Land Suitability and Sustainable Management Options for Cotton Production in Bafime and Larazourou, Korhogo Department, Côte d'Ivoire.

Abstract:

Cotton yields in the Northern Basin of Côte d'Ivoire have declined due to pests, diseases, soil degradation, water stress, and poor crop management, largely because detailed site-level pedological data remain scarce. This study characterized soil fertility constraints and evaluated land suitability for cotton production in two villages of Korhogo Department, Bafime and Larazourou, based on six composite topsoil samples (four from Bafime, two from Larazourou) and complete soil profiles (0–100 cm) collected in 2021. The soils were slightly acidic to near-neutral (pH 6.5) with moderate base saturation (55.6%), but soil fertility was classified as very low overall: total nitrogen (0.070%), organic carbon, cation exchange capacity (7.21 $cmol^+/kg$), and the sum of exchangeable bases (SEB, 4.21 $cmol^+/kg$) were all low, with SEB identified as the main fertility-related limiting factor. Climatically, average relative humidity during the growing season reached 79%, which exceeds cotton's tolerance threshold and constitutes the principal limiting factor identified in this study. Considered on soil characteristics alone, Larazourou was moderately suitable (S2) whereas Bafime was marginally suitable (S3), owing to a larger combination of moderate limitations (drainage, texture, coarse fragments, and effective soil depth); however, combining soil and climate components, both Bafime and Larazourou were classified as currently not suitable (N1) overall, driven primarily by excessive relative humidity rather than soil fertility. Targeted soil fertility management, informed by site-specific analyses, together with agronomic practices that mitigate humidity-related disease and pest pressure, are recommended to support more sustainable cotton production in these two villages.

Keywords: Soil quality, Cotton production, Agricultural sustainability, Soil properties, Land suitability

1. Introduction

Soil and water, as vital natural resources, face escalating pressure from increasing anthropogenic activities, reducing agricultural land availability per capita and challenging efforts to meet growing demands for food, fodder, fibre, and fuel (Surya *et al.*, 2020).

Cotton is a major global commodity, with Gossypium hirsutum (upland cotton) accounting for around 90% of global production (Shahbandeh, 2022). In Côte d'Ivoire, cotton cultivation ranks as the 4th largest agricultural export after cocoa, rubber, and cashew nuts, contributing

1.7% to the gross domestic product (GDP) (Didi *et al.*, 2018), and directly supports 180,000 producers, or about 2.5 million inhabitants (Oudin, 2020).

However, the cotton industry faces significant challenges, particularly in the Northern Guinea Savannah region, which encompasses northern Côte d'Ivoire, northern Ghana, and south-western Burkina Faso. This region has been a focal point for numerous studies on soil constraints to cotton production, soil fertility, and taxonomy. Surprisingly, despite the wealth of research in this area, a critical gap remains in synthesizing and applying this knowledge to address the specific challenges faced by cotton cultivation in the region.

Recent studies by Zhang *et al.* (2023), Li *et al.* (2022), and Zagbaï *et al.* (2006) have shed light on multifaceted challenges related to cotton production in this region. Similarly, Ramasundaram and Hemchandra (2001) in India have identified unique constraints. These findings underscore the complexity of cotton farming, emphasizing the need for region-specific solutions to promote sustainable and resilient practices.

Several studies have also been conducted on the soil fertility and taxonomy of northern Côte d'Ivoire, northern Ghana, and southwestern Burkina Faso (Zhang *et al.,* 2023; Li *et al.*, 2022). However, these studies have not focused on the specific needs of cotton production. A study by Kouakou *et al.* (2023) used a multi-criteria decision analysis (MCDA) approach to assess the suitability of land for cotton cultivation in the cotton basin of Côte d'Ivoire. The study found that 42% of the cotton basin of Côte d'Ivoire is highly suitable for cotton cultivation, 35% is moderately suitable, and 23% is marginally suitable. The study also identified the main constraints to cotton cultivation in the region, which include soil acidity, low organic matter content, and poor drainage. This study will build on the work of Kouakou *et al.* (2023) by conducting a more detailed, site-level assessment of land suitability for cotton cultivation in Bafime and Larazourou, Korhogo Department, Côte d'Ivoire, combining soil profile data with a long-term (1980–2020) climatic baseline. Specifically, this study aims to: (i) characterize the pedological constraints (physical and chemical) of the topsoils and soil profiles in Bafime and Larazourou; (ii) classify the climatic and edaphic (land) suitability of these two villages for cotton cultivation using the FAO/Sys framework; and (iii) propose site-adapted sustainable soil and land management options based on the constraints identified.

Soil forms the foundation of land resources and is pivotal for agricultural development and ecological sustainability (FAO, 2014). It represents a reservoir of biodiversity critical to our planet (INRA, 2018). Maintaining or enhancing soil fertility is a paramount challenge

(Sanchez, 2002), particularly in West Africa, where improving soil fertility and agricultural productivity are top priorities (CORAF, 2008).

The concept of land suitability revolves around adapting land for specific uses and is a fundamental aspect of land management (Driessen & Konijn, 1992). Assessing land suitability provides valuable insights into land-use constraints and opportunities, which are essential for informed land-use planning (AbdelRahman et al., 2016). Soil parameters, influenced by climate and topography, have a significant impact on crop performance (Sehgal, 1991). Land suitability classification aims to predict the agricultural potential of land development units based on land resources (Sys *et al.*, 1991). According to the FAO (1993), land capability refers to the "suitability of a given piece of land for specific uses," guiding decisions on the most suitable land use for a particular location and ranking limiting factors for specific crops. This study evaluates the suitability of land for cotton cultivation in Bafime and Larazourou, Korhogo Department, Côte d'Ivoire.

