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Research Article

Soil Characteristics and Pedoclimatic Evaluation of Rainfed *Sorghum* (*Sorghum bicolor* (L.) Moench) in the Mayo-Lemié Division, South-Western Chad

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In recent decades, many regions in the Chad Republic in Central Africa have experienced a continuous decline in agricultural yields. In order to determine the main factors leading to this decline in yields and mainly *Sorghum* yields, this study was conducted in South-Western Chad, in the Sudano-Sahelian environment. Three soil profiles of variable depths, namely, M1, M2, and M3, were dug along a toposequence, respectively, in the footslope, mid-slope, and the upslope. Soil samples collected from each horizon in the three soil profiles were labelled and sent to laboratories for mineralogical, geochemical, and physicochemical analyses. For land evaluation, climatic characteristics are divided into rating groups with respect to the crop and its climatic requirements. Parametric values were attributed to each soil characteristic for soil evaluation and the land index calculated. The main minerals identified in the studied soils are quartz, K-feldspars, plagioclase, kaolinite, smectite, illite, associated to traces of anatase, sepiolite, calcite, and interstratified minerals. In all the analyzed samples, silicon content is very high. It is closely followed by aluminum, iron, and potassium. The presence of kaolinite and smectite suggests that monosiallitisation is a crystallochemical processes acting at the bottom of profile towards bisiallitisation. All samples collected from the three soil profile horizons are mainly sandy and globally poor in nutrients. The pedoclimatic assessment of *Sorghum* cultivation reveals that the studied soils are marginally to moderately suitable for the production of *Sorghum* due to soil texture, wetness, and soil fertility. The decline in yields is related to low base saturation, in line with low exchange base content in the studied soils. These limitations could be solved by restoration of the cation balance through fertilization and liming, combining organic inputs with mineral fertilizer, and the realization of channels for the drainage of water at the base of the soil sequence.

1. Introduction

Sub-Saharan Africa region, especially the Sahel area, experienced a constantly growing degradation of its environmental characteristics since several decades [1]. This degradation is characterized by the deterioration of the major components of the ecosystems such as soil, vegetation, and water [1–3]. Among these components, soil degradation affects lives and income of millions of people, especially those living in rural areas [1, 4]. Soil degradation has severe negative impacts on food security, environment quality, and living standards [5, 6]. It remains a serious problem in most developing countries, especially in Sub-Saharan Africa, because of the decrease in soil fertility and the negative nutrient balance exacerbated by soil erosion [5, 6]. The predominance of rainfed agriculture and the weakness of management structures make soils extremely vulnerable to climate change [7]. Indeed, the cultivation of soils leads to a

rapid drop in organic matter and a collapse in chemical and biological fertility [8–10]. The decrease in organic matter content does not allow the long-term maintenance of soil fertility and thus sustainable agricultural production, due to the consequences on its physical, chemical, and biological effects [11]. It is well known that soil properties such as mineralogy, geochemistry, and texture are important for the stabilization of accumulating soil organic matter [6, 11, 12]. A good knowledge of the soil mineralogical composition has important practical implications for fertilizer use, application and management, and the bioavailability of nutrient elements in soil [13–16]. The effect of soil mineralogical composition on soil productivity is twofold [17]: (1) it influences chemical reactions regulating nutrient availability and uptake, and (2) it affects physical properties, controlling soil moisture balance and soil physical conditions. Due to their ion exchange properties and surface reactivity, soil minerals control the ionic equilibrium of the soil solution on which mineral uptake necessary for plant growth depends [16, 17]. The sequestration of organic carbon is realized through the formation of clay-humic complexes, sorption of organic matter on clay particles, and the formation of organometallic compounds. Soil minerals and organic matter have significant direct and indirect effects on the supply and availability of most plant nutrient elements [16], and consequently on crop yields. Soil minerals and organic carbon act as both sources and sinks of essential plant nutrients, which are important for sustaining crop production and thus yield improvement, especially in tropics. Also, most of this agricultural production, however, is done in the rural areas by the rural population, presently growing rapidly, resulting in pressure on the available agricultural land and consequently a high increase in soil degradation [4, 18–23].

Lately, in Chad, methods developed for increasing the productivity of crops such as lowland rice have evolved a lot, but progress has been slow for some subsistence crops such as *Sorghum*, millet, and cassava [24]. In Africa, *Sorghum* ranks second after maize with a production of around 21 million tons per year [25]. It is one of the main food grains in Chad. In Mayo-Lemié, it is the most widely cultivated and consumed cereal [26]. Its productivity in rainfed crops is very low compared to the yields (2.5 to 3.5 t/ha) described by Beernaert and Bitondo [27]. It is better suited than corn to hot, dry climates and high temperatures [28]. A good knowledge of the physical, chemical, mineralogical, and geochemical properties of soils allows us to have a preliminary idea of their behavior in order to use them sustainably. Studies on the characteristics of soils in Mayo-Lemié are almost absent. The objective of this work is thus to study the main characteristics of these soils in order to determine their suitability for rainfed *Sorghum* cultivation.

2. Materials and Methods

2.1. Study Area. The study area is located in South-Western Chad, in the middle of the Sudano-Sahelian environment [29]. It extends from 10°31′ to 11°06′ North and 15°00′ to 16°30′ East (Figure 1). The climate is characterized by a long dry season from October to May and a short rainy season, from June to September. The mean annual rainfall is about 652 mm, and the average temperature is 28°C. The main activities of the population are agriculture and animal breeding. *Sorghum* is the main crop [30]. The geological formations are fluviolacustrine or fluvial, deposited during the various transgressive or regressive phases of Lake Chad, from the beginning of the Quaternary era to present [31]. The dominant soils are sandy tropical ferruginous soils, poor in organic matter [32]. The vegetation consists of a shrub savannah dominated by *Acacia* and *Balanites*, depending on the type of soil, with a grassy carpet made up of Andropogoneae [32].

2.2. Methods. A field survey enabled to dig three soil profiles of variable depth along a top sequence. The three soil profiles, namely, M1, M2, and M3, were dug, respectively, in the footslope, mid-slope, and the upslope. They have been described in the field according to Baize [33]. The characteristics considered in the description are color, texture, consistency, structure, porosity, and transition between different horizons. Samples were collected from each horizon in each of the three profiles. The collected samples were labelled and sent to laboratories for mineralogical, geochemical, and physicochemical analyses. Soil color was determined by the Munsell Color Chart.

