Statistical analysis of the physico-chemical characterization of three arid soils in the Hadjer-Lamis region (Chad)

Abstract

The Hadjer-Lamis region is in western Chad, with the following geographical coordinates: 13°00'00'' north latitude and 15°44'00'' east longitude. It covers an area of 31426 km^{2}and has a Sahelian climate. This study, carried out in this region, aims to carry out a statistical analysis of the physico-chemical characterization of the soils of Dandi, Karal and Mani in the Hadjer-Lamis.The texture, electrical conductivity, water retention capacity and natural moisture content of the soil were determined at the Laboratoryof Soils, Waterand Plants (LASEP) in Chad. The organic matter content, soil reaction, total and assimilable phosphorus, total nitrogen, total potassium, CEC, exchangeable bases, and C/N ratio were determined at the Nationaloffice of soils (BUNASOL) in Burkina Faso. XLSTAT software version 7.5.2 was used for this work, and tests for comparison of means were carried out using the Fischer method with a threshold of 5%.Soil samples were taken from a depth of 0 to 20 cm, and the results of these analyses gave the following values for each soil in this order (% clay, % silt, % sand): Dandi (19.5%, 17.5%, 63%), Karal (17%, 7.5%, 75.5%) and Mani (14%, 7%, 79%). All three of these soils have a sandy-silty texture.Total phosphorus levels in Dandi, Karal and Mani are 182.50mg/100g, 265.50mg/100g and 388mg/100g dry matter respectively, while assimilable phosphorus levels are 13.08mg/100g, 42.33mg/100g and 18.10mg/100g dry matter respectively. All three soils have a slightly basic water pH: Dandi (8.07), Karal (7.29) and Mani (7.03).

Key words: arid, soil, physico-chemical characterization, texture, content, organic matter.

1- Introduction

Chad, a landlocked Sahelian country, lies between latitudes 7° and 24° North and longitudes 13° and 24° East. It has a warm continental climate. Rainfall in Chad varies from north to south between 100 and 1,200 mm per year, which has a major influence on the agricultural production system. This rainfall is characterized by very high annual variability, with a high risk of drought. The agricultural sector plays an important role in the growth of the Chadian economy.

Agriculture plays a key role in the national economy and remains the driving force behind the country's development, contributing at several levels. Agriculture's main contribution to the economy is its large share of GDP, estimated at 23%, of which 20% comes from food production and 3% from cash crops (groundnuts, cotton, gum arabic). It is also a major provider of jobs, employing 2/3 of the country's working population, more than half of whom are women.

The second fundamental contribution of agriculture is the production of food, which provides an immediate response to the issues of food insecurity and poverty, which are particularly acute given the recurrent food shortages in Chad. Agriculture's third contribution to overall growth is the supply of raw materials to the country's agri-food industries.

Most of the players in this agricultural sector are family farms, which for several decades have been faced with a combination of unfavorable situations that have had an impact on their production levels **(NYORE et al., 2003)**. Firstly, soil fertility is reduced **(KANTE, 2001)**. Fertilization and amendment practices help to modify soil properties **(PERNES-DEBUYSER and TESSIER, 2002; OGNALANGA et al., 2017; KPERA et al., 1997; BIGORRE, 2000)**.

Improving soil fertility management practices requires : the application of organic manure (manure, compost, crop residues) **(BLANCHARD, 2010)** and mineral fertilisers (NPKSB and urea) to crops; the practice of short or long fallow periods; the promotion of the use of nitrogen-fixing cover crops and fodder plants for the sustainable improvement of soil fertility and yields; training farmers to master simple, low-cost soil fertility management techniques combining light erosion control works and the addition of organic matter at plot level.

Many researchers have demonstrated the increase in certain yields with the use of nitrogen fertilizers **(GANRY, 1973; TRAORE, 1974; MIKO and MANGA, 2008; PIERI, 1989)**. The present work, which involves a characterization study of three of the above-mentioned soils, adds to and deepens our physico-chemical knowledge of these different soils.

2. Materials and methods

2.1 Description of the study site:

The research was carried out in Karal, Dandi and Mani, three localities in the Hadjer-Lamis region, which has the following geographical coordinates: 1300'00'' North latitude, 15^{o}44'00'' East longitude and an area of 31,426 km^2.

