nutrient availability (Gilbert and Renner, 2021).

Cotton is a nitrogen-demanding crop, and low total nitrogen content in the soil (very low in the study area) suggests that nitrogen fertilization will be crucial for achieving optimal cotton yields (Osanai et al., 2017; Barłóg et al., 2022). Adequate nitrogen application will help promote healthy plant growth and boll development. Organic matter content is an essential factor for cotton production (Min et al., 2021; Chen et al., 2023). The soil of the study area has relatively high organic matter content (0.8%). Higher organic matter levels contribute to better soil structure, moisture retention, and nutrient availability (Altenbuchner et al., 2016; Min et al., 2021). The soil of the study area could benefit from practices that increase organic matter, such as cover cropping and organic amendments (Chen et al., 2023). Available phosphorus is medium (16.8 mg kg^{-1}), indicating that external application of phosphorus is imperative for better crop performance. Phosphorus is crucial for cotton's early growth and root development (Koné et al., 2022). While the soil of the study area is within the normal range for the electrical conductivity, elevated electrical conductivity can affect cotton production by reducing water uptake and nutrient availability (Chen et al., 2010; Dodd et al., 2013; Ding et al., 2018; Li et al., 2023). Proper irrigation management is essential to mitigate any negative effects of salinity on cotton plants (Ibrahim, 2022).

TABLE 2 Analysis of variance (ANOVA) for the growth and yield parameters of cotton as affected by sowing dates, phosphorus levels and their interactions.

		Measured variables				
		Plant height	No of bolls/plant	Boll weight	Gin turnout	Lint yield
Source of variation	*d.f.*	F pr.				
Replication	2					
Sowing dates	2	<0.001	0.023	<0.001	0.004	<0.001
Phosphorus levels	3	0.15	0.582	0.908	0.838	0.48
Sowing dates × P levels	6	0.863	0.583	0.365	0.903	0.756
Residual	22					

d.f., degrees of freedom; F pr., test-F probability.

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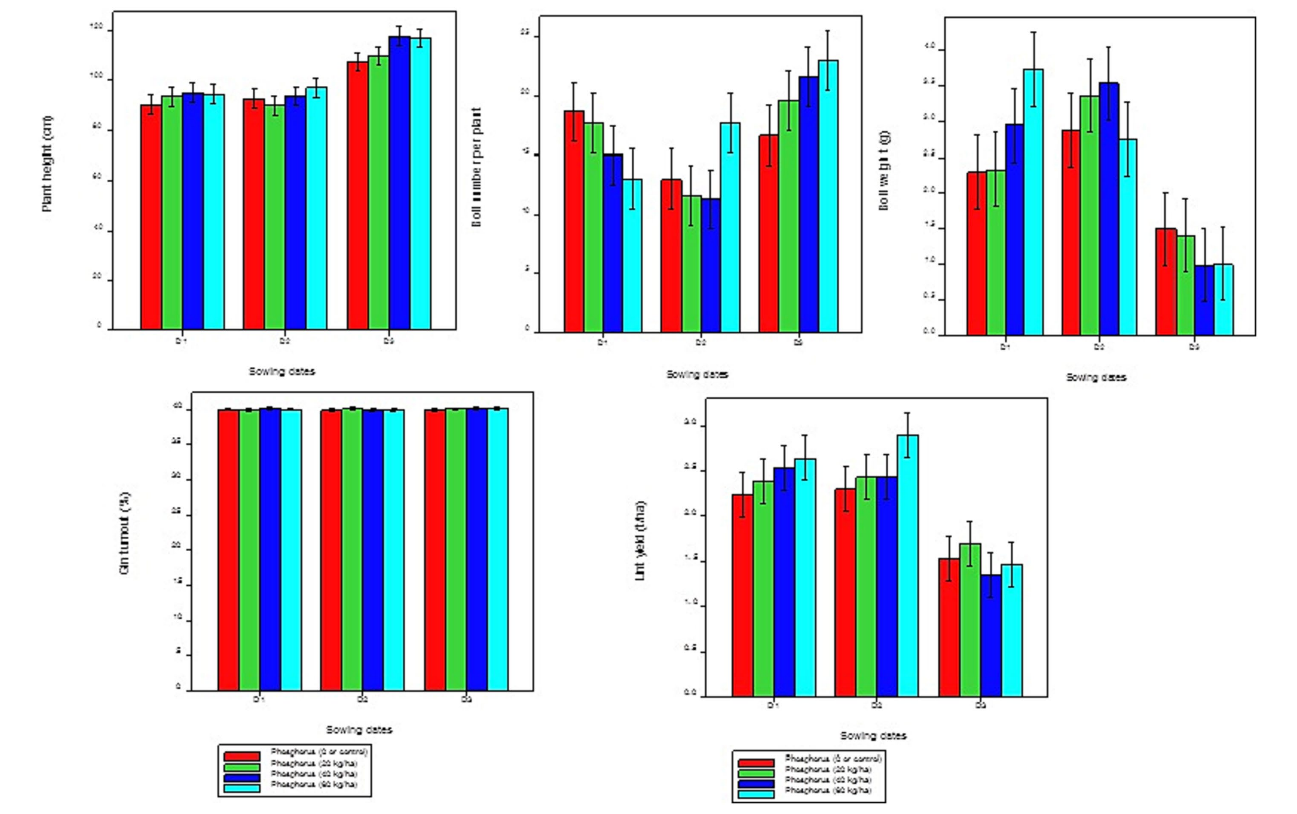