2. Materials and Methods

2.1. Sites Characterization

The study was conducted in Korhogo Department, located in northern Côte d’Ivoire, within the Poro Region. The area belongs to the Savanes Autonomous District and constitutes one of the country's major cotton-producing zones. Korhogo Department covers an area of approximately 12,500 km² and is characterized by a Sudanian climate, marked by an alternation between a four- to five-month wet season and a long dry season.

The vegetation is predominantly composed of wooded savannas and open woodlands, while the soils are highly susceptible to water erosion. These environmental characteristics make Korhogo particularly relevant for analysing agricultural practices and their agro-environmental implications within local cotton-based farming systems.

Within this study area, three primary classes of soils hold prominence in the French (ORSTOM/CPCS) pedological classification traditionally used in the region: tropical ferruginous soils, hydromorphic soils, and soils on basic rocks. In the international Soil Taxonomy (USDA) system, these soils are broadly classified as Alfisols. Bafime and Larazourou were selected as study sites because they are active cotton-producing villages representative of the two dominant local soil-texture conditions found within Korhogo Department's cotton-growing plots (a coarser, deep sandy profile in Bafime and a finer, sandy-loam profile in Larazourou), allowing the study to capture contrasting fertility and management conditions within a single department. The vegetative cover within the study area exhibits three distinct zones: the Forest Zone in the central western part, the Guinean Savanna Zone in the eastern sector, and the Sudanian Savanna Zone in the northern expanse, which together shape land use and ecological dynamics across the region. Notably, three of Côte d'Ivoire's primary rivers, namely Sassandra, Bandama, and Comoé, course through the Ivorian cotton basin, traversing the landscape from North to South (Dekoula, 2019). Korhogo Department was selected for this study owing to its susceptibility to pronounced climatic variations, which makes it one of the most vulnerable agro-ecological zones in the country (MINESUDD, 2013). Given this vulnerability, the study aims to provide stakeholders with practical, site-level decision-making tools to enhance agricultural resilience and productivity in this dynamic cotton-producing region.

2.2. Soil Sampling

The soil sampling methodology adopted for this study was designed to systematically collect representative soil samples from each plot at a depth of 0-0.2 meters, utilizing a soil auger. A meticulous approach was employed, involving the collection of 17 replicate samples at each sampling point within each plot. These 17 elementary samples from each sampling point were thoughtfully combined to form a singular composite sample, thereby capturing the inherent variability within each plot. To ensure a comprehensive assessment and account for potential spatial differences, the number of sampling points selected per plot was adjusted based on the plot's size, with a maximum of 5 sampling points for larger plots. Sampling was conducted in the villages of Bafime and Larazourou, Korhogo Department, as part of the 2021 sampling campaign. A total of six composite topsoil samples were collected: four from Bafime and two from Larazourou, reflecting the number of distinct cotton-growing plots surveyed in each village (four plots in Bafime, two in Larazourou) each plot yielding one composite sample. Each composite sample therefore integrates between 17 and 85 elementary increments (17 elementary samples × 1-5 sampling points per plot), consistent with reconnaissance-level soil survey practice for characterizing the dominant cultivated soils of a village (FAO, 2006). In addition to these six topsoil composites, one full soil profile (0-100 cm) was described in each village (two profiles in total; Figure 2), independently of the composite sampling, to characterize subsurface morphology and effective soil depth.

In the subsequent stages of analysis, the average values of physicochemical soil characteristics were calculated, with a primary focus on the topsoil layer. Additionally, for a more comprehensive understanding of the soil profile, each plot underwent soil profile characterization, extending to a depth of 0-1 meter. A land suitability study was systematically carried out in Bafime and Larazourou, and the averages of physicochemical soil characteristics were determined specifically for the topsoil layer within each village. This approach enabled a robust evaluation of soil properties and suitability for cotton cultivation under the conditions found in these two villages.

2.3. Laboratory Analysis

The six soil samples were delivered to ENVAL (Laboratoire de l'Environnement et de l'Alimentation de Côte d'Ivoire). The field samples were air-dried at room temperature, crushed, and sieved through a 2 mm sieve. The soil fraction < 2 mm was analyzed for physical and chemical properties. Particle size analysis was performed using the densimetric method, which involved using Robinson's pipette after dispersing 50g of soil in a solution of sodium hexametaphosphate ($NaPO_3$) (Bouyoucos, 1962). The organic carbon content of the soil was determined using the Walkley-Black wet combustion method, which involves oxidation with potassium dichromate and subsequent titration with iron sulfate (Crétenet & Gourlot, 2015). Soil pH was measured at a soil: solution ratio of 1:2.5 and distilled water (pH-H_2O) (Dabin, 1970). Total N was determined by the Kjeldahl wet digestion method.The assimilable phosphorus (P_{ass}), was determined by the Bray 1 method, and the Cation Exchange Capacity (CEC) were measured according to the NFX 31-130 standard (AFNOR, 1999). This method aims to displace all the cations adsorbed on the exchange sites of the CEC and then saturate these sites with a single cation, which is ammonium (NH_4^+). At the same time, the exchangeable cations (Ca^{2+}, Mg^{2+}, $K^{+,}$ and Na^+) were determined by Atomic Absorption Spectrophotometry (Optima 2100 DV).

Particle-size fractions (clay, silt, sand) were expressed as percentages of the <2 mm fine-earth fraction and were used to characterize soil texture in Bafime and Larazourou.

