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Analyze Climatic and Edaphic Factors for Ethiopia Cotton Production and Quality

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ABSTRACT

Cotton is crucial to Ethiopia's economy, providing livelihoods through production, processing, and trade, impacting millions nationwide. The demand for cotton is projected to rise significantly due to expanding spinning mills and textile industry parks. However, Ethiopia continues to import cotton due to insufficient domestic production and quality issues. Factors such as soil fertility, type, temperature, and rainfall are pivotal in determining cotton production and quality, akin to other agricultural crops. Understanding these climatic and demographic variables is essential for identifying optimal locations for cotton cultivation. This study delves into how Ethiopia's climatic and soil conditions affect cotton quality and yield. The research underscores climate change's profound impact on cotton output. Lower temperatures during germination phases reduce productivity, while adequate rainfall is critical for growth and flower maturation. Conversely, excessive rainfall during fiber maturation and harvest diminishes productivity and quality. Elevated temperatures during seedling, growth, and blooming phases benefit cotton production when accompanied by sufficient rainfall. Conversely, high evaporation rates, elevated temperatures, low humidity, and minimal rainfall negatively correlate with cotton flower and boll production, possibly due to water stress induced by evaporation. In conclusion, selecting suitable areas for cotton cultivation in Ethiopia requires a thorough understanding of how climatic and soil conditions influence productivity. The findings from this research can empower farmers to make informed decisions about cotton farming practices, potentially leading to improved production outcomes and sustainability. Addressing these challenges and leveraging favorable climatic conditions could reduce Ethiopia's reliance on cotton imports, bolstering the local cotton industry and benefiting both the economy and livelihoods. Continued research and targeted agricultural strategies are essential for navigating climate variability complexities and optimizing cotton cultivation practices in Ethiopia.

Keywords: Cotton, Productivity, Quality, Rainfall, Climate variability, Fiber strength

1. INTRODUCTION

A valued economic product, cotton is generated from the cotton plant and is an essential source of high-quality fiber for the textile industry. Because millions of people are employed and receive revenue from its production, processing, and selling, it is an essential economic engine in many nations. Cotton is grown by smallholder farmers mostly in Africa, where it is a major cash crop in irrigation and rain-fed agricultural systems [2]. Compared to other countries, cotton cultivation costs in Africa are relatively lower. Despite the vast potential for cotton production in Africa, the region's share in the global market stands at only 12% [1].

Ethiopia, as part of sub-Saharan African countries, also engages in cotton production with a long-standing tradition in the field. However, Ethiopia’s contribution to total cotton production in Africa is relatively low, accounting for only 5% [3]. Based on available reports, it is evident that despite having ample land resources for abundant cotton production, Ethiopia has faced challenges in achieving optimal performance in both cotton production and marketing of cotton products.

Cotton consumption is projected to rise significantly compared to the previous year. The increase is based on growing demand from existing and newly installed spinning mills and an increased number of textile industry parks. So, those existing and newly installed spinning mills need a high amount of good quality cotton fiber. However, the study shows that Ethiopia currently cultivates 3% of the total 2.6 million hectares that are suitable for cotton production.

The current annual production of cotton fiber is low and itis consumed by the domestic textile industry. The majority of Ethiopia's cotton cultivation takes place in the Awash Valley, Gambela, Humera, Danesha, and Metema. The country is still importing raw cotton to satisfy the domestic and of its textile factories [9]. Therefore, the country imports cotton because of a shortage of raw cotton and poor quality of domestic cotton fiber. Cotton fiber quality is defined by the physical properties that relate to its spin ability into yarn and contribute to textile performance and quality. Cotton fiber quality plays an important role in determining the spinning performance of final yarn quality parameters. the major parameters considered to determine the quality of the cotton material are Fineness(count), Fiber length, Fiber tensile strength, Fiber elongation, trash content, and Fiber maturity index/ratio [4].

Testing and managing raw material cotton quality and consistency is critical to the profitability of a spinning mill [6]. As cotton prices continue to rise, and considering that the raw material is the largest cost in producing yarn, reliable instrument-based fiber quality measurements, and benchmarks are the essential tools for controlling costs. As multiple factors are involved in deciding cotton productivity, yield, and quality are highly interrelated to climatic conditions and soil nutrients.