In the laboratory, methods for physicochemical analyses were those already used by Basga et al. [34]. Soil samples were air-dried at room temperature and sieved (2 mm) to discard coarse fragments. The pipette method was used for particle size distribution analysis after dispersion with sodium hexametaphosphate $(NaPO_3)_6$ and organic matter destruction by hydrogen peroxide (H_2O_2). Soil pH was measured in water and KCl via pH meter equipped with a glass electrode in 1 : 2.5 soil-water suspensions. The soil organic carbon (OC) was determined by the wet oxidation method [35]. The content in organic matter was calculated by multiplying the organic carbon values by the factor 1.72. The total nitrogen was measured by the Kjeldahl method. Available phosphorus was determined according to Bray II procedure [36]. Exchangeable cations were dosed by ammonium acetate extraction method at pH 7, and Cation Exchange Capacity (CEC) was determined using the sodium saturation method.

X-ray diffraction was used to obtain total and clay fractions on both disoriented powders and oriented aggregates (measurements in 2θ range from 2° to 45° with a scan step size of 0.02° and time per step of 2 s) according to the methodology of Moore Duane and Reynolds Robert [37]. Identification was done through air-drying (24 h), glycolation(22 h), and heating (500°C for 4 h). A Bruker Advance D8 diffractometer (copper Kα1 radiations, $\lambda = 1.5418$ Å, $V = 40$ kV, $I = 30$ mA) was used. Identification of mineral phases was carried out using Eva software. Diffuse reflectance infrared spectra were recorded between 4000 and 400 cm^{-1}, using a FTIR Perkin Elmer 2000 spectrometer (Perkin Elmer, Waltham, MA, USA) equipped with deuterated triglycine sulfate (DTGS) detector. Air-dried samples were analyzed at room temperature using Diamond

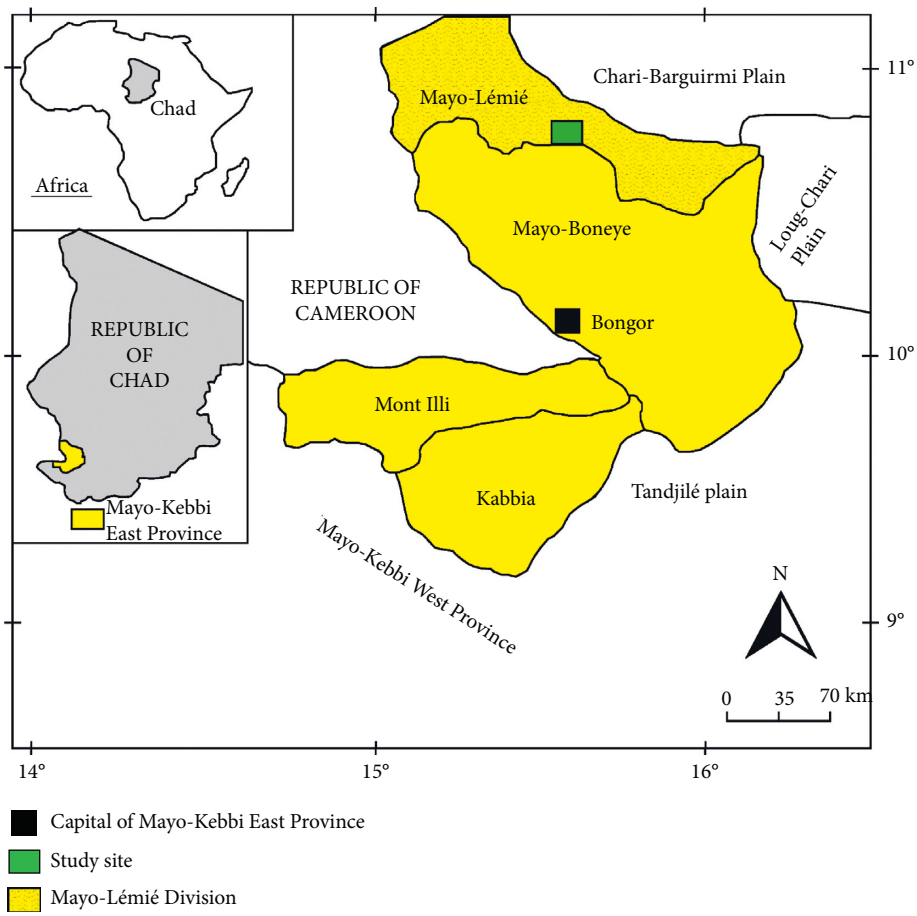

Figure 1: Location of the study area.

Attenuated Total Reflectance (ATR) accessories (Perkin Elmer). The spectrum resolution was $4\,\text{cm}^{-1}$, and the accumulation time was 5 min. Geochemical analyses were obtained by atomic absorption spectroscopy. Loss on ignition (LOI) was measured from total weight after ignition at 1000°C for 2 h.

2.3. Data Analysis. The F.A.O method adapted by Sys [38] permits to assess the climatic and pedoclimatic environment of the study site. This so-called parametric method assigns an earth characteristic value from 0 to 100. When the characteristic is optimal for a given use, it takes the value of 100; otherwise, this value is lower, between 100 and 0. The parametric method is done in two stages: climate and soil.

2.3.1. Climatic Suitability Evaluation. Climatic characteristics are divided into rating groups with respect to the crop and its climatic requirements [39]. The evaluation groups listed are as follows: rainfall, temperature, relative humidity, and insolation during the growing period from June to October. The climatic data were collected at the Guelendeng Meteorological Station. A parametric value is assigned to each characteristic of the climate and a climate index Ic calculated after Khiddir [40] is obtained according to the following formula:

$$\text{Ic} = R\min \times \sqrt{\frac{A}{100} \times \frac{B}{100} \times \cdots}, \quad (1)$$

Rmin = smallest parametric value. A, B, ... = other parametric values. If Ic is between 25 and 92.5, it will be adjusted from Sys et al. [39] by the following equation:

$$\text{Ic (aj)} = 16.67 + 0.9\text{Ic}, \quad (2)$$

Ic (aj) = adjusted climate index; Ic = unadjusted climate index.

