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Comparative Study of the physico-chemical Characterization of Three Arid Soils in the Hadjer Lamis Region (Chad)

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Abstract Soil samples were taken from the 0-20 cm range from three sites in the Hadjer Lamis region. According to the climatology (rainfall and temperature trends) over the last thirty years, Dandi, Mani, and Karal have an arid climate based on the Koppen-Geiger classification. A physico-chemical characterization analysis of these samples gives us the granulometry by sieving according to the NFP18-560(1978) standards in the bottom of the sieves for the different samples, which are as follows: Dandi: 63.4%, Karal: 70.5%, Mani: 2.1%. Mani has a plasticity index (PI) that cannot be measured, while Dandi and Karal have plasticity indices of 4.75 and 21.15 respectively. Using the soil classification table based on PI values, the Dandi soil is sandy and the Karal soil is sandy clay. The results of the chemical analyses reveal that these three soil samples have organic matter contents of 0.655%, 0.617%, and 0.519% respectively, which are not very appreciable, as these soils are poor overall. The pH-water varies between 6.26 (weakly acidic) and 7.64 (slightly alkaline) with an average of 7.72 (neutral), the exchangeable base content is normal for some samples and abnormal for others. The poverty of these soils is undoubtedly because they are arid

Keywords: *arid, climate, physico-chemical, soil, organic matter, fertility*

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1. Introduction

Food self-sufficiency is a quest for some African countries. Countries of sub-Saharan Africa are no exception to this rule [1]. To achieve food self-sufficiency, with the increase in the African population in general and sub-Saharan Africa in particular, it will be necessary to increase agricultural production, among other things [2,3].To achieve this, several levers need to be activated, at best in synergy, including increasing the area under cultivation and soil fertility [4,5], controlling and managing water, intensifying the diversification of agricultural products, strengthening the system for preventing and managing food crises, building the capacity of technical support services and producers organizations and supporting training in promising agricultural sectors. Achieving food self-sufficiency would be an asset for all countries, especially those in the Sahel. This is all the truer given that some of these countries are experiencing recurring food crises. The harsh climate in the Sahel is a major contributing factor (low rainfall, poor distribution of rain, etc.) [6], despite the efforts of those involved in the agricultural sector, yields from one year to the next depend on several factors: rain, drought, wind, locust invasion, etc. Soils are known for the spatio-temporal variability of their characteristics, outside certain privileged areas such as plains, lowlands, etc., one of the common characteristics of these soils is their aridity. Soils that are used for several purposes over time gradually lose their fertility. In fact, many soils in sub-Saharan Africa have a low level of intrinsic fertility due to natural constraints specific to each agro-ecological zone [7]. These deficiencies are determining factors in production [8,9] considers fertility as a judgement of "the productive capacity of an environment whose various characteristics are assessed".

Most fields in rural Africa are family farms, and land management strategies are still largely the result of collective choices. the concept of fertility must therefore be considered at several levels, from the plot to the region, and demographic trends mean that pressure on land is increasing considerably [10]. This observation, made generally in sub-Saharan Africa, could justify a study in the context of Chad, an agricultural country.

Chad, a landlocked Sahelian country, lies between latitudes 7^o and 24^o North and longitudes 13^o and 24^o 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 country is therefore exposed to the vagaries of the weather, with very marked effects on agricultural and food production.

Chad has a population of 16,722,196 (National Institute of Statistics, Economic and Demographic Studies (NISEDS), 2021), the demographic growth of Chad is 3.30, 44.2% of this population is affected by temporary or chronic food insecurity.

Agriculture and livestock farming are the basis of Chad's economic development, agriculture plays a predominant place in the national economy and remains the driving force behind the country's development, contributing at several levels.

The first 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 facing a combination of unfavorable situations that have had an impact on their production levels [11]. First, soil fertility has declined [12], with fertilization and amendment practices contributing to changes in soil properties [13-16].

Improving soil fertility management practices requires : the application of organic manure (manure, compost, crop residues) [17] and mineral fertilizers (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 crops 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 nitrogenous fertilizers [18-20] [9]. Vegetation cover and land use influence soil properties such as water retention and porosity. To compensate for these declines, a great deal of work has been done on soil characterization, including work by [21-23] on the characterization of soil physicochemical parameters.