Climate affects crop growth interactively; sometimes resulting in unexpected responses to fundamental conditions. Many factors; such as length of the growing season; climate (including solar radiation; temperature; light; rainfall; and dew); availability of nutrients and soil moisture; and cultural practices affect cotton yield and quality. The balance between vegetative and reproductive development can be influenced by soil fertility; soil moisture; cloudy weather; and perhaps other factors such as temperature and relative humidity [8].

Though little is known so far, temperature, rainfall levels (water availability), and soil type can affect the quantity and quality of cotton fiber. Amibara and Metema are the main cotton production areas in Ethiopia however there is no significant research conducted yet on the climatic and edaphic factors behind cotton growth, yield, and quality in both study areas. To fill these gaps, this research work subsequently investigated the matching degree between the simulated demographic and climate suitability conditions with cotton production and quality.

2. MATERIAL AND METHODS

2.1 Overview of the study area

This research was conducted in Metema, located in the Amhara regional state, and Middle Awash of the Afar regional state due to their significant cotton production. Metema, situated in the West Gonder zone of the Amhara region, is renowned for its high potential for cotton cultivation. The district is approximately 830 km northwest of Addis Ababa, 190 km west of Gondar, and 340 km west of Bahir Dar. Amibara, on the other hand, is located 250 km northeast of Addis Ababa, the capital city of Ethiopia, with a geographical location of 9.26°N to 9.45°N latitude and 40.15°E to 40.25°E longitude It is shown in Figure 1.

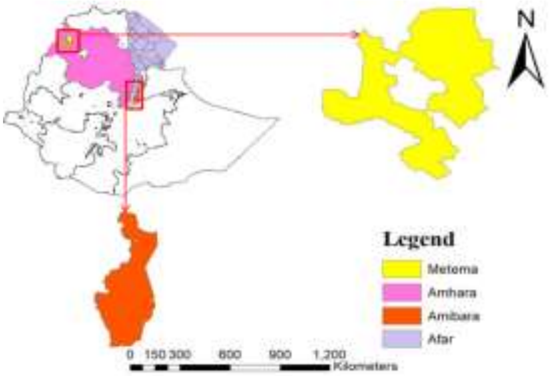

Fig 1. Map showing the study area location

2.2 Data collocation

The research utilized both primary and secondary sources of data. The study selected areas covered by cotton crops in hectares, cotton yields in kilograms, and climatic data from 2018 to 2022 in the district as indicators to assess the suitability of land for cotton cultivation based on data availability and research objectives.

Primary data: Primary data for the study was collected from various sources including farmers in selected kebeles, ginneries, and spinning mills that utilize cotton fiber as a raw material. Qualitative data was gathered through methods such as questionnaires and interviews. Instead of using a fully structured questionnaire, an interview guideline was prepared to ensure comprehensive coverage of all relevant aspects during the interviews and discussions.

Secondary data: The research utilized secondary data from various sources, including published papers from journals, government publications, public records, historical and statistical documents obtained from agricultural statistics (crop reporters), the Ethiopian Investment Agency, the Ethiopian National Metrology Agency, Wereda Agricultural Offices, ginneries, and spinning textile factories. Additionally, data from governmental and non-governmental offices related to cotton production and marketing were included in the study.

Variables: For statistical analysis, the following data on the variables were collected: Cotton Productivity (Yield), the area covered under cotton crop, and Climate data.

(a) Cotton Productivity (Yield) is determined by the amount of seed cotton produced per hectare and is used as a target variable to assess the influence of soil and climate variables on cotton crop production and quality. Production and input data from the Metema and Amibara Wereda Agricultural Offices between 2018 and 2022 were obtained for analysis. The yield variable was utilized to evaluate the relationship between soil, climate change, and the quality and productivity of cotton.

(b) Area covered under cotton crop: The area under the Cotton crop (land) is an important variable that helps identify the return to scale in the production of the crop. The variable is measured in hectares.

(c) Climate data (minimum temperature, maximum temperature, relative humidity, and rainfall) was obtained from the Ethiopian meteorological agency Bahirdar service branch for the period of 2018 to 2022 used in the study. Climate change variables relate to mean monthly temperature and precipitation.