Furthermore, Dandi is located at latitude 12^{o}48.954' North and longitude 14^{o}40.722' East, Karal is located at latitude 12^{o}52.752' North and longitude 14^{o}45.507' East and Mani is located at latitude 12^{o}44.622' North and longitude 14^{o}41.155' East. The climate in these areas is Sahelian, with a very long dry season from October to May and a rainy season lasting an average of 4 months. July and August are the wettest

months, with monthly cumulative rainfall varying from 80 to 180 mm, and average annual cumulative rainfall is 450 mm.

Average maximum temperatures in these areas range from 35 to 45°C during the month, while minimum temperatures vary between 11 and 22°C.The hottest months are March, April, May and June, while the coolest months are December, January and February.

2.2 Soil analysis in laboratories

Soil samples were taken in June 2023 from horizons (0-20 cm).The choice of these depths is dictated by the fact that they are the parts of the soil where the roots arborise, fixing the plant to its support and supplying it with the various elements necessary for plant growth: heat, water, all the nutrients: this is also where the notion of soil fertility is well attached **(TOUHTOUH et al., 2014).**

The samples were subjected to various physico-chemical characterizations: particle size analysis, maximum water retention capacity, electrical conductivity, natural water content was determined at the soil-water-plant analysis laboratory (LASEP) in N'Djamena (Chad).

Organic matter, organic carbon, total phosphorus, assimilable phosphorus, total potassium, total nitrogen, cation exchange capacity (CEC), exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), soil reaction (pH-water, pH-KCl) were carried out at the BUNASOL laboratory, Ouagadougou (Burkina Faso).

The particle size analysis was carried out using the densiometric method **(PAUWELS et al., 1992).**

The maximum water retention capacity (WRC_{max}) was estimated using the percolation method according to the relationship.

$$WCR_{\max}(\%) = \frac{(W_R + W_w)}{D.M} \times 100 \qquad (1)$$

Where W_R is the quantity of water retained (g), W_w is the quantity of water initially in the fresh sample (g) and D.M is the dry matter (g).Electrical conductivity is used to determine the level of salts soluble in water. It is measured using a conductivity meter on a soil suspension in a ratio (soil/water) of 1:5 after 2 hours of contact and the reading is taken with a conductivity meter, the results are given in (µs/cm) **(YACOUBA et al., 2018).**

Soil moisture, there are several methods to estimate it, in our experiment we chose the gravimetric method which consists of drying the soil sample at 105^{o}C for 24h, the weight loss after drying is equal to the water content of the soil, the values obtained can be expressed as a percentage in relation to the weight of the dry or wet sample **(BOUCHENAFA et al., 2014),**

$$\%\ soil\ humidity\ = \frac{(wet\ mass) - (dry\ mass)}{dry\ mass} \times 100 \quad (2)$$

The organic matter (OM) content was determined using the Walkey and Black (1934) method, which consists of cold oxidation of the organic carbon fraction with potassium dichromate ($K_2Cr_2O_7$ at 1N) in an acid medium and back titration with Mohr's salt (SO_4Fe, $SO_4(NH_4)_2$, 6 H_2Oat 0.5N).

The organic carbon content multiplied by 1.724 (Walkey at Black, 1934) gives the organic matter content. Total phosphorus and assimilable phosphorus were measured in accordance with international standard NF ISO 11263 **(BUOL et al., 2011b).**

Total nitrogen was obtained using the method described in international standard NF ISO 13878.The cation exchange capacity was measured using the Metson method (AFNOR standard NF X31-130), the natural water content of the soils studied was determined using the successive weighing method before and after drying the samples in an oven at 105oC in accordance with standard NF P 94 - 050 (1995), and the Ca2+, Mg^{2+}, Na^{+} and K^{+} element content was determined using the fluoro-nitro-perchloric method **(HOWELER, 1996).**The pH (pH-water and pH-KCl) (hydrogen potential) was determined using the method of Mc. Lead (1982).