The present work, which involves a comparative study of the soils at three of the above-mentioned sites, adds to and deepens our physicochemical knowledge of these different types of soil [23], their properties in relation to fertilization practices, and those related to water: affinity, retention, circulation, and the soil's behavior in relation to water.

2. Materials and Methods

This part of the work is reserved for the presentation of the equipment and methods used. The GPS coordinates and mean altitudes of the study sites will be presented later, see Table 1.

Soil analysis in laboratories

Soil samples were taken in June 2023 from different 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 grow, 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 best understood [23].

The samples were subjected to various physico-chemical characterizations (particle size analysis, Atterberg limits, normal Proctor, pH-water, pH-KCl, total phosphorus, assimilable phosphorus, total potassium, organic carbon, total nitrogen, cation exchange capacity, natural water content, exchangeable bases, plasticity index and consistency index).

The granulometric analysis was carried out at the SATOM laboratory in Ndjamena (Chad) and the chemical analyses were carried out at the BUNASOL laboratory in Ouagadougou (Burkina Faso).

Granulometric analysis by wet sieving was carried out in accordance with NF P 18-560 (1978). The Atterberg limits were determined in accordance with standard NF P 94 - 051 (1993). The liquidity limit (W_L) was determined using the Casagrande disc method and the plasticity limit (W_P) using the roller method. The optimum moisture content (W_{opt}) and maximum dry density (ρ_{opt}) were determined by normal Proctor in accordance with standard NF P 94 - 093 (1999). The optimum water content is an index that characterizes the behavior of a soil in the presence of water. It represents the quantity of water required to lubricate the soil particles and allow them to move within the mass to occupy as little space as possible. The pH (pH-water and pH-KCl) (hydrogen potential) was determined using the method of Mc. Lead (1982). Total phosphorus and assimilable phosphorus were determined in accordance with international standard NF ISO 11263 [24]. The organic matter (OM) content was determined using the Walkey and Black 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_2O at 0.5N). The organic matter content is estimated by multiplying the percentage of organic carbon by the factor 1.724). Total nitrogen is obtained using the method described in international standard NF ISO 13878. Cation exchange capacity was measured using the Metson method in AFNOR standard NF X31-130. The natural water content of the soils studied was determined by the method of successive weighings before and after drying the samples in an oven at 105°C in accordance with the requirements of standard NF P 94 - 050 (1995). The content of elements Ca^{2+}, Mg^{2+}, Na^+, K^+ was determined by the fluoro-nitro-perchloric method [25]. The plasticity index was calculated as the difference between the liquidity limit and the plasticity limit (Equation 1). The consistency index was calculated as the difference between the liquid limit and the natural water content, all related to the plasticity index (Equation 2).

3. Results

According to the GPS coordinates, the distance separating the sites is no more than ten kilometers and the average altitudes vary between 276 and 285 m with an average of 281.66 m.

Location of sample collection site

3.1. Physical Characteristics of Dandi, Karal and Mani Soils.

Table 1 shows the geographical coordinates of the study regions.

Tables 2, 3 and 4 show the geotechnical properties of soil samples from Dandi, Karal and Mani respectively.

Figure. 1 gives the cumulative particle size curves of the Dandi, Karal and Mani soil samples.