Phonological stages of cotton: The cotton production cycle is divided into four stages based on the phonological characteristics of the cotton plant. Sowing of cotton begins in June, while harvesting starts in the first week of December. The stages of the cycle are as follows: germination (0-30 days), vegetative growth (30-120 days), flowering and fruit formation (60-150 days), and maturity period (120-180 days). Additionally, there is a vegetative state (30-120 days) during which the stem and leaves develop [5].

2.3 Sample size and allocation in agricultural farms

In this study, cotton yield data for the previous five years was gathered from the agricultural office in Metema for 20 kebeles, as well as five years' worth of metrological data from the Ethiopian metrology agency Bahirdar Service Center.

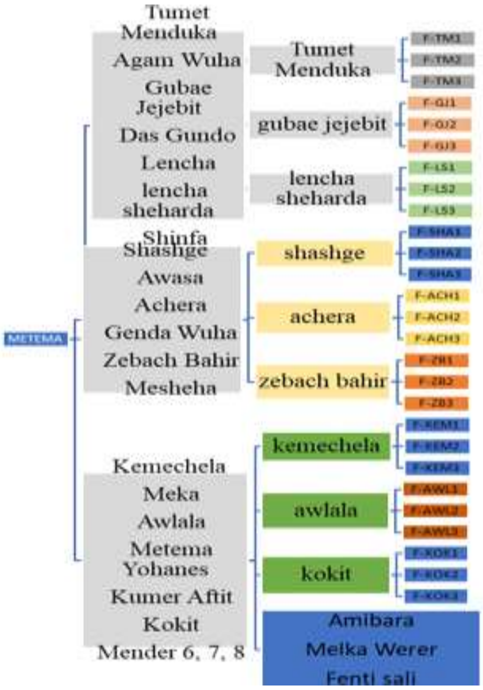

Fig 2. Purposive sampling of farms

Our classification of high, medium, and low production areas is based on farm output yield, as shown in Table 1. In addition, yield data for the previous two years was gathered from the agricultural offices of Amibara Melka Werer, Fenti Sali, and Amibara Kebele, as well as two years' worth of metrological data from the Ethiopian metrology agency Samara Service Center. Based on the above data we selected farms by purposive sampling techniques as shown in Figure 2.

2.4 Soil sampling, soil chemical, and physical analyses

To ensure consistent conditions across the site, the area was divided into sections. Samples were taken from each section where noticeable variations in soil, crop development, or yield were observed. Field observations of topographic variations, surface soil texture, and farmer experience were used to identify uniform areas. Within each area, subsamples were collected from every farm and evenly spread across the region. The number of subsamples combined per area sampled depended on the variability of the soil. A soil probe was used to collect subsamples by pushing them down to depths of 20, 40, and 60 cm. After pulling out the probe, the sample was placed in a clean bucket.

This process was repeated for each subsample spot, placing all samples in the same bucket. By combining multiple subsamples taken from the same region, a composite sample was created. In the field, a subsample was taken from each composite sample specifically designated for chemical property analysis to determine the levels of nitrogen (N), phosphorus (P), and potassium (K). Soil fertility is recognized as a significant factor influencing fiber quality. Soil nutrients, particularly nitrogen, play a crucial role in plant growth and metabolic activities, ultimately affecting fiber quality [8]. Phosphorus is essential for various compounds in plants, including nucleic acids, enzymes, proteins, and lipids, which also influence fiber properties and control important growth processes.

Potassium directly impacts productivity and fiber quality by influencing water relations, photosynthesis, respiration, enzyme activation, and transpiration. Besides this, we examine those three basic chemical properties and some physical properties like Ph and water holding capacity using the standard procedure for each element.

A milligram of a particular chemical per kilogram of soil or a milligram of chemical per liter of soil solution extract may be mentioned in the soil test report. Depending on the extraction technique and the kind of examined element, PPM can refer to a variety of ratios. 1 ppm stands for mg/kg when referring to components that are extracted from the exchange complex using a chemical extractant (1 ppm = 1 mg/kg) and ppm often refers to mg/L when an element's concentration in a soil solution is measured using only water for the extraction (saturated paste extract, 1:2 extract, etc.). The reason is that in chemical extraction, the amount of the element available in the soil, but attached to soil particles, is determined, while extraction with water is used to determine the concentration of the element in the soil solution.