2.4. Land-suitability evaluation

The suitability of land for cotton cultivation depends on the terrain, soil, and climate. Terrain and soil factors, such as topography and drainage, impact soil quality. We assessed terrain-soil suitability using the FAO method, which categorizes land into five suitability classes. The evaluation involves collecting land characteristics, matching them with land-use requirements, and identifying limitations. This assessment was conducted at 6 sampling points across the two villages of Bafime and Larazourou to determine the suitability of land for cotton cultivation. In the FAO Framework for Land Evaluation (FAO, 1976), each land unit is assigned suitability for land use, from the 5-member set S ϵ {S1, S2, S3, N1, N2} = {highly suited, moderately suited, marginally suited,currently not suitable,permanently not suitable}, as shown in Table 1. Throughout this evaluation, the degree of limitation of each land characteristic is scored on a 0–4 scale (0 = no limitation, 1 = slight, 2 = moderate, 3 = severe, 4 = very severe), which maps directly onto the five suitability classes (0→S1, 1→S2, 2→S3, 3→N1, 4→N2); the overall suitability class of a land unit is then determined by applying the criteria in Table 1 to the full set of characteristics assessed — which, for soil, allows several moderate (degree-2) limitations before the class is downgraded, whereas a single severe or very severe characteristic is normally sufficient to set the class — following the Simple Limitation Method.

Table 1: Criteria for determination of land suitability classes (Sys *et al.*, 1993)

Land classes	Criteria
S1 : Very suitable	Land units with no or only 4 slight limitations
S2 : Moderately suitable	Land units with more than 4 slight limitations, and/or no more than 3 moderate limitations
S3 : Marginally suitable	Land units with more than 3 moderate limitations, and/or one or more severe limitations.
N1: Currently not suitable	Land units with limitations severe enough to preclude successful use under current management, but that could be corrected by improved management or additional inputs.
N2 : Permanently not suitable	Land units with limitations so severe that they preclude any successful use for cotton cultivation and cannot be corrected.

2.5. Assessment of climatic suitability

Cultivation practices in the Côte d'Ivoire cotton basin have been defined by the Centre National de Recherche Agronomique of Ivory Coast (CNRA), and this division of the cultivation calendar is a function of the climatic conditions present in each agroecological zone (MINESUDD, 2013).The assessment of climate suitability for cotton production is based on several climate variables, including total rainfall during the growing season, total rainfall received between June and October, mean temperature during the growing season, and mean maximum temperature between June and October. These climate variables were selected because they are known to have a significant impact on the agronomic performance of cotton production (Sys *et al*., 1993).

In the agro-ecological zone, cotton is mainly sown in the first decade (D1: 21-31 May). Cotton is harvested from November to December. The main growing period was defined as the period between June and October. The primary meteorological data used are rainfall, temperature, and relative humidity. The rainfall data is based on data from the Société d'Exploitation et de Développement Aéroportuaire, Aéronautique et Météorologique (SODEXAM). These meteorological data constitute a secondary data source, as they were collected by agents present at the meteorological stations covering the study area. They were supplemented by data from the database of the Laboratoire Central des Sols, de l'Eau et des Plantes (LCSEP) of the Centre National de Recherche Agronomique of Ivory Coast (CNRA). These data present a sufficiently long series to highlight the evolution of rainfall over a long period and the intra-seasonal descriptors of rainfall. The temperature and relative humidity data were derived from the ERA5 reanalysis dataset (Copernicus Climate Change Service, ECMWF), accessed via the Google Earth Engine data catalogueat a native spatial resolution of 0.05 degrees, aggregated to monthly values, from 1980 to 2020. The climatic suitability was analyzed based on the recommendations of Sys et al. (1993).

2.6. Assessment of terrain and soil suitability

The lands were classified using the Simple Limitation Method (SLM). The SLM is the one that is very suitable for specific crops (Maize, Potato, Onion, and cotton) (Jafarzadeh *et al*., 2008).The simple limitation method implies that the crop requirement tables are made for each land utilization type. For each characteristic, the tables define the class-level criteria. The methodology suggests that, first, an evaluation of the climatic characteristics is made to determine the climate class level to be used in the subsequent review. The climate class level is determined by the single most limiting (lowest) class level among those found for particular climatic characteristics. The land (soil) class, in contrast, is determined by applying the number-of-limitations criteria of Sys et al. (1993) (Table 1) to the set of soil characteristics assessed, since several moderate limitations, rather than any one alone, are needed to downgrade the class.

In the land evaluation process, the morphological characterization of the soil profiles (0-100 cm depth) (Figure 2) and the physicochemical parameters of the topsoil (0-0.2 m) were first matched with the requirements of the cotton plant (Table 2). The limitations of the soils at each site for cotton cultivation were assessed according to the criteria of Sys et al. (1993) and expressed in terms of their degree of limitation (0, 1, 2, 3, and 4) (Table 1 and Table 2)

Table 2. Crop requirement for cotton according to Sys *et al* (1993)