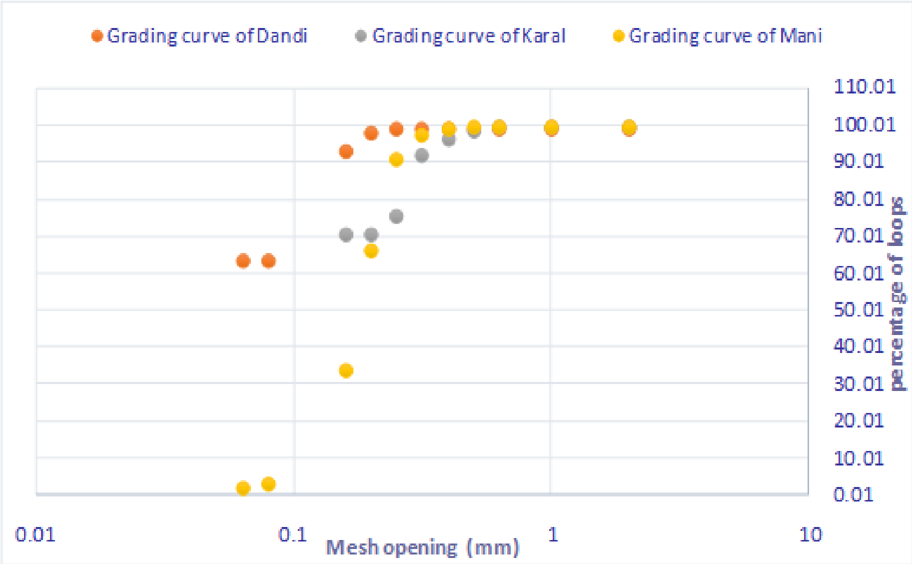

Figure 1. Granulometric curves for Dandi, Karal and Mani soils

Table 1. GPS coordinates and average altitudes of sites in the study area

Localités	GPS coordinats		Medium altitude (m)
	N	E	
Dandi	12°48.954'	14°40.722'	284
Karal	12°52.752'	14°45.507'	276
Mani	12°44.622'	14°41.155'	285

Legend: N: latitude North E: longitude East

Table 2. Geotechnical properties of materials for Dandi

Locality	Geotechnical properties	Numerical values
Dandi	Plasticity of the base material	
	Liquid limit (Ll) (%)	27
	Plasticity limit (Wp) (%)	22,25
	Water content (w) (%)	02,83
	Consistency index (Ic)	5,08
	Plasticity index (Ip) (%)	4,75
	Normal Proctor test	
	Optimum water content (Wopt) (%)	17,7
	Maximum dry Density (γ_d) (g/m^3)	1,75

Table 3. Geotechnical properties of materials for Karal

Locality	Geotechnical properties	Numerical values
Karal	Plasticity of the base material	
	Liquid limit (Ll) (%)	40,45
	Plasticity limit (Wp) (%)	19,25
	Water content (w) (%)	4,49
	Consistency index (Ic)	1,70
	Plasticity index (Ip) (%)	21,15
	Normal Proctor test	
	Optimum water content (Wopt) (%)	20,2
	Maximum dry Density (γ_d) (g/m^3)	1,53

Table 4. Geotechnical properties of materials for Mani

Locality	Geotechnical properties	Numerical values
Mani	Plasticity of the base material	
	Liquid limit (Ll) (%)	
	Plasticity limit (Wp) (%)	
	Water content (w) (%)	2,92
	Consistency index (Ic)	
	Plasticity index (Ip) (%)	
	Normal Proctor test	
	Optimum water content (Wopt) (%)	10
	Maximum dry Density (γ_d) (g/m^3)	1,88

Plasticity index: $I_P = W_L - W_P$ (1)

W_L designates the liquid limit and W_P the plastic limit.

Consistency index: $IC = \frac{W_L - W}{I_P}$ (2) I_P designates the Consistency index.

3.2. Chemical Characteristics of Dandi, Karal and Mani Soils

Many of chemical parameters were studied, and to this end we drew up two tables, Tables 5 and 6, which give the proportions 1 and 2 of the chemical parameters in the three soil samples studied.

Tables 7, 8 and 9 show the equilibrium ratios between Ca^{2+}, Mg^{2+} and K^+ cations and the CEC of Dandi, Karal and Mani soils respectively.

Table 5. Proportions of some chemical elements present in the three soils

Parameters	Dandi	Karal	Mani	Standards
TOM (%)	0,655	0,617	0,519	3,6-6,5
TC (%)	0,380	0,358	0,301	1,26-2,5
TN (%)	0,036	0,041	0,029	-----------
C/N	11	9	10	11-15
TP (ppm)	192	279	384	0,2-0,23 $(g.kg^{-1})$
AP (ppm)	2,02	5,50	9,72	3-8

Legend: TOM: Total Organic Matter, TC: Total Carbon, TN: Total Nitrogen, C/N: Carbon on Nitrogen, TP: Total Phosphorus, AP: Assimilable Phosphorus