2.5 Cotton sampling and methods for testing cotton fibers

After the cotton fibers are separated from the seed at the ginning mill, a sample is taken before they are pressed into bales. To assess the quality of the cotton, a widely used sampling method called the Zoning method approach is employed. This technique, known as zoning, is utilized to select samples from unprocessed cotton (Figure 3). Cotton's physical characteristics can vary significantly from region to region and even within areas. Due to the non-uniformity of cotton in bulk, multiple sub-samples must be randomly taken from different locations within the bulk. When sampling from cotton bales, a required number of fibers are selected one by one from various parts of the bale. The moisture content of the cotton samples is adjusted to a predetermined range in a climate-controlled chamber once they are placed inside the classing office.

2.6 Measuring fiber trash content

To evaluate the lint quality of a cotton sample, it is essential to measure the amount of trash or non-lint content present [7]. The Shirley Analyzer is a laboratory instrument developed at the Shirley Institute in Manchester, England, that provides an effective method for both quantitative and qualitative assessments of foreign matter in cot-ton lint (Figure 4). Shirley Analyzer separates waste from lint with minimal fiber loss, making it the most efficient method for completely separating lint from foreign object

Fig 3. Preparation of fiber samples for testing

Fig 4. Shirley trash analyzer machine and sample testing

2.7 Measurement of fiber trash content

To assess cotton lint quality, measuring non-lint content is crucial [7]. The Shirley Analyzer, developed at the Shirley Institute in Manchester, England, efficiently quantifies and qualifies foreign matter in cotton lint (Figure 4). This laboratory instrument effectively separates waste from lint with minimal fiber loss, making it highly efficient for comprehensive lint purification and foreign object removal.

2.8 Measurement of fiber strength

Pressley strength tester is used to determine the bundle of fiber strength of textile raw materials, which is finally, expressed in Pressley valve for example tensile strength in g/tex [10]. The use of Pressley requires a torsion balance of up to 5 mg and 0,01 mg accuracy. An instrument of a Pressley strength tester determines the resistance of cotton fibers.

2.9 Measurement of fiber length

Fiber length is one of the most important characteristics of cotton that contributes to increased yarn strength, spin ability, and fewer end breaks during spinning. The presence of short fibers in yarn can lead to increased wastage, yarn irregularity, poor appearance, and end breakages. The fibrograph is used to extract the upper half mean length, mean length, and uniformity index by applying tangents to the curve. Digital fibrographs has replaced dial gauges with push-button digital counters, automating the length measurement process. This method calculates parameters such as 2.5%, 50% span length, uniformity index, short fiber%, short fiber content (SFL), and floating fiber index. Span lengths are the lengths that extend into the draught zone, and the fibrogram is produced by calculating the cumulative frequency distribution of the span length. This test method is significantly faster than array methods frequently used in fiber laboratories for assessing fiber length and length distribution. A photoelectric device called a fibrograph instrument is used to perform these tests.

3. RESULTS AND DISCUSSION

3.1 The effects of climate variability on cotton yield

3.1.1 Effects of temperature and humidity

According to the findings, an increase in temperature during the sowing season, coupled with sufficient rainfall, promotes higher cotton yields. Warmer temperatures during fiber maturation and picking stages also enhance crop yield. Temperature predominantly influences plant growth and development, with air temperature being a primary meteorological factor affecting cotton output. Heat stress reduces fruit retention, leading to lower lint yields, delayed crop maturity, and reduced lint quality. Cotton seed germination is notably sensitive to planting-day temperatures below optimal levels, affecting germination rate and percentage. Ideal germination occurs between 20°C to 30°C, facilitating faster growth without significant reductions in germination percentage. Rising temperatures can shorten the growing season, potentially decreasing cotton's developmental stages and impacting overall crop yield and quality. The temperature effect on production of cotton is shown in Figure 5.