Land characteristics		Class, degree of limitation, and rating scale					
		S1	S2	S3	N1	N2	
		0	1	2	3	4	4
		100 95	85	60	40	25	0
Climatic characteristics (c)							
Rainfall growing season (mm)		1000-850	850-750	750-600	600-500	-	<500
Rainfall during the ripening stage		<25	25-50	50-75	75-100	-	>100
Mean temp. growing stage (°C)		28-26	26-24	24-22	22-20	-	<24
Mean max temp. growing stage (°C)		35-32	32-28	28-26	26-24	-	<24
Mean temp. of ripening stage (°C)		<25	25-50	50-75	75-100	-	<100
Mean R.H. in the growing season		<50	50-60	60-70	70-80	>80	-
Topography (t)							
Slope (%)	(1)	0-1	1-2	2-4	4-8	-	>6
	(2)	0-2	2-4	4-8	8-16	-	>16
	(3)	0-4	4-8	8-16	16-30	30-50	>50
Wetness (w)							
Flooding	(4)	F0	-	-	F1	-	F2+
Drainage	(5)	good	-	Moderate	Imperfect	Poor, but	Poor,
		imperfect	-	Moderate	Good	drained	Not drained
Physical soil characteristics(s)							
Texture/Structure		C<60s, SiC Co,SiCL,Si,SiL,CL	C<60v, SCC>60s, L	C>60v, SL, SCL	FS,S,LS,Lcs	-	Cm,SiCmcS
Coarse fragment (g^{100g-1})		0-3	3-15	15-35	35-55	-	>55
Soil depth (m)		>1	1-0,75	0,75-0,50	0,50-0,25	-	<0,25
Soil fertility characteristics (f)							
Apparent CEC ($cmol^+/kg$)		>24	24-16	<16 (-1)	<16 (+1)	-	-
Base saturation (BS) (%)		>80	80-50	50-35	>35	-	-
Sum of basic cations (SBC)		>6.5	6.5-4.6	4-2.8	2.8-1.6		-
($cmol^+/kg$)				6-5.6	5.6-5.2	<1.6	
pH_{H20}		6.7-7.0	7.0-7.6	7.6-8	8-8.5	<5.2	<8.2
						-	
Organic carbon (g^{100g-1})	(6)	>2.0	2-1.2	1.2-0.8	<0.8	-	-
	(7)	>1.8	1.2-0.8	<0.8	-	-	-
.	(8)	>0.8	0.8-0.4	<0.4	-	-	-
EC_e (dSm^{-1})		<2	2-4	4-8	8-15	>15	-

Source: Sys et al. (1993). Notes on textural classes (USDA system): C, clay; SiC, silty clay; SC, sandy clay; CL, clay loam; SiCL, silty clay loam; SCL, sandy clay loam; Si, silt; SiL, silt loam; L, loam; FS, fine sand; S, sand; LS, loamy sand; Co, coarse-textured soils; Lcs, loamy coarse sand. Structure qualifiers: C<60v / C>60v, clay content below/above 60% with vertic (shrink-swell) structure; C<60s / C>60s, clay content below/above 60% with blocky structure; Cm, massive clay; SiCm, massive silty clay; SiCmcS, massive silty clay over coarse sand.

Wetness/flooding: F0, no flooding limitation; F1, slight flooding limitation; F2+, moderate to severe flooding. Rating scale (0-4): 0 = no limitation, 1 = slight, 2 = moderate, 3 = severe, 4 = very severe, mapping to classes S1, S2, S3, N1 and N2 respectively. (1) Irrigated; (2) Full mechanization; (3) Animal traction/Manual; (4) Medium- and fine-textured soils; (5) Coarse-textured soils; (6) Fine-textured soils (organic-carbon threshold set); (7) Medium-textured soils (organic-carbon threshold set); (8) Coarse-textured soils (organic-carbon threshold set, applicable to Bafime and Larazourou in this study).

3. Results

3.1. Texture of different soils

The soils in the Korhogo cotton-producing area are predominantly sandy, with sand content averaging 88.0% in Bafime and 66.0% in Larazourou (Table 3). Clay content is very low at both sites (2.3% in Bafime; 6.4% in Larazourou), while Larazourou also carries a markedly higher silt fraction (25.7% versus 8.3% in Bafime). This high sand content, combined with the low clay proportion, indicates a low water- and nutrient-retention capacity, particularly in Bafime. These textural characteristics can increase the vulnerability of soils to rapid drainage, nutrient leaching, and water stress, thereby potentially limiting cotton productivity, especially during prolonged dry periods.

Table 3: The texture of different soils

Village	Clay (%)	Silt (%)	Sand (%)
Bafime	2.30	8.35	**88.03**
Larazourou	6.40	25.70	**65.95**

Note: These percentages of texture represent averages from the topsoil samples collected in each village. Fractions do not sum to exactly 100% because coarse fragments (gravel, >2 mm) were excluded from the fine-earth particle-size analysis and are reported separately as part of the soil profile descriptions (Figure 2).

3.2. Soil morphological description and physicochemical properties

The soils of the different cotton production plots, in the great majority, exhibit the following descriptive characteristics, considering the surface horizons, as shown in Figure 2 (pictures a, b, and c).In the Korhogo department, the soils that support cotton cultivation in the villages of Bafime and Larazourou have superficial horizons.

The soils in the village of **Bafime** are red in colour (5 YR 4/6), dry, humus-bearing, lumpy structure induced by coarse elements and roots, Sand (S) texture, very porous, numerous roots with a preferential subhorizontal orientation, moderate internal drainage, diffuse transition by colour, and more or less regular boundary. The village of **Larazourou** has soils with a brown colour (7.5 YR 5/3), dry, humic, lumpy structure induced by coarse elements and roots, Sandy Loam (SL) texture, very porous, numerous roots with a preferential subhorizontal orientation, moderate internal drainage, diffuse transition by colour, more or less regular limit. Textural classes were assigned using the USDA soil texture triangle applied to the laboratory particle-size data (Table 3).