If Ic < 25, the equation becomes Ic (aj) = 1.6 Ic.

2.3.2. Soil Evaluation. Soil evaluation was carried out in accordance with the table of soil and climate characteristics of Sys et al. [39]. Parametric values were attributed to each soil characteristic, and the following formula was used to determine the calculated land index:

$$I_T = \text{Ic} = R\min \times \sqrt{\frac{A}{100} \times \frac{B}{100} \times \ldots}, \quad (3)$$

where I_T is the land index; Rmin is the minimum parametric value; A, B, ... are the other parametric values. The suitability class corresponding to the land index will be preceded by a letter showing the most limiting factors such as: t = for

topography, c = for climate, w = drainage, s = texture and structure, f = fertility and n = salinity.

3. Results

3.1. Morphological Organization of Soils in the Studied Site. Three soil profiles, M3, M2, and M1, were described in the studied site (Figure 2).

The M3 profile is located at 315 m a.s.l. It is about 186 cm thick. It is made up of three horizons, which are as follows, from top to bottom:

0–26 cm. Light gray-reddish horizon (2.5YR7/1); loamy sand, texture, very weakly expressed blocky structure; friable and brittle when dry and not plastic when wet; presence of numerous roots and rootlets. High biological porosity and matrix porosity; the limit is progressive and regular;

26–156 cm. Light red horizon (2.5YR7/8); sub-blunt blocky structure, loamy sand texture, friable when dry, nonplastic when wet, presence of roots and rootlets; low biological porosity and matrix porosity; the limit is progressive and regular;

156–186 cm and more. Yellow horizon (2.5YR8/8), Sandy clay loam texture, no roots.

The M2 profile is in the middle part of the soil sequence. The altitude is around 314 m. The soil profile is about 215 cm thick. Five horizons were distinguished. From top to bottom, the succession is as follows:

0–10 cm. Light gray horizon (10R7/1); sandy-clayey-silty texture, blocky structure, not very friable when dry, not plastic when wet. Presence of rootlets; high matrix porosity and medium biological porosity; the limit is progressive and regular;

10–30 cm. Pink horizon (7.5YR8/3); blocky structure, sandy-clay texture, not very friable when dry; low plastic when wet; presence of roots and rootlets; the limit is progressive and regular; 30–75 cm. Pink whitish horizon (10YR8/2); clay texture, massive structure; low biological porosity; low matrix porosity; presence of millimetric ferruginous friable nodules; presence of roots and rootlets; the limit is progressive and regular;

75–175 cm. Light gray horizon (5Y7/1); polychrome isalteritic horizon with greyish and brownish bands; clay-sandy texture; massive structure; presence of millimetric ferruginous friable nodules; absence of roots and rootlets; the limit is progressive and regular;

175–215 cm and more. Yellow color (2.5Y8/6); polychrome isalteritic horizon with greyish and brownish bands; sandy-clay texture; massive structure; presence of millimetric ferruginous friable nodules; absence of roots and rootlets.

The M1 profile is located at the base of the soil sequence. The average altitude is 313 m a.s.l. The thickness is about 205 cm. From top to bottom, the succession of horizons is as follows:

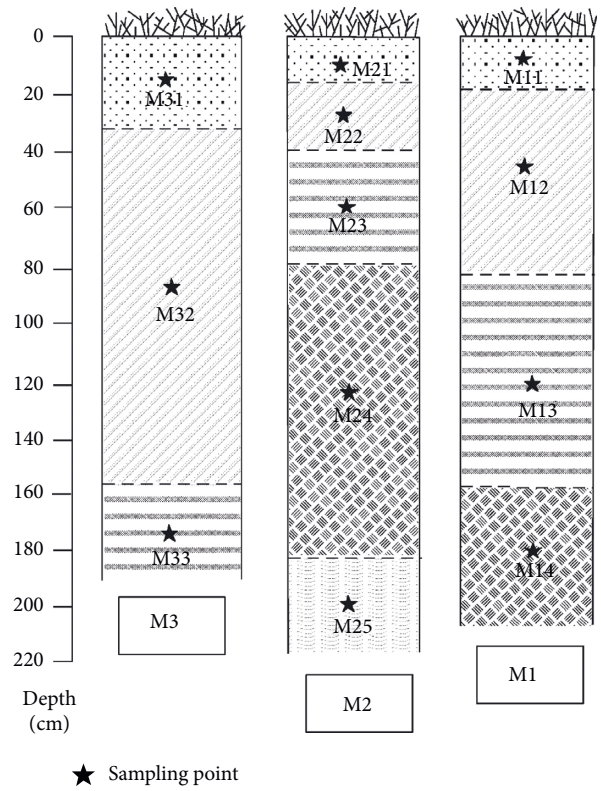

Figure 2: Morphological organization of the studied soils.

0–11 cm. White horizon (5YR8/1); sandy loam texture, blocky structure, slightly friable when dry and plastic when wet. Presence of roots and rootlets; high matrix porosity, medium biological porosity; the limit is progressive and regular;

11–80 cm. Light red horizon (2.5YR6/6); blocky structure, clay texture, very slightly friable and not brittle in the dry state; plastic when wet; presence of roots and rootlets; presence of numerous ferruginous nodules; the limit is progressive and regular;

80–154 cm. Yellow alloteritic horizon (10YR8/8); sandy loamy texture, massive structure; presence of pedoturbated domains with clay texture; presence of millimetric friable ferruginous nodules; low biological porosity and matrix porosity; presence of roots and rootlets; the limit is progressive and regular;

154–205 cm and more. Yellow isalteritic horizon (2.5Y8/8) with greyish and brownish bands; sandy-clay loam texture; massive structure; presence of millimetric friable ferruginous nodules; absence of roots and rootlets.