FIGURE 3
Means for the plant height, boll number per cotton plant, individual boll weight, gin turnout, and lint yield as affected by the interaction between sowing dates and phosphorus levels.

TABLE 3 Means for the growth and yield parameters of cotton as affected by sowing dates and phosphorus levels.

Factors	Treatments	Measured variables				
		Plant height (cm)	Boll number per plant	Boll weight (g)	Gin turnout (%)	Lint yield (t ha^{-1})
Sowing dates	25/11/2022	93.2[b]	18.8[a]	2.8[a]	40.08[a]	2.4[a]
	15/12/2022	93.3[b]	19.4[a]	3.1[a]	40.12[a]	2.5[a]
	4/1/2023	112.9[a]	16.4[b]	1.2[b]	39.97[b]	1.5[b]
	p-value	<0.001	0.023	<0.001	0.004	<0.001
	L.S.D. $_{(0.05)}$	5.6	2.2	0.8	0.12	0.4
Phosphorus level (kg ha^{-1})	0	96.8[a]	17.9[a]	2.2[a]	39.98[a]	2.0[a]
	20	102.8[a]	19.2[a]	2.4[a]	40.06[a]	2.3[a]
	40	102.1[a]	17.7[a]	2.5[a]	40.07[a]	2.2[a]
	60	97.6[a]	18[a]	2.5[a]	40.12[a]	2.1[a]
	p-value	0.15	0.582	0.908	0.838	0.48
	L.S.D. $_{(0.05)}$	6.4	2.5	0.9	0.31	0.4

*Means along the same column within a specific category and bearing different letter(s) differ significantly at 5% error rate.

Sandy clay loam is generally suitable for cotton cultivation (Herring et al., 2010; Wang et al., 2020). The soil texture provides good water-holding capacity while allowing for adequate drainage in cotton cropping systems (Li et al., 2005; Duncan, 2012; Mauget et al., 2021). Cation exchange capacity in the soil of the study area is relatively low at 2.92 cmol$_{(+)}$ kg^{-1} soil. Cotton plants require adequate nutrient availability throughout their growth cycle. A low cation exchange capacity may indicate limited nutrient-holding capacity in the soil, potentially requiring regular fertilization to meet the crop's nutrient needs (Räty et al., 2021; Enang et al., 2022; Shruthy, 2023). Calcium levels are 1.71 cmol$_{(+)}$ kg^{-1} soil, which is relatively low. Calcium is important for cotton plant development and plays a role in preventing diseases like blossom-end rot (White and Broadley, 2003; Said et al., 2021; Varan and Caydamli, 2021). The levels of magnesium and potassium are moderate, which can be beneficial for cotton growth (Gerendás and Führs, 2013; Shahzad et al., 2019; Xu et al., 2020; Xie et al., 2021). Shahzad et al. (2019) found that potassium application positively influenced boll setting and yields in cotton. The soil texture in the study area is suitable for cotton production. However, the low cation exchange capacity and relatively low calcium levels suggest that regular fertilization with calcium-containing amendments may be necessary.