(A) Department KORHOGO /village: Bafime (Latitude:9° 28’8.59’’ N, Longitude: 5° 33’ 22.13 W)

Depth (cm)	Image	Morphological characteristics
0-2		Dry, humus-rich, red (5 YR 4/6), lumpy structure induced by coarse elements and roots, loamy sand texture (5-10 % clay)
2-11		Fresh, humus, yellowish red (5 YR 4/6), gritty structure induced by coarse elements and roots, loamy sand texture (10-15% clay), porous, coherent, many roots (mm) with preferential subhorizontal orientation, good internal drainage, 26 % of gravel content,
11-29		Fresh, humus-bearing, yellowish-red (5 YR 4/6), gritty structure induced by coarse elements and roots, loamy sand texture (10-15 % clay), porous, coherent, many roots (mm) with preferential subhorizontal orientation, good internal drainage, 28 % of gravel content, clear gradual transition through.
29-65		Fresh, not very humic, yellowish red (5 YR 5/6), general polyhedral subangular structure, sandy clay loam texture with medium sand (25-35 % clay), not very porous, coherent, a few rare roots (mm) with preferential subhorizontal orientation, 26 % of gravel content, medium internal drainage.
>65		Rocks and Concretions

(B) Department KORHOGO /village: Larazourou (Latitude:9° 29’59.3’’ N, Longitude: 5° 55’ 7.17 W)

Depth (cm)	Image	Morphological characteristics
0-2		Dry, humic, brown (7.5 YR 5/3), loamy sand texture and , good internal drainage, 13 % of gravel content
2-12		Fresh, non-humic, brown (7.5 YR 5/6), alteration spot, dark red (2.5YR 3/6) polyhedral structure with subangular grumbling, sandy clay loam texture (20-35% clay) not very porous, coherent, some roots (mm) with preferential subhorizontal orientation, 23 % of gravel content, medium internal drainage, progressive transition.
12-36		Fresh, not very humic, brown (7.5 YR 5/8), gritty structure induced by coarse elements and roots, loamy sand texture (15-25 % clay), porous, coherent, some acini (mm) with preferential subhorizontal orientation, 47 % of gravel content, good internal drainage, progressive transition.
36-55		Fresh, non-humic, brown (7.5 YR 5/6), alteration spot, dark red (2.5YR 3/6) polyhedral structure with subangular grumbling, sandy clay loam texture (20-35% clay), not very porous, coherent, some roots (mm) with preferential subhorizontal orientation, 23 % of gravel content, medium internal drainage, progressive transition.
55-100		Fresh, not humic, brown (7.5 YR 5/6), alteration spot (3.5YR 3/6), polyhedral structure with sub-angular grumbling, sandy-clay texture (45% clay), not very porous, coherent, some roots (mm) with preferential sub-horizontal orientation,10 % of gravel content, average internal drainage.

Figure 2: Characteristics of soil profile (Study areas: **Bafime, and Larazourou**)

The results indicate that all soils have moderately acidic to near-neutral pH values. The overall pH-water values of the studied soils range from 6.25 to 6.85 (mean 6.52), which suggests that the topsoils are slightly acid to near-neutral. The pH values observed in these areas, therefore, indicate that soil acidity is not a significant constraint to cotton growth. Although the pH values are relatively uniform, there are differences in pH of up to 0.6 units between the different sites. The change in pH leads to transformations in the chemical and physical properties of the soil. It is accompanied by a shift in cation exchange capacity, as well as in physical properties (Pernes-Debuyser & Tessier, 2005). The base saturation rate of the soils in the study area varies from 38.8% to 66.6% (mean 55.6%), which coincides with the published values of 40% to 60% (Amonmide *et al.*, 2019). Soil organic carbon has low values (0.24% - 0.42%), and total nitrogen is likewise low (0.050% - 0.090%), in all the soils of the study area (Table 4). This carbon content is below the average threshold value of 2% (Dabin, 1970). The CEC shows low values ranging from 4.90 to 8.99 $cmol^{+}$/kg. Under the Sys et al. (1993) evaluation criteria, apparent CEC thresholds are adjusted for coarse-textured (sandy) soils; consequently, these CEC values were rated as posing no additional limitation (degree 0; Table 7) in the land-suitability evaluation, even though they remain low in absolute terms relative to typical fertile-soil benchmarks. The sum of exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) averages 4.21 $cmol^{+}$/kg and contributes to just over half of the cation exchange capacity of these soils (Reddy et al., 2012). The presence of these bases in insufficient quantities in the soil is unfavorable to the growth of the cotton plant. In the soils of the study area, the main dominant cation is Ca^{2+}. It varies between 1.25 and 4.48

Cmol$^+$/kg. In all soils, the dominant cation is Ca^{2+}, followed by Mg^{2+}, Na^+, and K^+. The electrical conductivity, ranging from 0.04 to 0.06 dS m^{-1}, indicates very low salinity levels in the soils of the study area. This suggests that the soils are non-saline and pose no salinity risk to cotton cultivation (Santos & Castro, 2020). The particle size distribution indicates that the majority of the soils have a relatively high proportion of sand compared to silt and clay fractions, particularly in Bafime. Overall, Larazourou consistently shows a finer texture (higher clay and silt content), along with a higher CEC and a larger reserve of exchangeable bases, than Bafime (Table 4), suggesting a comparatively greater nutrient-holding capacity, consistent with Larazourou's more favourable soil suitability class (S2) relative to Bafime (S3; Section 3.4).