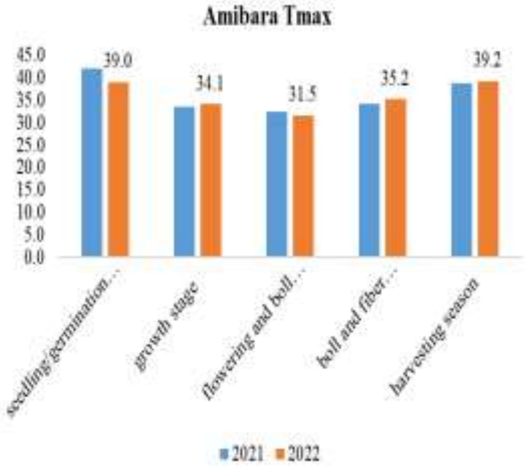

Fig 5. Temperature effect on production of cotton

Table 1. Average production of each kebele

S.No.	Metema Wereda Kebeles	Avg. cotton production (kg/hector) from 2018-2022 in Methama and year 2021-2022 in Amibara	Level
1	Tumet Menduka	1121	High Production
2	Agam Wuha	1120	>>
3	Gubae Jejebit	1023.8	>>
4	Das Gundo	1014.8	>>
5	Lunch	948	>>
6	Lencha Sheharda	918.8	>>
7	Shinfa	904	>>
8	Shashge	896.4	Medium Production
9	I was awasa	887.4	>>
10	Achera	846	>>
11	Genda Wuha	731.4	>>
12	Zebach Bahir	727.2	>>
13	Mesheha	712	>>
14	Kemechela	696.6	Low Production
15	Meka	694	>>
16	Awlala	632	>>
17	Metema Yohanes	622.6	>>
18	Kumer Aftit	545.8	>>
19	Kokit	475.2	>>
20	Mender 6, 7, 8	469	>>
21	Amibara	957	High production
22	Melka Werer	824.8	Medium production
23	Fenti sali	710.6	Low Production

Table 2. Impact of rainfall variability on cotton productivity in Metema (M) and Amibara (A)

Month and year	Average rainfall (mm)					Average rate of production (kg/hr)
	Seedling/germination establishment	Growth stage	Flowering and Boll development Season	Boll and fiber maturation season	Harvesting season	
Metema-2018	169.0	251.1	218.9	21.2	0.0	814.9
Metema -2019	259.5	213.3	184.8	33.4	0.0	780.15
Metema -2020	158.8	211.7	170.1	4.8	0.0	707.95
Metema -2021	194.6	204.6	156.7	42.7	0.0	762.2
Metema-2022	295.1	253.6	174.8	19	0.0	936.65
Amibara-2021	152.4	259	167	4.8	0.0	872.6
Amibara-2022	186.8	287	170.72	12.4	0.0	810.4

3.1.2 Impact of precipitation

In semi-arid regions, moisture is the most restrictive element for crop production, posing the greatest threat to cotton yields. Seasonal rainfall fluctuations are a significant factor in agriculture and are analyzed using rainfall data from the five years between 2018 and 2022 for seven months (June – December). The table's monthly rainfall variability demonstrates that as rainfall increases, so does agricultural yield.

During the growth and development period, the highest rainfall recorded was 225 mm per month.

Effect of soil on cotton productivity:

Soil pH: - The study results indicate that the pH values of the surface soil ranged from 5.7 to 6.8, while the subsurface pH also ranged from 5.7 to 6.8. This suggests that the soils are moderately acidic to neutral, as shown in Figure 6.

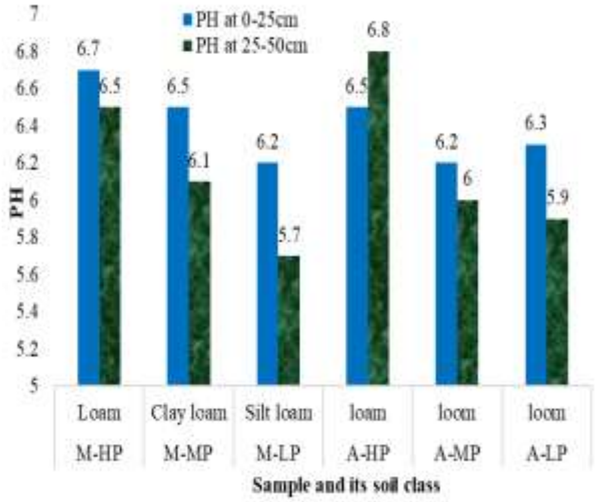

Fig 6. Soil pH values vs Soil samples

3.1.3 Effect of Nitrogen

The study found that the total nitrogen concentration in the surface soils ranged from 0.04 to 0.12%. At greater depths, specifically 25 to 50 cm, the range widened to 0.02 to 0.13%, which is classified as low to medium, as depicted in Figure 7.