Chato-Msilale soil is prominently accompanied by a number of challenges, including a low cation exchange capacity and the need for managements. Wang et al. (2020) found that the highest yields in cotton followed the soil texture trend of loam > clay > sand. Trace elements (Cu, Zn, Mn, and Fe) are essential for cotton nutrition but they highly vary in the study areas. The concentrations of these micronutrients should be within optimal ranges (Khoshgoftarmanesh et al., 2010; Bahamonde et al., 2019). More soil tests can help determine if any of these elements need to be supplemented through fertilization.

4.2 Influence of sowing dates and phosphorus levels on cotton performance

The results indicate that sowing dates have a significant impact on various growth and yield parameters of cotton, including plant height, boll number per cotton plant, individual boll weight, gin turnout, and lint yield. Plant height varies significantly with different sowing dates, with sowing date D3 resulting in significantly taller plants compared to D1 and D2. The taller cotton plants recorded in late sowing could be explained by the extended duration for vegetative growth in a season. Wang et al. (2023) report that late sowing in cotton accelerates leaf aging, promoting vegetative growth and concentrated boll opening for mechanical harvesting, but it delays physiological maturity, potentially diminishing cotton yield. Gin turnout and lint yield all exhibit significant differences based on sowing dates. The sowing dates D1 and D2 result in significantly higher yields compared to D3. The differences in cotton gin turnout among the various sowing dates might seem subtle at first glance, but in agricultural studies, even small variations can have significant practical implications (Echer et al., 2019). The differences in gin turnout between the sowing dates D1 and D2 is not statistically significant, but they differ significantly with the sowing date D3.

The number of bolls per plant and weight of an individual boll vary significantly with sowing dates, with sowing dates D1 and D2 outperforming sowing date D3. Overall, these results suggest that the choice of sowing date can have a substantial impact on cotton growth and yield. In particular, sowing date D3 appears to lead to taller plants with more leaves but lower yields, while D1 and D2 result in higher yields. The significance of these findings underscores the importance of selecting the appropriate sowing date for cotton cultivation to optimize both growth and yield. However, sowing date D3 generally resulted in inferior performance in terms of yield parameters. Therefore, it is important to consider these results in the context of local conditions and other factors that may influence cotton growth and yield.

In the present study, sowing dates D1 and D2 produced higher gin turnout of 40.08 and 40.12%, respectively relative to gin turnout of 39.97% recorded in sowing date D3, with the same trend realized for the separate yields of lint. Previous studies have found varying performance of cotton as affected by sowing dates, nutrient inputs, and sowing densities (Guzman et al., 2019; Li et al., 2021; Abaza et al., 2023). Importantly, parameters widely reported to be affected include plant height, number of branches, fruiting nodes, number of bolls, boll retention rate, seed cotton yield, and lint yield (Khan et al., 2017, 2019; Tuttolomondo et al., 2020). Khan et al. (2017) found that in early sowing cotton lint yield was 26% higher than late sowing, and attributed this increase to a relatively longer duration of the crop in the field through the cropping season, which maximizes period for the utilization of growth resources. In assessing cotton in three sowing dates, Tuttolomondo et al. (2020) found that cotton lint yield was 1.6 $t\,ha^{-1}$, with the highest ~2 $t\,ha^{-1}$ recorded at early sowing. Sharif et al. (2020) found that early sown cotton produced seed yield ~3 $t\,ha^{-1}$ higher than seed yield ~2 $t\,ha^{-1}$ recorded in late sown cotton. Zhang et al. (2017) conducted field experiments in 2014 and 2015 in Inner Mongolia to test the effect of sowing dates (20-April, 30-April and 10-May) on cotton parameters (i.e., yield, fibre quality, lint production efficiency) and nutrient (i.e., N, P, and K) uptake and utilization. Zhang et al. (2017) found that middle sowing date (30-April) was superior to other sowing dates for all measured variables in cotton. According to Zhang et al. (2017), the middle sowing date produced the highest seed cotton yield (~ 7 $t\,ha^{-1}$) and lint yield (~ 3 $t\,ha^{-1}$).