Table 4: Mean physicochemical properties of the topsoil (0–0.2 m) in Bafime and Larazourou

Village	pH (H_2O)	OC (%)	N tot. (%)	CEC	SEB	BS (%)	Ca^{2+}	Mg^{2+}	K^+	Na^+
Bafime	6.53	0.35	0.070	6.82	3.82	52.5	2.75	0.72	0.30	0.054
Overall (n=6)	**6.52**	**0.34**	**0.070**	**7.21**	**4.21**	**55.6**	**3.04**	**0.78**	**0.33**	**0.063**
Larazourou	6.49	0.33	0.070	7.98	4.98	61.9	3.61	0.91	0.38	0.080

Note: OC, organic carbon; N tot., total nitrogen; CEC and SEB (sum of exchangeable bases: Ca^{2+}+Mg^{2+}+K^++Na^+) in cmol$^+$/kg; BS, base saturation; Ca^{2+}, Mg^{2+}, K^+ and Na^+ in cmol$^+$/kg. Values are means of four (Bafime) and two (Larazourou) composite topsoil samples (2021 campaign). Electrical conductivity (EC), measured separately, ranged from 0.04 to 0.06 dS/m across both villages, confirming non-saline conditions at all sites.

3.3. Climate requirements for cotton production

Table 5 presents the distribution of different climate variables from the 1980s to the 2020s. The distribution of cotton is primarily determined by rainfall, temperature, and relative humidity (Figure 4). In the northern savannah zone, where cotton is grown, the growing season for cotton begins in June and continues through October. The ripening season starts in November and lasts until December, when cotton is also harvested. The average rainfall and temperature during the growing and ripening season are suitable for cotton production. However, the relative humidity in the study area is too high for cotton-growing requirements.

Area	RGS (mm)	RRP	TGS (°C)	TGSmax (˚C)	TRS (˚C)	RH
Korhogo	909	23	25.3	32.8	25.5	79

Table 5: Average of climatic variables in the different study areas from 1980 to 2020

RGS: Rainfall during the growing season (mm), RRP: Rainfall during the ripening season, TGS: Mean temp. Growing season; TGS_{max}: Mean max temp. Growing stage, TRS = Mean temp of ripening stage; RH = Relative humidity in growing season

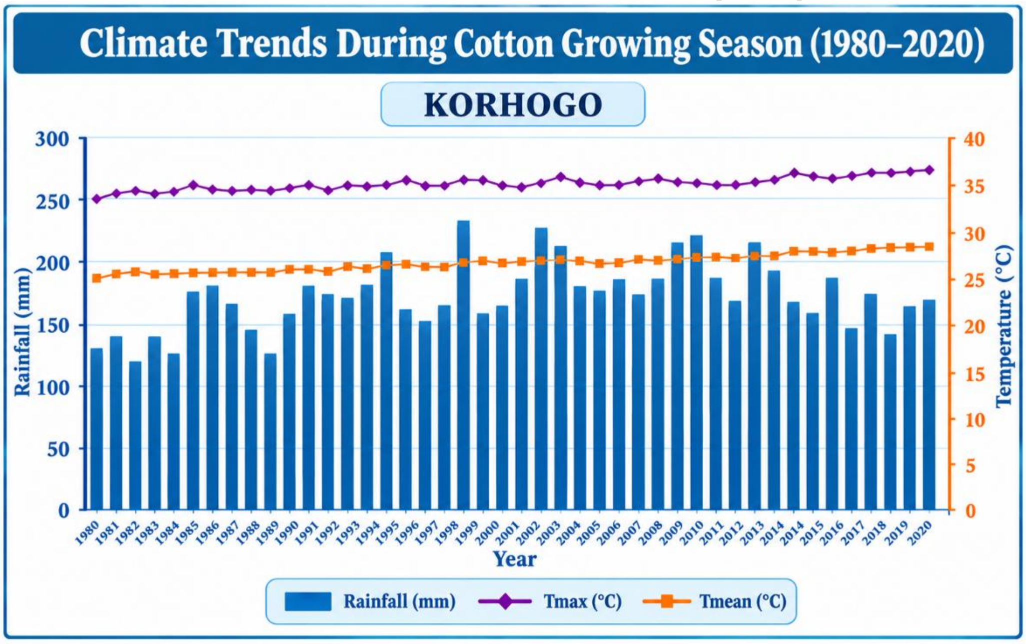

Figure 4: Climate Trends During Cotton Growing Season (1980–2020). Monthly rainfall (mm, bars) and mean/maximum temperature (°C, lines) for Korhogo Department, aggregated from the ERA5 reanalysis (Copernicus/ECMWF, 0.05° resolution) and SODEXAM/CNRA station records; see Table 5 for suitability thresholds.

3.4. Suitability evaluation for cotton production

The agro-climatic requirements for the considered land utilization types were temperature (°C), relative humidity, and total growing period rainfall (mm) (Figure 4). Rainfall and temperature parameters (RGS, RRP, TGS, TGSmax, TRS) showed no more than slight limitations (degree 0-1; Table 6). Relative humidity, however, averaged 79% during the growing season, which falls within the 70-80% bracket that Sys et al. (1993) classify as a severe limitation (degree 3) for cotton. Following the Simple Limitation Method, under which the overall class is set by the single most limiting characteristic, the agro-climatic situation of the study area is therefore currently not suitable (N1) for the considered varieties of cotton (Table 6), driven entirely by excessive relative humidity; all other climatic parameters remain favourable.