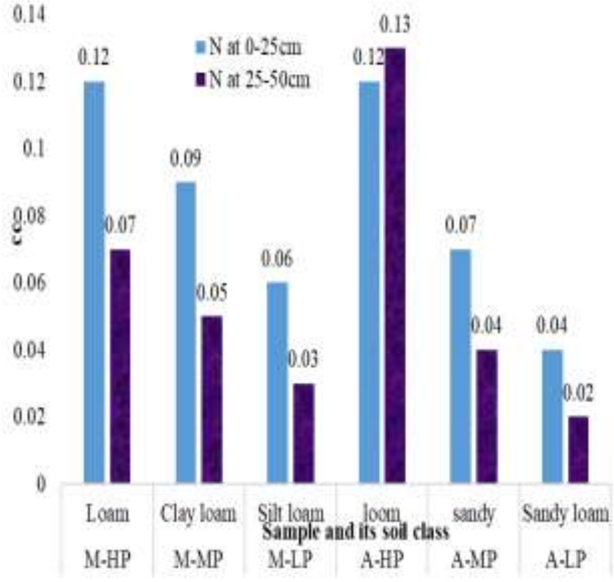

Fig 7. Nitrogen content (Percentage) vs. Soil samples

Soils with total nitrogen content exceeding 0.07% are likely to mineralize significant amounts of nitrogen in subsequent crop cycles, whereas soils with less than 0.07% total nitrogen have limited capacity to do so.

This suggests that most soils have good potential for nitrogen mineralization. Organic matter serves as the primary source of nitrogen in soils, supported by a significant positive correlation between macronutrients and total nitrogen. The soil profile layer with the highest macronutrient content (0.13%) corresponds to the highest total nitrogen value, while the layer with the lowest macronutrient content (0.02%) exhibits the lowest total nitrogen value.

3.1.4 Effect of Phosphorus

The concentration of accessible phosphorus ranged from low to very high, varying from 7.5 mg kg-1 in the subsoil of sample A-LP to 36 mg kg-1 in the surface layer of sample A-HP, as illustrated in Figure 8. Areas with a pH approaching neutral (6.8) showed the highest amount of phosphorus relative to the total phosphorus content. Therefore, the range of accessible phosphorus in the surface areas of each sample was considered sufficient.

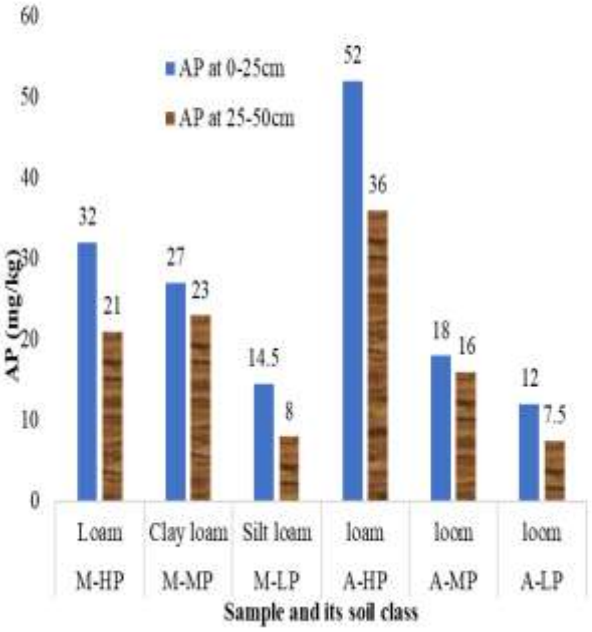

Fig 8. Available Phosphorus in soil samples

3.1.5 Effect of Potassium

The accessible potassium levels in all soil samples ranged from 98 to 724 mg kg-1, indicating a classification from medium to extremely high as shown in Figure 9. The surface sample M-HP contained the highest amount of accessible potassium (724 mg kg-1), while sample A-LP had the lowest (98 mg kg-1), with values generally decreasing with increasing depth. Available potassium values were higher in the 0-25 cm depth range compared to the 25-50 cm depth range, as depicted in Figure 9.