Table 6. Proportions of some chemical elements present in the three soils

Localities / Parameters		Dandi	Karal	Mani	Standards
TP	KT	478,00	494,00	324	3700
E B	Ca^{2+}	2,34	8,11	1,44	5-8
	Mg^{2+}	1,25	3,77	0,70	1,5-3
	K^+	0,87	0,37	0,67	0,15-0 ,25
	Na^+	0,61	0,25	0,05	0, 3-0 ,7
SB	S	5,07	12 ,50	2,86	7,5-15
V	V	38	51	26	60-90
CEC	T	13,34	24,50	11	10-20
Sr	pH-K	5,56	5,42	5,62	--------
	pH-E	7,64	6,28	6,26	---------

Legend : TP: Total Potassium (mg/kg), EB: Exchangeable Bases (meq/100g), SB: Sum of Bases (meq/100g), V: saturation rate (%), Sr: Soil reaction, CEC: Cation Exchange Capacity (meq/100g), pH-K: pH-KCl, pH-E; pH-eau, Ca^{2+}:Assimilable calcium , Mg^{2+}:Assimilable magnesium, Na^+ : Assimilable sodium , K^+: Assimilable potassium

The organic matter content is estimated by multiplying the percentage of organic carbon by the factor 1,724.

Normative reference values [25-28]. The critical threshold value for total potassium is 3.7 $g.kg^{-1}$ [29].

$$S = \sum X^{n+} = Ca^{2+} + Mg^{2+} + K^+ + Na^+ \quad , \quad X = \{Ca,\ Mg\ ,K,\ Na\}$$

and n = {1,2}

S(meq/100g): Sum of «exchangeable bases».

Saturation rate: $V(\%) = \frac{S}{T} \times 100$ (3)

T(meq/100g): Cation Exchange Capacity (CEC).

In the case of acid soils, an "Exchange Acidity Rate" or EAR is calculated, which in fact corresponds to a "desaturation rate":

$$EAR = \frac{(aluminium\ ions\ \ plus\ hydrogen\ ions)}{T} \times 100 = \frac{(T-S)}{T} \times 100 \quad (4)$$

Table 7. Equilibrium ratio between Ca^{2+}, Mg^{2+}, K^+ cations and CEC in the soil of Dandi

Locality	Parameter Reports	Values	Standards	Quantity
Dandi	Ca^{2+}/Mg^{2+}	1,87	[2-9]	Low
	K^+/Mg^{2+}	0,69	[0,05-0,1]	Very high
	Ca^{2+}/K^+	2,68	‹ 12	Low
	K^+/CEC	0,065	‹ 2	Very low
	$(Ca^{2+}+Mg^{2+})/K^+$	4,16	[12-15]	Very low

Table 8. Equilibrium ratio between Ca^{2+}, Mg^{2+}, K^+ cations and CEC in the soil of Karal

Locality	Parameter Reports	Values	Standards	Quantity
Karal	Ca^{2+}/Mg^{2+}	2,15	[2-9]	Normal
	K^+/Mg^{2+}	0,09	[0,05-0,1]	Normal
	Ca^{2+}/K^+	21,91	› 12	Very high
	K^+/CEC	0,015	‹ 2	Very low
	$(Ca^{2+}+Mg^{2+})/K^+$	32,25	[12-15]	Very high

Table 9. Equilibrium ratio between Ca^{2+}, Mg^{2+}, K^+ cations and CEC in the soil of Mani

Locality	Parameter Reports	Values	Standards	Quantity
Mani	Ca^{2+}/Mg^{2+}	2,057	[2-9]	Normal
	K^+/Mg^{2+}	0,95	[0,05-0,1]	Very high
	Ca^{2+}/K^+	2,14	‹ 12	Low
	K^+/CEC	0,06	‹ 2	Very low
	$(Ca^{2+}+Mg^{2+})/K^+$	3,22	[12-15]	Very low

Reference values [29].

4. Discussions

Table 1 gives the GPS coordinates and average altitudes of the sites in the study area, which vary between 276 and 285 m, with an average of 281.66 m. The altitudes of the sites are close to each other.

Physical analysis: tables 2, 3 and 4 give the geotechnical properties of the Dandi, Karal and Mani soils respectively.

Table 4 shows that the soil sample from Mani has Atterberg limits that cannot be measured, the clay content of this soil is low, and we were unable to roll the soil. This is consistent with the grading curve for the Mani soil in figure 1. This curve stands out from the others because of its shape, which begins close to the mesh opening axis. This soil has a very low clay content.