To evaluate the suitability of the land for cotton cultivation, the results obtained for climate and soil parameters in the study area are summarized in Tables 3, 4 & 5. The class and degree of limitation assigned to each input parameter in the land suitability evaluation are shown in Tables 6 & 7. Considered on their own, soils in Larazourou are “moderately suitable” (S2) for cotton production, whereas soils in Bafime are “marginally suitable” (S3), owing to a combination of five moderate limitations (drainage, texture, coarse fragments, effective depth, and sum of basic cations) that exceeds the three-limitation threshold defining S2 under the Sys et al. (1993) criteria (Table 1); Larazourou, with three moderate limitations, remains within this threshold. Low soil fertility (SEB) is a shared constraint in both villages, compounded in Bafime by shallower effective depth and coarser texture; these limitations can be addressed by applying amendments and introducing improved agronomic and conservation practices. However, because the climatic class (N1, driven by excessive relative humidity) is more restrictive than either soil class (S2 in Larazourou, S3 in Bafime), and the overall land suitability class is determined by the single most limiting component (climate or soil), the combined land suitability of Bafime and Larazourou for cotton cultivation is currently not suitable (N1), primarily on climatic grounds rather than soil fertility.

Table 6 : Climatic Suitability Classification and Limitation Levels

Area	RGS	RRP	TGS (°C)	TGSmax (°C)	TRS (°C)	RH Max	Limitation / Suitability class
Korhogo	0	0	1	1	1	3	L3 / N1

Table 7 : Soil Limitation and Suitability Classes by Profile

Land characteristics	Bafime	Larazourou
Topography		
Slope (%) (Manual tillage Operation)	0	0
Drainage	2	2
Flooding	0	0

Soil characteristics		
Texture class	2	2
Coarse fragments (vol %)	2	2
Depth (cm)	2	1
Soil fertility		
CEC (soil) ($cmol^+$/kg)	0	0
SBC ($cmol^+$/kg)	2	1
BS (%)	1	1
O.C. (%)	1	0
ECe (dS m-1)	0	0
pHH2O	0	0
Suitability class for dominant soil	S3	S2

Note: The suitability classes shown in Table 7 reflect soil characteristics only: S3 for Bafime, driven by a combination of five moderate limitations (drainage, texture, coarse fragments, depth, and sum of basic cations) that exceeds the threshold of three moderate limitations defining S2 under the Sys et al. (1993) criteria (Table 1), and S2 for Larazourou, whose three moderate limitations (drainage, texture, coarse fragments) remain within that threshold. Regardless of this difference, the overall land suitability class, combining both climate (Table 6) and soil components, is currently not suitable (N1) for both villages, since the climatic limitation (excessive relative humidity) is more severe than any soil-related limitation in either village.

4. Discussion

4.1. Climatic suitability for cotton production

Climatic conditions play a pivotal role in cotton cultivation, as in any form of agriculture. This study, in conjunction with existing research, identifies key climatic factors affecting the suitability of cotton production (Shi *et al.*, 2021). Our findings indicate that the northern part of the savannah zone in Côte d'Ivoire enjoys favorable rainfall and temperature conditions for cotton production. The suitability of cotton cultivation primarily hinges on environmental factors related to temperature and precipitation. Cotton, being a thermophilic crop, thrives in regions with relatively high temperatures, greatly influencing its yield and fiber quality (Luo *et al.*, 2014). The crop requires a substantial level of heat, typically ranging from 25 to 35°C for around 150 days (CIRAD, 2006). Rainfall is another critical factor for cotton cultivation. Profitable cotton production occurs in areas with rainfall between 850 and 1100 mm during the growth phase. Yields tend to be uneconomical in regions with less than 500 mm of rainfall, underscoring the importance of well-distributed rainfall, especially during the growing season. Excessive rainfall, lasting more than two weeks during harvest, negatively impacts fruit opening and cotton fiber quality due to the loss of essential waxes (Zhang *et al.*, 2021). Cotton has limited tolerance for waterlogging stress, which leads to reduced photosynthetic rates and significant yield losses (Zhang *et al.*, 2021). While the early growth stages require sufficient rainfall, sunny and dry weather is essential after flowering.

However, despite suitable rainfall and temperature conditions, relative humidity in the study area (79%) consistently exceeds the requirements for cotton cultivation, placing the climatic suitability of Korhogo Department in the currently not suitable (N1) class under the Sys et al. (1993) criteria. Excessive humidity throughout the vegetative cycle can harm cotton yields directly by impeding plant growth or indirectly by promoting parasitism and diseases (Stern *et al.*, 2006). Additional research conducted by the Centre National de Recherche Agronomique (CNRA) in Côte d'Ivoire quantified the impact of parasitism on cotton production, with the severity increasing from the Northwest to the South. Thus, humidity and temperature are documented in the literature as critical indicators of disease and pest risk in most cases. It should be noted that the present study did not directly measure disease incidence, pest pressure, or yield losses; the elevated relative humidity recorded in Korhogo Department is therefore interpreted here as a potential agronomic risk factor supported by prior research, rather than as a directly observed outcome of this study.