2.3 Statistical analysis

The data collected were subjected to an analysis of variance (ANOVA). Means comparison tests were performed using Fisher's method at the 5% threshold. XLSTAT software version 7.5.2 was used.

3. Results and discussion

3.1 Results

3.1.1 Physical analysis

Table 1 shows the average results of the granulometric analysis of the soils in the various localities. The table shows that the sand content varies from 63 to 79%, with the highest content recorded in Mani. There is a significant difference between localities for this parameter. Silt content varies from 7 to 17.5%, with the highest silt content recorded in Dandi, with a significant difference between localities for this parameter. There is also a significant difference between localities in terms of clay content, which varies between 14 and 19.50%. The highest clay content was found in Dandi.

Table 1: Soil sample analysis

Parameters	Fisher's F	Associated P	Localities		
			Dandi	Karal	Mani

Sand (%)	17,32	0,02	63[b]	75,5[a]	79[a]
Silt (%)	16,19	0,02	17,5[a]	7,5[b]	7[b]
Clay (%)	18,20	0,02	19,5[a]	17[a]	14[b]

Table 2: correlation matrix between Dandi, Karal and Mani soils

Localities	Sand	Silt	Clay
Sand	1,00		
Silt	**-0,986**	1,00	
Clay	**-0,931**	**0,855**	1,00

In bold, significant values (outside the diagonals) at the alpha=0.050 threshold (two-tailed test).

3.1.2 Chemical analysis

The results for the chemical parameters of the three soils studied are shown in tables 3 and 5.

Table 3: Proportion of chemical elements 1

Parameters	Fisher's F	Associated P	Localities		
			Dandi	**Karal**	**Mani**
KT	**191,62**	**0,001**	**480,50[a]**	**483[a]**	**325[a]**
Ca^{2+}	**0,74**	**0,54**	**256,50[a]**	**460[a]**	**446,10[a]**
Mg^{2+}	**0,74**	**0,54**	**153,90[a]**	**276[a]**	**267[a]**
K^{+}	**0,74**	**0,54**	**500,17[a]**	**897[a]**	**869,89[a]**
Na^{+}	**0,74**	**0, 54**	**294,97[a]**	**529[a]**	**513,01[a]**
S	**0,74**	**0,54**	**1205,55[a]**	**2162[a]**	**2094,68[a]**
V	**15,32**	**0,02**	**41,09[a]**	**53,43[a]**	**19,50 [b]**
T	**0,74**	**0,54**	**12,82[a]**	**23[a]**	**22,30[a]**
PHK	**0,05**	**0,95**	**6,28[a]**	**6,33[a]**	**6,03[a]**
PHE	**0,48**	**0,65**	**8,07[a]**	**7,29[a]**	**7,03[a]**

Legend: KT: total potassium, K^{+}: available potassium, Ca^{2+}: calcium, Mg^{2+}: magnesium, Na^{+}: sodium, S: sum of bases, V: saturation level, T: cation exchange capacity, PHK: pH-KCl, PHE: pH-water.

Table 4: Correlation matrix for chemical analysis 1

Parameters	KT	Ca^{+2}	Mg^{+2}	K^{+}	Na^{+}	S	V	T	PHK	PHE
KT	1,000									
Ca^{2+}	-0,234	1,000								
Mg^{2+}	-0,234	**1,000**	1,000							
K^{+}	-0,234	**1,000**	**1,000**	1,000						
Na^{+}	-0,234	**1,000**	**1,000**	**1,000**	1,000					
S	-0,233	**1,000**	**1,000**	**1,000**	**1,000**	1,000				
V	**0,884**	-0,274	-0,274	-0,274	-0,274	-0,273	1,000			
T	-0,234	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	-0,274	1,000		
PHK	0,128	0,139	0,139	0,139	0,139	0,139	0,223	0,139	1,000	
PHE	0,292	0,050	0,050	0,050	0,050	0,051	0,155	0,050	**0,852**	1,000
In bold, significant values (off diagonal) at the alpha=0.050 threshold (two-tailed test)										