Table 2, the Dandi soil has a plasticity index (PI) of 4.75 or for 0 < PI < 5, the degree of plasticity gives a non-plastic soil (the test loses its meaning in this value range) or, based on the classification of soils according to their plasticity index 1< PI <7, the soil is sandy. For the sample from Karal (Table 3), we have a plasticity index of 21.15, but for 15<PI<40, the degree of plasticity gives a plastic soil or, based on the classification of soils according to plasticity index values, 17⩽PI, the soil is clayey. These last two soil samples show extensions of the plastic domain that are smaller than the material presented by [30], and we can also see that the Dandi and Karal PI frame those presented by [31].

Table 3 shows that the Mani soil sample has Atterberg limits that cannot be measured, and the agility of this soil is very low, making it impossible to roll the soil. this corroborates the particle size results obtained in Table 2.

In addition, Dandi has a plasticity index (PI) of 4.75 or for 0 < PI < 5, the degree of plasticity gives a non-plastic soil (the test loses its meaning in this value range) or based on the classification of soils according to the plasticity index 1< PI < 7, the soil is sandy, for the sample from Karal, we have a plasticity index of 21.15, or for 15< IP< 40, the degree of plasticity gives a plastic soil or based on the classification of soils according to plasticity index values, 17≤IP, the soil is clayey.

These two soil samples show extensions of the plastic domain lower than the material presented by [30], and we also see that the IPs of Dandi and Karal bracket those presented by [31].

Chemical analysis: Table 6 gives us the following results: the total potassium, TK (mg/kg) of the three samples varies between 324 and 494 with an average of 432. The total potassium levels obtained are low compared with the normative value, which is around 3700 mg.kg-1. Karal has the highest level, 494 mg.kg-1, followed by Dandi (478 mg.kg-1) and Mani (324 $mg.kg^{-1}$). Exchangeable bases (meq/100g): the Ca^{2+} content in the three samples ranged from 1.44 to 8.11, with an average of 3.96. This average is low compared with the normative values, which range from 5-8 [29]. On the other hand, Karal had a content of 8.11 meq/100g, which is slightly higher than the norm, followed by Dandi (2.34 meq/100g) and Mani (1.44 meq/100g), which had low contents compared with the normative values.

Mg^{2+} (meq/100g) in the three samples varies from 0.70 to 3.77 with an average of 1.90, which is normal. On the other hand, Karal has a content of 3.77 meq/100g, which is slightly higher than the normative values [1.5-3]. Next comes Dandi with 2.34 meq/100g (normal content), then Mani with 0.70 meq/100g, a low content.

The K^+ content varies from 0.37 to 0.87 meq/100g, with an average of 0.63 meq/100g. This average is high compared with the normative values, which are in the range 0.15-0.25. Furthermore, Dandi (0.87 meq/100g) and Mani (0.67 meq/100g) have very high contents, while Karal has a slightly high content of 0.37 meq/100g.

Na^+ has a normative value range of 0.3-0.7 meq/100g [29], Na+ levels in the samples vary from 0.05 to 0.61 meq/100g with an average of 0.30 meq/100g, a normal level. Dandi has a normal content of 0.61 meq/100g, Karal has a slightly low content of 0.25 meq/100g and Mani a very low content of 0.05 meq/100g.

The sum of the S bases varies from 2.6 to 12.50 meq/100g with an average of 6.81 meq/100g, which is below the critical thresholds of 7.5-15 meq/100g, Karal has a sum of the bases of 12.50 meq/100g, which is above the critical thresholds, the content of the Dandi sample is 5.07 meq/100g, which is low, and that of Mani is 2.86 meq/100g, which is very low.

The saturation levels of all the samples are low compared with the normative values (Table 6).

The pH is an indication of the general level of assimilable chemical elements in the soil and is directly related to the exchangeable cations and anions. It plays an important role in the mechanism for retaining or releasing nutrients.

Table 6 gives us the following results by parameter: pH-water, the reading of the soil results shows that this parameter is around an average of 6.72 (neutral, ([6.6;7.4]) with a minimum of 6.26 (weakly acidic, ([6;6.6]) and a maximum of 7.64 (slightly alkaline, ([7.4;7.8]) [29].