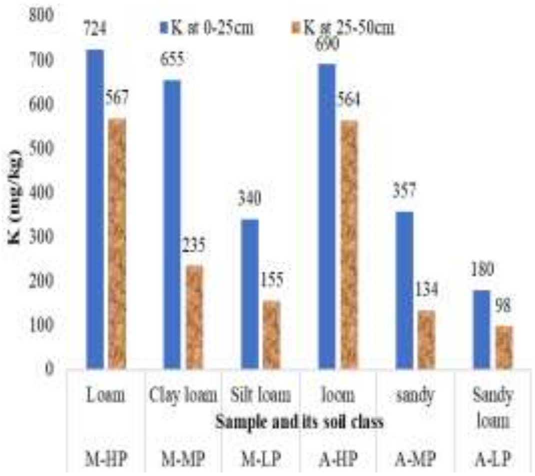

Fig 9. Potassium levels in soil samples

3.2 Impact of soil conditions on cotton quality

3.2.1 Effect of fiber length

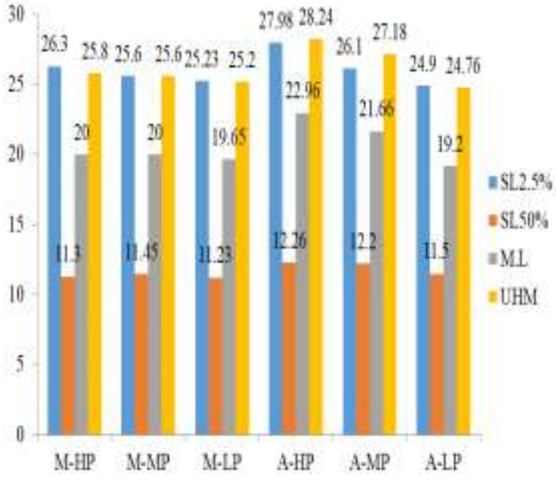

Fig 10. Fiber length, mean length, and upper half mean

Fiber length refers to the average length of the longer half of the fibers, also known as the upper half mean length. Length uniformity is expressed as a percentage and is calculated by dividing the mean length by the upper half mean length. If all fibers in a bale were of the same length, the upper half mean length, average length, and uniformity would all be 100%. However, natural fluctuations in fiber length mean that the length uniformity of cotton fibers can never reach 100%. The evenness, strength, and efficiency of the yarn-spinning process are all influenced by the uniformity of fiber length, as depicted in Figure 10.

3.2.2 Short fiber percentage

Cotton with a high short fiber content (SFC) is considered lower-quality raw material because it generates more waste during processing and produces yarn with increased hairiness, reduced strength, and a more uneven surface. The results indicate that the short fiber content of cotton at the Amibara site (lowest value: 12.4) is lower than at the Metema site (lowest value: 18.2), primarily due to maturity issues, as illustrated in Figure 11.

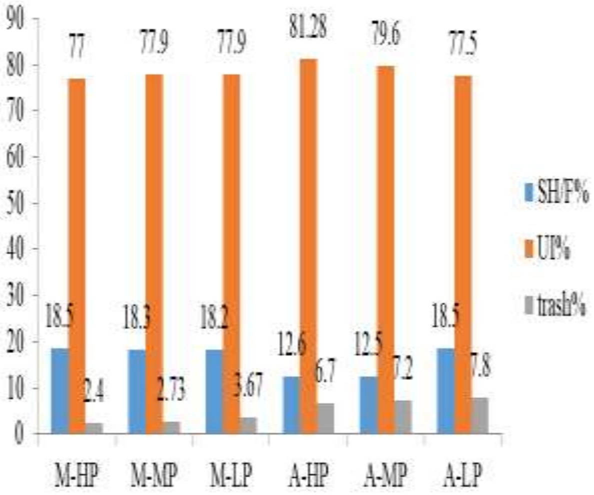

Fig 11. Short fiber, uniformity index, and trash percentage

3.2.3 Influence of trash content

Trash content, which includes non-lint components in cotton such as leaves and cotton plant bark, is measured in terms of percentage. A high percentage of trash results in increased processing waste in textile mills and lower yarn quality. Small trash fragments are particularly problematic because they are more difficult for mills to separate from cotton lint compared to larger fragments. Shirley's trash analyzer results showed that cotton trash at the Amibara site exceeded that at Metema, primarily due to environmental factors like temperature effects on cotton plant leaves, windstorms, soil and fiber mixing, and the drying and crushing of cotton leaves at maturity. Fiber handling and manual harvesting methods also contribute to higher trash content.