The present study also investigated the main effect of phosphorus levels on growth and yield parameters in cotton. The differences in gin turnout of cotton between the phosphorus levels are relatively small. These results do not provide enough evidence to conclude that the variation in cotton gin turnout is due to the variation in phosphorus levels. Although there is a slight increase in cotton gin turnout with increasing phosphorus levels, the differences observed (e.g., from 39.98 to 40.12%) are not statistically significant. This finding implies that the practical significance of the observed differences may be limited. Similar to gin turnout, there is a slight increasing trend in lint yield, starting at 2.0 $t\,ha^{-1}$ at absolute control and reaches 2.3 $t\,ha^{-1}$ at 20 kg P ha^{-1}. The observed differences in yield parameters are smaller than the L.S.D. values, reinforcing that the differences are not statistically significant. The trends in gin turnout and lint yield are not consistent and do not exhibit a clear pattern of increase or decrease with increasing phosphorus levels. However, application of phosphorus at 20 kg P ha^{-1} provides a numerical increase observed in the measured variables. Many factors could have contributed to these inconsistent results, including imbalanced nutrition (Li et al., 2019). The soil test result in the present study indicates a moderate level of phosphorus in the soil (16.8 mg P kg^{-1} soil). This level of phosphorus may be suitable but not sufficient for cotton growth and yield. Based on the work of Savoy and Joines (2009), the optimal phosphorus application rate for soils with medium available phosphorus is in the range of 15 to 20 kg P ha^{-1}. This is attributed to the fact that the availability of phosphorus in soil is not solely determined by its total content; factors like soil pH, organic matter, and microbial activity also play a role (Bueis et al., 2019). In acidic soils, phosphorus tends to become less available, while alkaline conditions can lead to its precipitation and reduced uptake by plants (Zhu et al., 2021). Additionally, phosphorus can form complexes with other elements in the soil, limiting its accessibility to plants (Johan et al., 2021). The results observed in the present study could be attributed to the imbalance between phosphorus and other essential nutrients, such as nitrogen, potassium, and micronutrients, in the soil and their adequacy to cotton plants (Singh et al., 2013; Santos et al., 2021; Shah et al., 2022; Shao et al., 2023). An imbalanced nutrient profile can affect cotton yield even if phosphorus levels are sufficient (Sekhon and Singh, 2013; Iqbal et al., 2020; Solangi et al., 2023).

The interaction between sowing dates and phosphorus levels is not significant for plant height, suggesting that the effect of sowing dates on plant height is consistent across different phosphorus levels, and vice versa (Iqbal et al., 2023). Similarly, the interaction is not significant for the number of leaves per cotton plant, implying that the influence of sowing dates on the number of leaves and the influence of phosphorus levels on the number of leaves are consistent and do not interact significantly (Khan et al., 2019). For all yield parameters of cotton, the interaction between sowing dates and phosphorus levels is not significant (Sawan, 2017; Guo et al., 2023; Pinnamaneni et al., 2023). This indicates that the combined influence of sowing dates and phosphorus levels does not significantly affect these yield parameters (Iqbal et al., 2020; Sankaranarayanan et al., 2021; Wang et al., 2021). These findings suggest that the effects of sowing dates and phosphorus levels on cotton yields appear to act independently of each other (Khan et al., 2019). These results suggest that, in this specific experiment, the effects of sowing dates and phosphorus levels on cotton growth and yield are largely independent and do not strongly interact (Killi and Bolek, 2006; Qamar et al., 2016; Atta et al., 2023). However, it is essential to consider such interactions in agricultural experiments as they can provide insights into how different factors influence crop performance and help in making informed decisions for crop management (Tian et al., 2023). This study opens a need for further analysis of the economics of phosphorus fertilizer used in cotton production, which is discussed in another study. Similar to this study, Iqbal et al. (2020) reported that elevated phosphorus rates improved nutrient accumulation, reproductive organ biomass, and yields in cotton relative to the absolute control. Interactions between sowing dates and manipulated cropping practices have been reported to have significant positive effect on growth and yield parameters of cotton (Jalota et al., 2008).