Table 5: Proportion of chemical elements 2

Parameters	Fisher's F	Associated P	Localities		
			Dandi	**Karal**	**Mani**
TOM	0,56	0,61	$0,68^{a}$	$0,61^{a}$	$0,61^{a}$
TC	0,58	0,60	$0,40^{a}$	$0,35^{a}$	$0,35^{a}$
TN	4,71	0,11	$0,03^{a}$	$0,04^{a}$	$0,02^{a}$
C/N	1,14	0,42	$13,27^{a}$	$7,83^{a}$	$17,05^{a}$
TP	111,13	0,002	$182,50^{c}$	$265,50^{b}$	388^{a}
AP	0,47	0,66	$13,08^{a}$	$42,33^{a}$	$18,10^{a}$
Cond	218,41	0,001	322^{b}	$666,50^{a}$	$160,50^{c}$
Ret	14,51	0,02	$45,22^{a}$	$34,66^{b}$	$42,84^{a}$
MC	203,98	0,001	$2,77^{b}$	$4,40^{a}$	$2,87^{b}$

Legend: TOM: Total Organic Matter, TC: Total Carbon, TN: Total Nitrogen, C/N: Carbon to Nitrogen ratio, TP: Total Phosphorus, AP: Assimilable Phosphorus, Cond: Electrical Conductivity, Ret: Water Retention, MC: Moisture content.

Table 6: Correlation matrix for chemical analysis 2

Parameters	TOM	TC	TN	C/N	TP	AP	Cond	Ret	MC
TOM	1,000								
TC	**0,999**	1,000							
TN	-0,371	-0,404	1,000						
C/N	0,652	0,672	**-0,871**	1,000					
TP	-0,430	-0,415	-0,407	0,346	1,000				
AP	0,037	-0,005	0,525	-0,178	-0,061	1,000			
Cond	-0,021	-0,055	**0,856**	-0,609	-0,416	0,490	1,000		
Ret	0,524	0,544	-0,762	0,673	-0,119	-0,277	-0,792	1,000	
MC	-0,220	-0,254	0,799	-0,557	-0,063	0,556	**0,931**	**-0,913**	1,000
En gras, valeurs significatives (hors diagonale) au seuil alpha=0,050 (test bilatéral)									

3.2 Discussions

Table 1 shows a higher average percentage of sand in the Mani soil sample (79%) than in the other localities. On the other hand, the Dandi soil sample had a higher average silt content (17.50%) than Karal (7.50%) and Mani (7%). Dandi also had a higher clay content (19.50%) than the other two localities.

The results obtained show from the textural triangle **(FADWA et al., 2015)** that the three soils are of sandy-loam type.

They are similar to those studied by **SABER et al, (2014),** these authors worked in the Bouskoura region and found the percentage of clay varying between 6.30 and 8.30%, that of silt varying between 19.40 and 35% and that of sand varying between 57.30 and 74.30%, but results obtained by **OGNALANGA et al, (2017),** who worked on the soil of south-eastern Gabon (Franceville), which has a fine silt texture, the work of **AKASSIMADOU et al. (2014),** which gave a clayey silt texture, and that of **TEMGOUA et al. (2015)**, which gave a clay texture on the three horizons.Table 2 shows the similarity matrix of the soil samples studied. Sand content is negatively correlated with silt content (R = - 986) and clay content (R= - 0, 931).

As sand content increases, silt and clay content decreases. Furthermore, silt content is positively correlated with clay content (R=0.855). An increase in silt systematically leads to an increase in clay.

Table 3 shows that the KT content varied from 325 to 480.50 mg/100g dry matter (DM), with the highest value found at Dandi, but the difference between localities was not significant.

Calcium content varied between 256.50 and 460 mg/100g DM. The highest value was recorded in Karal. There was no significant difference between localities.

Magnesium content ranged from 153.90 to 276 mg/100g DM. The highest value was found in Karal. There was no significant difference between localities.

Potassium content varied between 500.17 and 897 mg/100g DM. The highest potassium content was found at Karal.

No significant differences were observed between localities. The sodium content varied between 294.97 and 529 mg/100g DM. The highest value was found in Karal. There was no significant difference between localities. The total base content varied between 1205.55 and 2162 mg/100g DM. The highest S content was found in Karal. No significant differences were observed between localities. The saturation rate varied between 19.50 and 53.43%, with the highest content observed in Karal. There was a significant difference between localities.