4.2. Land suitability for cotton production

The assessment of potential soil fertility, based on organic carbon (OC) and the Sum of Exchangeable Bases (SEB, equivalent to SBC in Table 2 and Table 7), reveals that nearly all the soils in the study exhibit limitations in at least one of these properties. Generally, soil pH levels do not pose significant limitations across most of the soils. However, soils with a clay content exceeding 60%, characterized by massive structures, as well as coarse loamy/sandy soils, are considered unsuitable for cotton cultivation (Sehgal, 1990). Soil physical characteristics, with the exception of sites featuring very low clay contents, do not present major limitations. In particular, sand content strongly exceeds that of clay and silt in Bafime (88.0%), a pattern also presents but less pronounced in Larazourou (66.0%). This is unfavourable for cotton production, since clay minerals are the main carriers of exchangeable cations such as Ca^{2+}, Mg^{2+}, and K^{+}, and their scarcity in these sandy soils limits nutrient retention. For successful cotton growth, a soil depth of 100-200 cm aligns with FAO recommendations, while depths of less than 100 cm are uneconomical for optimal cotton growth (Sehgal, 1991). The observed soil profiles (Figure 2) confirm this pattern: in Larazourou, the profile extends to at least 100 cm without reaching a rock or concretion layer, whereas in Bafime, effective soil depth is limited to approximately 65 cm by an underlying layer of rocks and concretions. Cotton cultivation stands as a staple activity in northern Côte d'Ivoire, thriving under diverse soil conditions and across a wide range of landforms within the study area. Considered on soil characteristics alone, Larazourou is classified as moderately suitable (S2), while Bafime is marginally suitable (S3) owing to the combined effect of several moderate limitations drainage, texture, coarse fragments, and effective depth which together exceed the threshold used to define S2 in the Sys et al. (1993) system, in addition to low soil fertility (SEB) shared by both villages. However, because the climatic component of the evaluation is more limiting (N1, driven by excessive relative humidity; Section 4.1) than either soil class, the overall combined land suitability of both villages is currently not suitable (N1). Addressing the fertility- and depth-related soil limitations through appropriate amendments and conservation measures could improve the soil suitability class in both villages, but would not by itself resolve the climatic limitation, which is the primary constraint on the overall classification.

It's important to note that limitations stemming from permanent characteristics such as soil depth, slope, and stoniness may not be easily correctable, whereas the soil fertility limitations affecting both villages, and the additional physical limitations placing Bafime in class S3 (drainage, texture, coarse fragments), can be meaningfully improved through management. The climatic limitation driving the overall N1 classification (excessive relative humidity) is not correctable through farm-level intervention, but its agronomic impact can be mitigated. Therefore, adopting a strategic approach involving the prudent use of organic manures in conjunction with inorganic fertilizers, together with cultural practices that reduce humidity-related disease and pest pressure, can help sustain cotton yields and maintain soil fertility for future generations, even though the site's inherent climatic constraint cannot itself be removed.

4.3. Study scope and limitations

This study characterizes cotton-growing soils at two representative villages (Bafime and Larazourou) within Korhogo Department, based on six composite topsoil samples, each integrating between 17 and 85 elementary increments collected across one to five sampling points per plot. This composite-sampling design follows established reconnaissance soil-survey practice, in which a small number of spatially aggregated composite samples are used to characterize the dominant soil conditions of a mapping unit or village (FAO, 2006; Sys et al., 1991), rather than a large statistical sample intended for inferential testing. The present dataset is therefore well suited to describing the typical fertility status and land-suitability class of the two villages, but the ranges reported for individual physicochemical parameters should be interpreted as the spread observed among sampling points rather than as population-level variability. Because the assessment is limited to two villages, the results should be extrapolated to the wider Korhogo cotton basin with caution. Expanding the sampling network to additional villages and cropping seasons, and complementing composite sampling with replicated plot-level measurements, would strengthen the statistical power of future assessments and is recommended as a priority for follow-up work.

5. Conclusion

This study shows that, combining soil and climate characteristics, cotton cultivation in Bafime and Larazourou (Korhogo Department) is currently not suitable (N1), a classification driven primarily by excessive relative humidity (79% during the growing season) rather than by soil fertility. Considered on soil characteristics alone, Larazourou is moderately suitable (S2) while Bafime is marginally suitable (S3), the latter reflecting a larger combination of moderate limitations in drainage, texture, coarse fragments, and effective depth, in addition to low levels of Sum of Exchangeable Bases (SEB) and organic carbon (OC) common to both villages. Based on six composite topsoil samples from two villages, these findings characterize local soil and climate conditions but are not sufficient to generalize to the wider Korhogo cotton basin. While the climatic limitation is not correctable at farm level, the individual soil-related limitations in both villages remain at a moderate degree of severity rather than severe, indicating that targeted management can meaningfully improve the soil suitability class particularly in Bafime, where limitations are more numerous and help offset part of the overall constraint. Based on the constraints measured in this study, three management priorities are proposed for Bafime and Larazourou; none of these interventions were tested within the present study, and their effectiveness should be verified through follow-up trials. Firstly, given the low sum of exchangeable bases (SEB averaging 3.82 cmol$^+$/kg in Bafime and 4.98 cmol$^+$/kg in Larazourou) and the low absolute CEC values (4.90–8.99 cmol$^+$/kg) identified in Section 3.2, there is a need for targeted soil fertility management, combining organic amendments (including retention of crop residues) with mineral fertilizers applied on the basis of soil analyses to raise the pool of exchangeable bases. This should be guided by site-specific soil and leaf sampling rather than blanket recommendations, given the marked textural contrast measured between the two villages (88.0% sand in Bafime versus 66.0% in Larazourou; Table 3). Secondly, the shallow effective soil depth measured in Bafime (approximately 65 cm, limited by an underlying rock and concretion layer; Figure 2) constrains root development and water storage; soil and water conservation practices that control erosion, improve infiltration and reduce runoff (e.g., mulching, contour tillage, vegetative strips) are recommended specifically for this village, whereas Larazourou's greater soil depth (≥100 cm) makes it comparatively more resilient to this particular constraint. Thirdly, since the overall N1 classification is driven by excessive relative humidity rather than soil fertility, practices that reduce humidity-related disease and pest pressure around the crop canopy are recommended as a priority alongside soil management: wider plant spacing and row orientation to improve airflow, timely pruning and weed control to reduce canopy density, use of disease-tolerant cotton varieties where available, and integrated pest/disease monitoring during the most humid months. Realigning current land-use and input practices with the site-specific suitability classes identified in this study, rather than applying uniform recommendations across both villages, would support more productive and sustainable cotton farming in Bafime and Larazourou.

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