The choice of phosphorus levels in soil management is crucial (Balemi and Negisho, 2012; Johan et al., 2021). The findings of the present study likely show that higher phosphorus levels may lead to better cotton yields, but the effect may depend on the timing of sowing (Nachimuthu et al., 2022; Wang et al., 2022). It is also likely that the data may reveal trade-offs between seed yield and lint yield (Jiang et al., 2019; Conaty and Constable, 2020). For instance, increasing phosphorus levels or changing sowing dates might boost seed production but could potentially reduce lint yield or vice versa. This study also reveals that the number of bolls on cotton plants is directly affected by the interaction between sowing dates and phosphorus levels (Ahmad et al., 2019; Sun et al., 2022, 2023). Understanding this relationship can help in crop management to encourage more boll formation, which, in turn, can lead to higher cotton yield (Khan et al., 2019; Li et al., 2022; Guo et al., 2023). These findings can guide farmers and agronomists in tailoring their crop management strategies to suit local conditions and resource availability. In addition, sowing dates and phosphorus fertilization practices can be optimized to achieve desired outcomes in terms of total yield, seed yield, lint yield, and boll count (Mauget et al., 2019). Despite the observed trend in interaction between sowing dates and phosphorus levels, these findings stem from scientific research based on field experiments. The results emphasize the importance of empirical data collection and analysis to make informed decisions in agriculture. Therefore, these insights may be used as a basis for further experiments and refinements in farming practices. The interaction illustrates the complex relationship between sowing dates and phosphorus levels in cotton farming and how this it affects various aspects of cotton yield towards enhancing crop production and overall farm profitability.

5 Conclusions and recommendations

5.1 Conclusion

In conclusion, the study conducted in Chato District, Tanzania, aimed to assess cotton performance under local conditions by investigating the impact of different sowing dates and phosphorus levels on soil properties, plant growth, and yield parameters. The soil analysis in the study area revealed variations in pH, electrical conductivity, organic matter, and nutrient levels.

The study's key findings emphasize the substantial impact of sowing dates on various cotton parameters, including plant height, boll number, individual boll weight, gin turnout, and lint yield. Notably, sowing dates D1 and D2 proved to be more favorable, resulting in higher yields compared to sowing date D3. The analysis revealed no significant influence of phosphorus levels on the measured parameters, indicating that the applied phosphorus levels did not notably affect cotton growth and yield. The interaction between sowing dates and phosphorus levels did not yield significant effects. Overall, these insights offer valuable guidance for optimizing cotton cultivation in Chato District, emphasizing the importance of selecting appropriate sowing dates for improved yields.

5.2 Recommendations

In light of these findings, it is recommended to consider the optimal sowing dates, specifically favoring D1 and D2, for better cotton yield in Chato District. Additionally, further investigations may be needed to explore the potential benefits of adjusting phosphorus levels or exploring other soil amendments to enhance soil fertility and improve cotton performance.

Furthermore, it is worth noting that this study represents the first field trial in Chato district involving the use of fertilizers and manipulation of sowing dates. Therefore, future research could build upon these findings and explore additional factors that may influence cotton production in the district and similar areas.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JT: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. GM: Data curation, Formal analysis, Methodology, Software, Supervision, Writing – review & editing. EN: Data curation, Formal analysis, Methodology, Software, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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