3.2. Mineralogical Characterization of the Studied Soil. From the X ray diffractograms of the total powder, the main minerals identified in the studied soil are quartz, K-feldspars, plagioclase, kaolinite, smectite, and illite, associated to traces of anatase and calcite (Figure 3). Quartz is by far the most important mineral (57.04–82.91%). It is followed by k-feldspar (5.72–17.53%), plagioclase (0.00–6.51%),

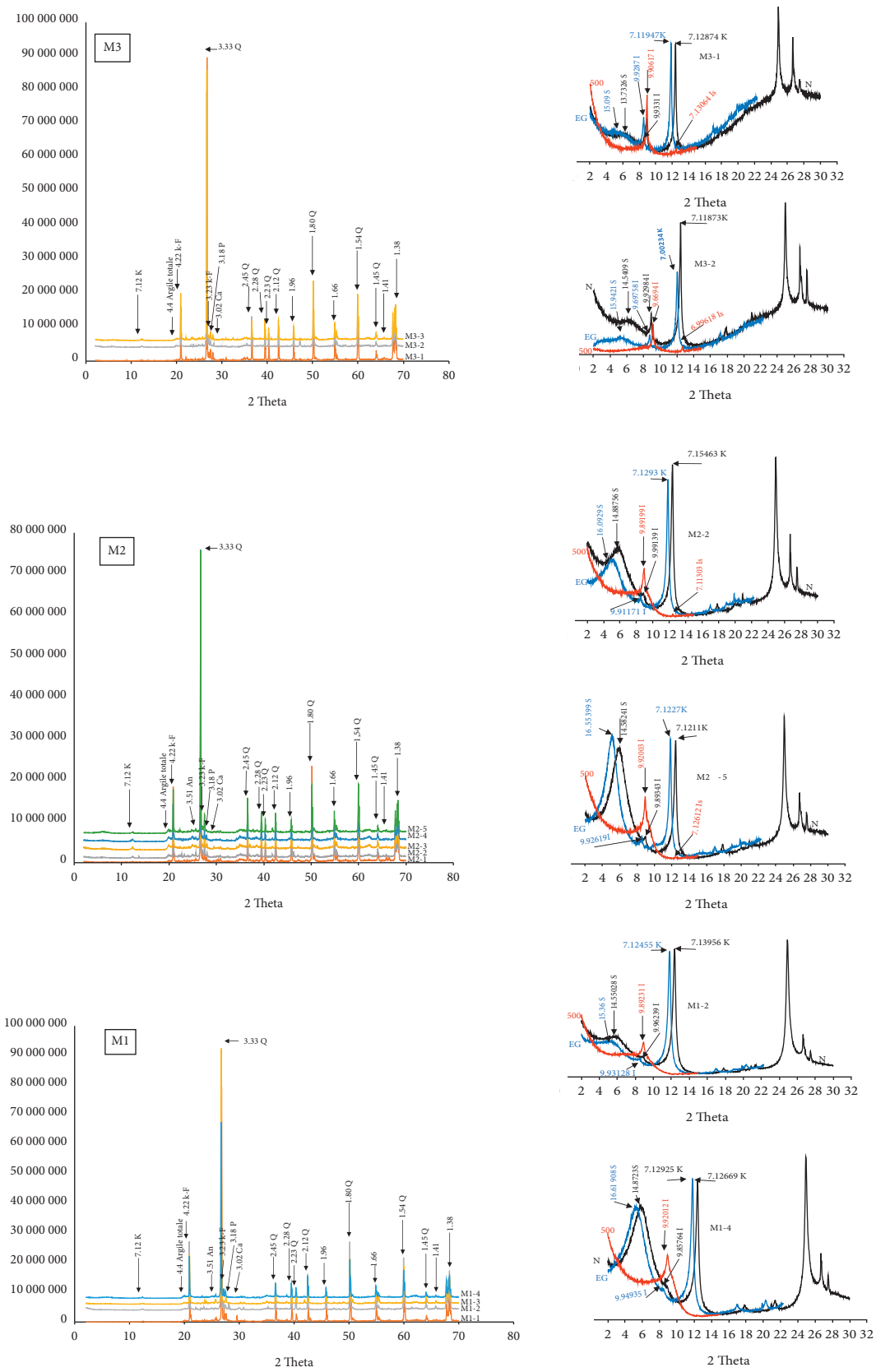

Figure 3: XRD patterns of samples bulk samples and clay fraction (K: kaolinite; S: smectite; I: illite; Q: quartz; F: feldspar; P: plagioclase; Is: interstratified clay mineral; N: air dried condition; EG: glycolated condition with ethylene glycol; H: heated at condition at 500°C).

Table 1: Mineralogical composition of the studied soils.

Samples	Quartz%	F.K%	Plagioclase%	Anatase%	Hematite%	Calcite%	Kaolinite%	Illite%	Smectite%	Total clay%
M3-1	79.44	11.69	4.98	0.00	0.00	0.25	1.93	0.58	0.21	2.72
M3-2	80.90	6.69	2.80	0.00	0.00	0.15	6.66	1.58	0.39	8.63
M3-3	78.26	9.07	2.30	0.00	0.33	0.20	6.73	1.59	0.40	8.72
M2-1	82.91	6.99	1.92	0.00	0.00	0.38	5.66	0.27	0.47	6.40
M2-2	66.89	16.98	3.33	0.00	0.00	0.27	9.91	0.71	0.66	11.28
M2-3	57.04	12.33	2.54	1.93	0.00	1.11	21.42	1.54	1.42	24.38
M2-4	59.99	11.80	2.63	1.48	0.00	0.43	20.39	1.46	1.36	23.21
M2-5	67.49	17.53	1.03	0.00	0.00	0.31	10.70	1.26	1.13	13.09
M1-1	79.90	10.31	0.76	0.00	0.00	2.25	4.97	0.78	0.33	6.08
M1-2	79.18	5.72	6.51	0.00	0.00	0.31	6.06	0.27	0.24	6.57
M1-3	81.13	10.48	0.00	0.00	0.00	0.19	6.99	0.31	0.28	7.58
M1-4	72.85	10.27	0.00	0.60	0.26	0.23	13.44	0.64	1.12	15.20

kaolinite (1.93–21.42%), illite (0.27–1.54%), smectite (0.21–1.42%), and calcite (0.15–2.25%) (Table 1). Total clay minerals contents varied highly from one horizon to another, ranging between 2.72 and 24.38%, with kaolinite being the most important fraction (Table 1). The identification of the mineral composition of the clay fraction through different treatments, air-drying (24 h), glycolation (22 h), and heating (500°C for 4 h), confirms the presence of kaolinite, illite, and smectite (Figure 3). Furthermore, a peak of 7–7.13 Å appears in the diffractograms after heating at 500°C and might characterize the presence of interstratified minerals of 1 : 1/2 : 1 type.