The cationic capacity content of the sample varied between 12.82 and 23 meq/100g, with the highest content in Karal. There was no significant difference between localities.

. The pH-KCl value varied between 6.03 and 6.33, with the highest value observed in Karal. There was no significant difference between localities.

Table 4 shows the chemical parameter similarity matrix, in which TP is positively correlated with V (R= 0.884).

Ca^{2+} is positively correlated with Mg^{2+}, K^{+}, Na^{+}, S and T, in addition Mg^{2+} is positively correlated with K^{+}, Na^{+}, S and T, in addition K^{+} has a positive correlation with Na^{+}, S and T, a positive correlation was also noted between Na^{+} and S, T, a positive correlation also noted S and T, finally pHK is positively correlated with pHE.

Table 5 shows the proportion of chemical elements 2.In this table, we can see that the TOM content in the soils varied from 0.61 to 0.68 mg/100g DM, the highest value was found in Dandi but there was no significant difference between localities.

The TC content in the three soils varied from 0.35 to 0.40 mg/100g DM, the highest value was found in Dandi, but there was no significant difference between localities.TN content varied from 0.02 to 0.04 mg/100g DM, with the highest value observed in Karal, but there was no significant difference between localities.

The C/N ratio varied from 7.83 to 17.05, with the highest value observed in Mani and no significant difference between localities.

The TP content varied between 182.50 and 388 mg/100g, with the highest value observed in Mani, with a significant difference between localities. The AP content varied between 13.08 and 42.33 mg/100g DM, with the highest value observed in Karal, with no significant difference between localities.

Electrical conductivity varied from 160 to 666.50µs/cm, the highest value was observed in Karal, with a significant difference between localities. Water retention varied from 34.66 to 45.22%, with the highest value observed in Dandi; there is a significant difference between localities. Moisture content varied from 2.77 to 4.40%, with the highest value observed in Karal; there is a significant difference between localities.

Table 6 shows the similarity matrix for the chemical parameters, in which TOM is positively correlated with TC (R= 0.999), so that when the TOM content increases, the TC content systematically increases.

TN is negatively correlated with C/N (R= - 0.871), so when the amount of TN increases, C/N systematically decreases. On the other hand, there is a positive correlation between TN and Cond (R= 0.856), so when the TN parameter decreases, the Cond parameter automatically decreases.

The Cond parameter is positively correlated with the MC parameter (R= 0.931), with the two parameters increasing or decreasing together. There is a negative correlation (R=- 0.913) between the parameters ret and MC, with an increase in one systematically leading to a decrease in the other and vice versa.

Conclusion

The quality of soils in the Hadjer-Lamis region (Dandi, Karal, Mani), assessed through physico-chemical analysis of the parameters, leads to the conclusion that:

The texture of the three soils is of the sandy-loam type, the pH-water of the three soils is slightly basic and varies between Mani (7.03) and Dandi (8.07), the organic matter levels are generally low and increase from Mani (0.61mg/100g) to Dandi (0.68mg/100g).Cation Exchange Capacity increases from Dandi (12.82mg/100g) to Karal (23mg/100g), the sum of bases (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) varies from Dandi (1205, 55 mg/100g) to Karal (2162mg/100g), the KT varies from Mani (325mg/100g) to Karal (483mg/100g), the total carbon content is very low and varies from Mani (0.35mg/100g) to Dandi (0.40mg/100g).

The C/N ratio varies from Karal (7.83) to Mani (17.05), the moisture content varies from Dandi (2.77%) to Karal (4.40%), total phosphorus and assimilable phosphorus vary respectively from Dandi (182.50mg/100g) to Mani (388 mg/100g) of dry matter and from Dandi (13.08 mg/100g) to Karal (42.33 mg/100g) of dry matter.Electrical conductivity increased from Mani (160.50 µs/cm) to Karal (666.50 µs/cm) and water retention increased from Karal (34.66%) to Dandi (45.22%).

The results of the physico-chemical analyses give parameter values that differ slightly from one another depending on the type of soils present.

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