The average pH-water values obtained are lower than those obtained in [32]. The pH-water of the soils analysed is comparatively higher than the pH-water obtained in the work of [33], while the pH-KCl varies between 5.42 and 5.62 with an average of 5.52, which is higher than the pH-KCl obtained by [14].

The results of the analyses (Table 5) showed that the soil samples from the three sites had low levels of organic matter [0.519-0.655], compared with the work of [14], although these levels were better than the organic matter levels of [34].

The total nitrogen content (Table 5) varies in the range [0.029-0.041%] with an average of 0.035%. Karal has the highest content of 0.041%, followed by Dandi (0.036%) and Mani (0.029%), assimilable phosphorus varies from [2.02-9.72ppm] with an average of 5.74 ppm which is normal, while Mani has a level of 9.72ppm which is high, Karal has a level of 5.50ppm which is normal, while Dandi has a level of 2.02ppm which is low, taking into account the normative values.

Total phosphorus varies from [192-384ppm] (Table 5) with an average of 285ppm, which is a little high. In addition, the total phosphorus content of the Dandi sample is 192 ppm, which is slightly below the norms, while Karal (279 ppm) and Mani (384 ppm) have levels that are above the normative values.

The C/N ratios of the three soils vary from 9 to 11, with an average of 10, which is outside the norm, only Dandi has a normal content, which reflects the speed of decomposition of the organic matter in these soils. These parameters (Table 5) are all lower than those obtained in the work carried out by [34]. CEC range from 11 to 24.50 meq/100g, with an average of 16.28 meq/100g, which is normal. Dandi and Mani have normal CEC, but Karal has a high CEC (Table 6).

Tables 7, 8 and 9 give the equilibrium ratios between the cations Ca^{2+}, Mg^{2+}, K^+ and CEC of the soil samples studied from Dandi, Karal and Mani respectively. The different equilibrium ratios considered in this study are Ca^{2+}/Mg^{2+}, K^+/Mg^{2+}, Ca^{2+}/K^+, K^+/CEC and $(Ca^{2+}+Mg^{2+})/K^+$.

The Ca^{2+}/Mg^{2+} equilibrium ratio varies in tables 7, 8 and 9 from 1.87 to 2.15 with an average of 2.02, which is normal. However, in Table 7, this value is 1.87, which is low; this result (Table 7) suggests that there is a slight deficiency of Ca^{2+} over Mg in the Dandi soil.

In Table 8, Ca^{2+}/Mg^{2+} is 2.15, which is a normal value, so there is a balance between assimilable calcium and assimilable magnesium. This balance is also observed for the Mani soil sample (Table 9).

The K^+/Mg^{2+} ratio is high for the soil samples from Dandi (Table 7) and Mani (Table 9). In these soils, magnesium is deficient in relation to potassium, whereas the soil sample from Karal (Table 8) has a normal value.

The Ca^{2+}/K^+ ratio is 21.91 in the Karal soil (Table 8), which is very high, potassium is deficient in relation to calcium, but the ratio is 2.14, less than 12, which is low for the Mani sample (Table 9). It is 2.68, lower than 12, and low for the Dandi sample (Table 7). Dandi and Mani have a low Ca^{2+}/K^+ ratio, whereas Karal has a high Ca^{2+}/K^+ ratio [33].

The K^+/CEC ratios for the three soil samples are low (K^+/CEC is less than 2) [33]. In tables 7 and 9, the soil samples from Dandi (4.16) and Mani (3.22) have low $(Ca^{2+}+ Mg^{2+})$/K+ ratios, whereas (Table 8) the soil sample from Karal (32.25) has a high ratio [29].

5. Conclusion

The soils studied have slightly different grain sizes at a depth of 0-20 cm, leading to different plasticity indices, some of which are not even measurable. The pH-water values are all around neutral, and the organic matter content is not very appreciable in most cases, whereas the C/N and CEC values are. The nutrient balance reveals mineral deficiencies and excesses, including Ca^{2+} deficiencies in the Dandi and Mani samples and total carbon deficiencies in all three samples, as well as an excess of Mg^{2+} in the Karal sample and an excess of K^+ in all three samples. Overall, the soil sample from Karal has better physico-chemical characteristics than the others, followed by the sample from Dandi, and in third place the sample from Mani.

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