Infrared spectra of soil samples in M3, M2, and M1 are globally similar (Figure 4). The main minerals are quartz, kaolinite, smectite, and sepiolite. Kaolinite is identified by the bands located at 3620 cm^{-1} and 3695 cm^{-1}. Quartz is recognizable by different peaks, 777 cm^{-1}, 800 cm^{-1}, 907 cm^{-1}, 906 cm^{-1}, 910 cm^{-1}, and 1160 cm^{-1}. Smectite is identified by the band located at 999 cm^{-1} and 1630 cm^{-1}. Sepiolite is identified by peak at 524 cm^{-1}.

3.3. Geochemical Characteristics of the Studied Soils. In M3 soil profile, silicon is the most abundant element. Its content ranged between 58.45 and 76.07% (Table 2). Except for SiO_2, only aluminum and iron are significantly represented. Their contents ranged, respectively, between 6.27 and 12.22%, and between 5.73 and 6.01%. In addition to these three main elements, CaO and K_2O are well expressed in the middle part of the soil profile, with 9.40% and 4.24%, respectively. The other elements are present in traces with quantities below 1.2%. The atomic ratio Si/Al ratio is generally very high, ranging between 4.24 and 9.83. Also, K_2O/Al_2O_3 ratio is low in the studied area, ranging between 0.13 and 0.55. In M2 and M1 profiles, the proportion of SiO_2, Al_2O_3, Fe_2O_3, and K_2O are similar to those obtained in M3 profile. It is, however, noted that the quantity of CaO decreases in M2 profile reaching 4.46% and becomes very negligible in the M1 profile at the bottom of the soil sequence with a content of 1.55% in the surface horizon (Table 2).

3.4. Physicochemical Characteristics of the Studied Soils. In the M3 profile, located at the top of the sequence, the soil texture is characterized by a high level of sand (68.00% to 76.50%). Sand contents decrease from the surface horizon to the bottom horizon. Clay contents are low compared to those of sand, ranging between 12 and 21.5%. Its contents increase from the top of the profile to the bottom. Silt contents are the lowest, ranging from 49.5 to 11.5%. Soil pH is almost constant along the profile. It ranges between 6.0 and 6.3. It is always higher than $pH_{KC}l$. Exchangeable bases are largely dominated by Mg^{2+} and Ca^{2+}, with values ranging, respectively, between 1.76 and 4.8 cmol (+)/kg and between 4.62 and 8.25 cmol (+)/kg (Table 3). The other exchangeable bases are below 0.5 me/100 g. The sum of bases and CEC varied, respectively, between 9.19 and 10.88 cmol (+)/kg, and between 20.37 and 28.88 cmol (+)/kg, resulting in base saturation between 37.67 and 49.72%. The CEC of the clay fraction is very high, ranging between 108 and 169 cmol (+)/kg, in line with the presence of 2 : 1 clay minerals in the studied site. SOM and total nitrogen contents are low. They range, respectively, between 2.23 and 5.76%, and between 0.12 and 0.27%. The C/N ratio ranged between 3.93 and 15.22. Phosphorous content is very low, ranging between 0.50 and 1.00 ppm.

In M2, soil physicochemical characteristics are globally similar to those obtained in M3 (Table 3). The high difference is noted in the particle size distribution. There is an increase in silt and clay contents and a decrease in sand content in all parts of the profile. Also, there is a decrease in Ca^{2+} and Mg^{2+} contents, resulting in a decrease of the sum of exchangeable bases and consequently a decrease in base saturation (41.33 to 56.31%). The CEC is slightly high (20.28–34.24 cmol (+)/kg against 20.37–28.88 cmol (+)/kg). The CEC of the clay fraction is slightly low but remains globally high, reaching 135.2 cmol (+)/kg of clay.

In M1, there is an increase in silt (22.00–27.00%) and a slight increase in clay contents in some parts of the profile (9.00–52.00%). Sand contents fluctuate along the profile (21.00–69.00%) but remain globally low, compared to M2 and M3 (Table 3). SOM content is still low, but a high value of C/N (92.14) is noted at the base of the soil profile. Ca^{2+} and Mg^{2+} contents decrease slightly compared to the other soil profiles (2.32–4.40 cmol (+)/kg and 0.64–1.71 cmol (+)/kg, respectively). Consequently, there is a slight decrease of the sum of exchangeable bases (3.85–6.67 cmol (+)/kg), but an increase in base saturation (15.92–32.15%). The CEC is slightly low (17.64–24.18 cmol (+)/kg), and the CEC of the