3.2.4 Influence of fiber strength

Fiber strength is measured in grams per tex, representing the force in grams needed to break a bundle of fibers one tex in size. Strong correlations exist between yarn and fiber strength, with stronger cotton fibers better able to withstand breakage during manufacturing. The study revealed that reduced yarn strength is linked to lower fiber uniformity in cotton with a higher proportion of short fibers. Samples M-HP, A-HP, and A-MP, which have a lower percentage of short fibers and optimal yarn length, exhibit greater strength compared to others, as depicted in Figure 12.

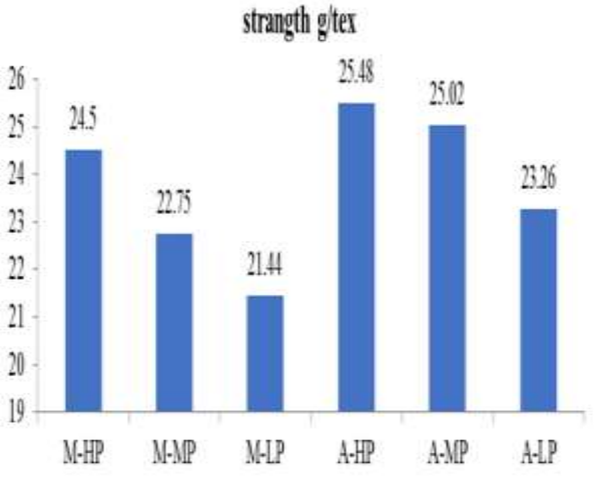

Fig 12. Results of fiber strength testing

4. CONCLUSION

In conclusion, this study highlights the significant impact of climatic changes on cotton yields, varying across different stages of the crop's growth cycle. It stresses the importance of considering specific environmental conditions where cotton is grown, as climate change effects can vary based on these factors. Furthermore, the study underscores that climate change adversely affects cotton productivity during distinct growth phases. These findings underscore the complex relationship between climate variability and cotton production, advocating for targeted mitigation strategies to address challenges faced by farmers throughout the growth cycle. Further research is essential to develop adaptation measures and enhance the resilience of cotton production systems in response to changing climatic conditions. Air temperature plays a crucial role in cotton production, influencing seed germination and overall plant development. Lower temperatures slow germination rates, while warmer conditions promote higher yields. Temperature extremes during maturity stages significantly impact yield, although early growth stages show less sensitivity to temperature fluctuations. High evaporation rates, combined with maximum temperatures, low humidity, and minimal rainfall, adversely affect cotton flower and boll production. Optimal daytime temperatures during flowering and boll formation are critical for maturation under sunny conditions. Additionally, this study emphasizes the vital role of rainfall in influencing cotton plant growth and productivity. Adequate rainfall supports fruit-bearing branches, boll quantity, and size, while evaporation negatively impacts boll development, necessitating balanced moisture levels for optimal production. Timely rainfall, especially before squaring, positively affects cotton yields, highlighting the importance of understanding rainfall patterns for effective cultivation practices. The study underscores the intricate relationship between climatic factors and cotton production, emphasizing the need for stable environmental conditions to optimize crop yields. While higher average temperatures may enhance productivity, factors like evaporation and inadequate moisture levels can reduce flower and boll production. Moreover, the positive correlation between rainfall and growth parameters underscores water availability's critical role in promoting cotton development. These insights underscore the importance of considering multiple climatic variables to mitigate climate change impacts and enhance cotton yield resilience. Further research is crucial for developing sustainable agricultural strategies and improving cotton production system resilience. Regarding soil conditions, the study finds the pH levels suitable for crop production, decreasing with soil depth. Cotton maturity is influenced by cell wall development, with juvenile fibers resulting from premature harvesting. Adequate rainfall during fiber development stages is crucial, although both study sites experienced insufficient rain during this critical period. Soil texture analysis indicates suitable conditions for maximizing agricultural output through effective management practices tailored to soil suitability and potential.

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