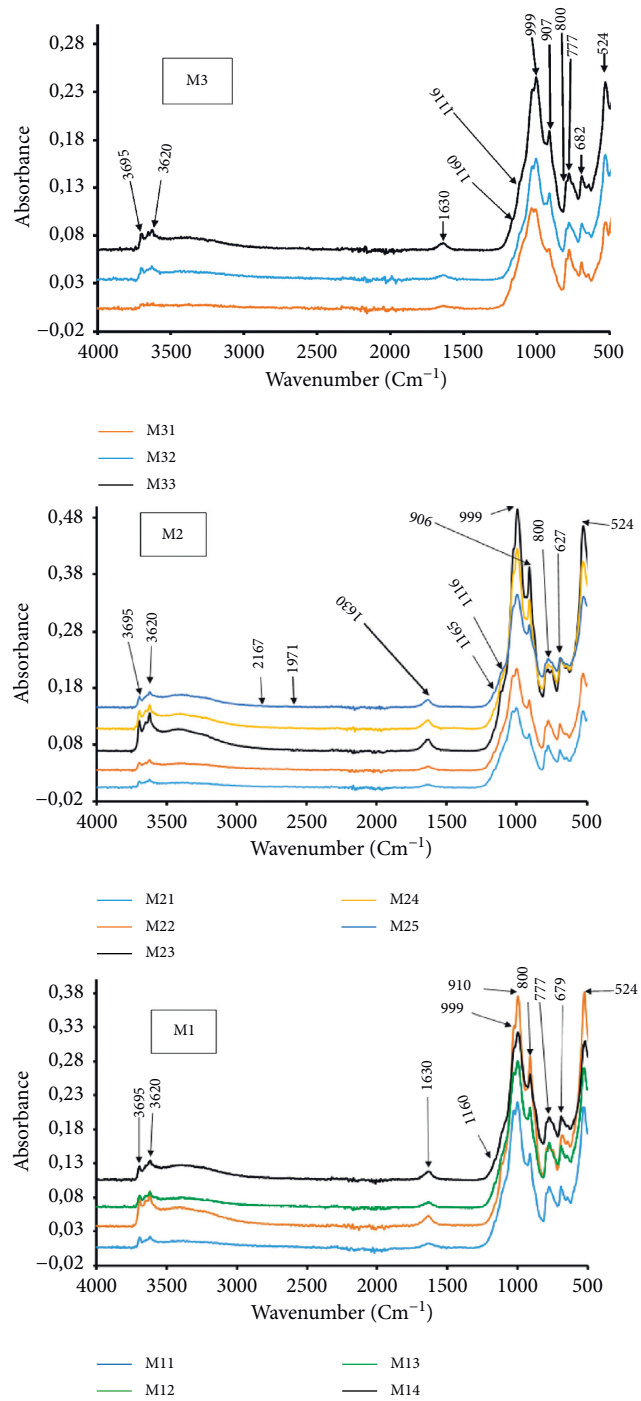

Figure 4: Infrared spectra of the studied soils.

clay fraction also reaches a high value of 198 cmol (+)/kg of clay but with a low value of 42.00 cmol (+)/kg of clay noted in the 11–80 cm depth.

3.5. Climatic and Soil Evaluation. The parametric values obtained show that the climate is very suitable for the cultivation of *sorghum* (Table 4). However, relative humidity and temperature are slight limitations. The obtained class is S1, and the calculated climatic index is 89.53. If water and soil nutrients are not limitations, 75–90% of optimum yield can be obtained according to Beernaert and Bitondo [27]. Since the average yield of *Sorghum* in tropical areas according to Beernaert and Bitondo [27] is 3 t/ha (2.5 to 3.5 t/ha), then an average yield of 2.47 t/ha can be obtained in this climate.

The land unit represented by the M3 profile located at the top of the slope is marginally suitable for *Sorghum* growth with a calculated parametric value 44.29, corresponding to classes S2 and S3 (Table 5). The sandy texture and soil fertility related to low base saturation inducing a nutrient deficit are severe limitations.

The pedoclimatic assessment of M2 located in the middle part of the slope gives a parametric value of 60.47 (Table 5). This parametric value obtained is at the limit of moderately suitable (class S2) for the cultivation of *Sorghum*. Drainage and soil fertility also related to low base saturation might constitute severe limitation for the production of *Sorghum*.

The pedoclimatic assessment of M1 located downslope is moderately to marginally suitable for *Sorghum* growth (Table 5). The parametric value obtained is 41.33. Poor drainage causing flooding (S3) and soil fertility related to low base saturation (S2) are severe limitations for *Sorghum* cultivation.

4. Discussion

4.1. Morphological, Mineralogical, and Geochemical Characteristics of Soils. At the top of the slope (M3), soils are essentially sandy. At the base of the sequence and in the middle position (M2 and M1 profiles), the surface horizons are sandy-clay. The clay contents gradually increase to a certain depth before decreasing. The sandy texture of the studied soils is related to the fluviolacustrine or fluvial nature of the geological formations deposited during the various transgressive or regressive phases of Lake Chad from the beginning of the Quaternary era to present [31]. The sandy texture along the whole soil sequence confirms the predominance of sandy tropical ferruginous soils [32]. From the top of the toposequence to the base, the passage from one horizon to another is overall progressive. This is a sign for the studied soils of being autochthonous, which results in the *in situ* development on the fluviolacustrine or fluvial geological formations under the Sudano-Sahelian climate of the study area. The presence of friable ferruginous nodules in M2 and M1 towards the base of the soil sequence and at the bottom of the two soil profiles characterizes the dynamic of ion, and its accumulation as consequence of the presence of favorable conditions to its stabilization [41].

The main minerals identified in the studied soils are quartz, K-feldspars, plagioclase, kaolinite, smectite, and illite, associated to traces of anatase, sepiolite, calcite, and interstratified minerals. This mineral assemblage is characteristic of semiarid areas [42–44]. The development of montmorillonite, sepiolite, and calcite is characteristic of a confined and consequently less acidic environment, confirmed by the high pH obtained [43, 44]. This mineral assemblage is characteristic of a conservatory geochemical mineral assemblage. In all the samples analyzed, silicon

Table 2: Chemical composition of the studied soils.

Profile	Depth (cm)	SiO_2%	Al_2O_3%	Fe_2O_3%	K_2O%	Na_2O%	CaO%	MgO%	P_2O_5%	SO_3%	LOI%	Total	Si/Al	K_2O/Al_2O_3
M3	0–26	76.07	6.27	2.64	3.05	0.47	0.83	0.20	0.03	0.05	10.37	99.98	9.83	0.49
	26–156	58.45	7.76	5.73	4.24	1.10	9.40	0.62	0.00	0.22	10.68	98.20	6.10	0.55
	156–186	63.94	12.22	6.01	1.60	0.21	0.83	0.14	0.02	0.07	14.46	99.50	4.24	0.13
M2	0–10	79.80	7.86	3.18	2.75	0.43	0.54	0.21	0.01	0.06	4.06	98.90	8.22	0.35
	10–30	57.77	8.18	5.87	4.10	0.82	4.46	0.44	0.03	0.10	17.98	99.75	5.72	0.50
	30–75	66.37	11.65	5.33	2.70	0.53	0.72	0.35	0.02	0.06	11.31	99.05	4.61	0.23
	75–175	64.29	11.90	5.97	3.02	0.69	1.09	0.55	0.07	0.29	11.85	99.72	4.38	0.25
	175–215	74.72	8.06	4.44	2.50	0.44	0.78	0.41	0.02	0.05	7.69	99.09	7.51	0.31
M1	0–11	68.82	8.20	6.16	3.49	0.56	1.55	0.34	0.05	0.12	9.20	98.50	6.80	0.43
	11–80	54.97	15.42	8.22	2.74	0.39	0.39	0.48	0.03	0.06	16.64	99.33	2.89	0.18
	80–154	75.89	7.47	2.97	2.65	0.34	0.60	0.21	0.02	0.05	8.69	98.89	8.23	0.35
	154–205	69.43	6.72	4.72	3.03	0.62	0.50	0.31	0.00	0.09	14.02	99.45	8.38	0.49

Table 3: Physicochemical characteristics of the studied soils.

Profile	M3			M2			M1			
Depth (cm)	0–26	26–156	>156	0–30	30–75	75–215	0–11	11–80	80–154	>154
Texture (%)										
Clay	12.00	16.00	21.50	21.5	20.00	12.00	9.00	52.00	12.00	29.5
Silt	11.50	9.59	10.50	4.50	7.00	8.00	22.00	27.00	25.00	9.00
Sand	76.50	74.50	68.00	74.00	73.00	80.00	69.00	21.00	63.00	61.5
Textural class	Loamy sand	Loamy sand	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy loam	Sandy loam	Clay	Sandy loam	Sandy clay loam
Organic carbon (%)	2.29	3.35	1.30	2.67	1.35	1.30	1.06	1.80	1.45	1.29
Organic matter (%)	3.93	5.76	2.23	3.90	2.32	2.23	1.82	3.09	2.49	2.21
Total nitrogen (%)	0.27	0.22	0.12	0.27	0.22	0.12	0.08	0.25	0.12	0.014
C/N	3.93	15.22	10.88	9.88	6.13	10.83	13.25	7.2	12.00	92.14
pH H_2O (1/2.5)	6.3	6.0	6.2	7.00	5.9	5.7	6.3	6.5	6.8	6.7
pH KCl (1/2.5)	5.3	5.1	5.6	6.1	4.8	4.4	5.2	5.4	5.8	5.1
P Bray II (ppm)	1	1	0.5	1.00	1.00	0.5	0.36	0.15	0.31	0.17
Exchangeable bases (meq/100 g of soil)										
K^+	0.19	0.19	0.19	0.63	0.51	0.31	0.63	0.37	0.27	0.37
Na^+	0.32	0.20	0.21	0.91	0.32	0.32	0.51	0.42	0.31	0.49
Ca^{++}	8.25	6.72	4.62	9.80	7.32	6.08	3.34	4.40	2.32	2.35
Mg^{++}	1.92	1.76	4.8	2.40	4.96	4.80	1.32	1.48	1.71	0.64
Sum of bases	10.88	9.19	10.13	13.74	13.11	11.51	5.80	6.67	4.61	3.85
Base saturation (%)	37.67	42.38	49.72	41.33	56.31	48.00	32.15	30.54	26.13	15.92
CEC7 (meq/100 g of soil)	28.88	21.68	20.37	33.24	23.28	24.08	17.84	21.84	17.64	24.18
CEC (meq/100 g of clay)	136	108	169	154	116	200	198.2	42.00	147.00	81.96
EC (ms/cm)	0.5	0.01	0.02	0.6	0.01	0.02	0.01	0.01	0.01	0.02
ESP (%)	1.1	0.9	1.0	2.73	1.37	1.32	2.80	1.90	1.75	2.02

Table 4: Climatic suitability evaluation for the production of *Sorghum*.

Characteristics	Values	Classes	Limitations	Parametric values
Group I: Precipitation				
Precipitation during crop cycle (mm)	677	S1-1	0	97
Precipitation during 3rd cycle (mm)	221.6	S1-1	0	100
Group II: Temperature				
Mean temperature during crop cycle (°C)	27.5	S1	1	88.3
Mean maximum temperature during crop cycle (°C)	33.1	S1-1	1	91
Mean minimum temperature during crop cycle (°C)	21.9	S1-0	0	100
Relative humidity during crop cycle (%)	73	S1-1	1	88
n/N during crop cycle	0.68	S1	0	100
Calculated climatic index (CR)		S1		89.53

Table 5: Land suitability evaluation for the production of *sorghum*.

Characteristics	Evaluation of M3 for the production of *Sorghum*				Evaluation of M2 for the production of *Sorghum*				Evaluation of M1 for the production of *Sorghum*			
	Values	Classes	Limitations	Parametric values	Values	Classes	Limitations	Parametric values	Values	Classes	Limitations	Parametric values
Topography (*t*)												
Slope (%)	2	S1-1	1	90	1	S1-1	0	95	1	S1-0	0	100
Wetness (*w*)												
Flooding	FO	S1-0	0	100	F1	S2	2	72.5	F1	S2	4	60
Drainage	Good	S1-0	0	100	moderate	S2	2	72.5	Imperfect	S3	2	60
Physical soil characteristics (s)												
Texture/structure	S	S3	3	40	SA	S1-0	0	100	C<60s	S1-0	0	100
Soil depth (cm)	>90	S1-0	0	100	>100	S1-0	0	100	>90	S1-0	0	100
Coarse fragments (%)	—	S1-0	0	100	—	S1-0	0	100	0	S1-1	0	100
$CaC0_3$ (%)	0	S1-0	0	100	0	S1-0	0	100	0	S1-0	0	100
Gypsum (%)	0	S1-0	0	100	0	S1-0	0	100	0	S1-0	0	100
Soil fertility characteristics (f)												
Apparent CEC (cmol (+)kg^{-1} clay)	125.41	S1-0	0	100	125.41	S1-0	0	100	85.25	S1-0	0	100
Base saturation (%)	20.41	S2	2	68.75	32.15	S2	2	74	27.69	S2	2	74.85
Organic carbon (%)	2.20	S1-0	0	100	2.20	S1-0	0	100	2.2	S1-0	0	100
pH-H_2O	5.9	S1-1	0	100	6.3	S1-0	0	100	5.6	S1-1	1	85
Salinity and sodicity (*n*)												
CEe (ms/cm)	0.2	S1-0	0	100	0.2	S1-0	0	100	0.01	S1-0	0	100
ESP (%)	0.36	S1-0	0	100	2.8	S1-0	0	100	0.6	S1-0	0	100
Suitability and calculated land index (Is)		S3sS2f		44.29		S2wf		60.47		S3wS2f		41.33

content is very high. It is closely followed by aluminum, iron, and potassium. The presence of kaolinite and smectites suggests that monosiallitisation is a crystallochemical processes acting at the bottom of profile towards bisiallitisation as already noted by Tsozué et al. [45] in the Sudano-Sahelian of Cameroon. The abundance of silicon in the samples is due to the fact that the Si-O-Si bond is generally considered to be very stable and therefore almost indestructible [46]. The high levels of Si in the soils are in line with the high sand content and the sandy texture noted in all soil horizons. The Si/Al atomic ratio is very high in all horizons. This indicates an excess of SiO_2 in the form of quartz, in line with the high quantities of quartz noted in the mineralogical analysis, the high content of the sand fraction, and the predominance of the sandy texture noted in the macroscopic description of the soil profile. The K_2O/Al_2O_3 ratio is low, confirming the low content of illite minerals and the high expression of neoformed clay mineral kaolinite + smectites in the clay fraction. However, the high content of primary minerals, which include quartz and K-feldspar, is an indication of low chemical alteration due to low precipitation as described by Aouam [47].

4.2. Physicochemical Constraints. The physicochemical characteristics of soils show that all samples taken from the three soil profile horizons are poor in nutrients. They are characterized by low pH and CEC. Low pH correlates with low base saturation. The difference between pH_{KCl} and pH_{H_2O} is negative, marking the predominance of the negative charge in the studied soils [48]. CEC values vary from low to moderate. These CEC values are related to the low clay content in soil samples characterized by sandy-textured and confirm their poverty. The C/N ratio is very low. This indicates a fast mineralization, as consequence of the high temperature and the sandy texture of the soils. Similar results were obtained by Yerima et al. [49] in the soils of northern Cameroon. Also, potassium contents were low. It could be attributed to the sandy texture because a soil with low content in clay and silt has a reduced ability to retain potassium. Phosphorous content is very low. The phosphorus deficiency is explained by the fact that its fixation on the humic-clay complex depends on the percentage of clay, pH, and calcium. Some authors have even found that it is the most limiting essential element in acidic soils, and its deficiency can be so magnified that plant growth declines, thus leading to low yields [50]. In its ionic form, it is endowed with an electronegative charge. It can only bind to the complex formed by clay and humus, with both being electronegative, by a bond that takes place through a "calcium bridge," which is calcium, (noted Ca^{2+}) serving as a link (the "bridge") between it and the clay. Calcium deficiency might thus influence the availability of phosphorous in the studied soils.

4.3. Land Evaluation. In the study site, the climate was found to be very suitable for *Sorghum* growth. As for soil characteristics, texture, soil fertility, and wetness are the main limitations. In the M3 profile, located upstream of the slope, the sandy texture is a severe limitation for the production of *Sorghum*. Soil fertility constitutes a moderate limitation due to low base saturation meaning that the M3 unit is moderately suitable and might thus give rise to acceptable yield according to Beernaert and Bitondo [27]. Due to soil texture and soil fertility, M3 might be marginally suitable for the production of *Sorghum,* and consequently, the yield would be low. On the other hand, in the M2 profile, located in the middle part of the soil sequence, the flooding phenomenon, drainage, and soil fertility (low base saturation) are moderate limitations compared to M3. M2 is moderately suitable for *Sorghum* growth and might give acceptable yield. In the M1 profile, located at the bottom of the soil sequence, the clay texture blocks the infiltration of water and creates floods, which affect the growth of *Sorghum* and, therefore, represent a severe limitation. Also, soil fertility constitutes a moderate limitation as consequence of low base saturation. M1 is, therefore, marginally suitable for the production of *Sorghum*. In general, it is to admit that the qualities of the studied lands seem to preclude the continuous use. The risks of low productivity associated with these soils are high to very high. This situation could be solved by the restoration of the cation balance through fertilization and liming, combining organic inputs with mineral fertilizer, and the realization of channels for the drainage of water at the base of the soil sequence. Combining organic inputs and mineral fertilizer was already proposed by many authors [18, 51–54]. The efficacy of this process will be enhanced by the presence of 1 : 1 and 2 : 1 clay minerals and Fe and Al oxides in the studied soil, which play an important role in the dynamic and the stabilization of soil organic matter [55, 56]. Using early varieties can also help avoid flooding that usually occurs late in the crop cycle. Introducing other speculations into the cropping system could also be an alternative.

5. Conclusions

Soils in Mayo-Lemié Division are morphologically characterized by sandy texture and the presence of ferruginous nodules. The main minerals observed are quartz, K-feldspar, smectite, kaolinite, sepiolite, calcite, and anatase. In all the three soil profiles, silicon is by far the most abundant element. It is followed by aluminum and iron. The presence of kaolinite and smectites suggests that monosiallitisation is a crystallochemical processes acting at the bottom of profile towards bisiallitisation. The physicochemical characteristics showed that all the analyzed soils are poor in nutrients. The pedoclimatic assessment of *sorghum* cultivation reveals that the studied soils are marginally to moderately suitable due to soil texture, wetness, and soil fertility. The risks of low productivity associated with these soils are high. These limitations could be solved by restoration of the cation balance through fertilization and liming, combining organic inputs with mineral fertilizer, and the realization of channels for the drainage of water at the base of the soil sequence. This work will be followed by the search for optimal fertilizer types and doses to increase yields, the search for varieties adapted to the climate of the study area, and the search for suitable technical itineraries for optimal *Sorghum*

production in the Department of Mayo-Lemié in south-western Chad.

Data Availability

All the data used to support the findings of this study are included within the paper.

Conflicts of Interest

The authors would like to hereby certify that there were no conflicts of interest in the data collection, processing the data, the writing of the manuscript, and the decision to publish the results.

Authors' Contributions

All the authors substantially contributed to this article. The conceptualization of the study was done by Agoubli Issine and Désiré Tsozué, with input from Aubin Nzeugang Nzeukou, Rose Yongue-Fouateu, and Bertin Pagna Kagonbé. The data acquisition, investigation, methodology, and visualization for the paper were performed by Agoubli Issine and Désiré Tsozué, with substantial input from Aubin Nzeugang Nzeukou, Rose Yongue-Fouateu, and Bertin Pagna Kagonbé. Agoubli Issine, Désiré Tsozué, and Rose Yongue-Fouateu wrote the initial draft, and Désiré Tsozué and Rose Yongue-Fouateu were involved in the reviewing, editing, and the validation of the paper. All authors have read and agreed to the published version of the manuscript.

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