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Physico-chemical properties of soils under herbaceous groups in the wetlands of the Congolese Cuvette District, Congo

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Abstract

The present study aimed to evaluate the physico-chemical characteristics of soils under the main herbaceous groups used for agro-pastoral activities in the wetlands in Cuvette District in Congo. Soil samples were removed with an auger in the depth of 0-20 cm and were subjected to physico-chemical analyses at the soil science laboratory of the University of Abomey-Calavi in the Republic of Benin. The results obtained revealed that the soils were clayey in the amphibious savannahs, silty in the aquatic grasslands and sandy in the steppe-like savannahs soils were acidic (pH varying between 3.13 and 5.96), with low nitrogen content (0.03 to 0.45%) and fairly high assimilable phosphorus content (13.46 to 58.65 ppm). The C/N ratios were moderately balanced in the amphibious savannahs but reflected very strong edaphic constraints in the grasslands and steppe-like savannahs. The cation exchange capacity was moderately low and potassium contents seemed to be quite low overall. Their organic matter content varied from 1.38 to 5.08%. The Ca/Mg and K/Mg ratios appear to be balanced, but the (Ca+Mg)/K ratios showed unsatisfactory values overall. The soils did not seem to be fertile enough; agro-pastoral practices should maintain the balance to ensure the sustainability of the wetlands.

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Introduction

Tropical grasslands are among the natural areas with significant agricultural and pastoral potential (Megevand, 2013). In wetlands, grasslands also provide food security and climate change mitigation (Ramsar, 2018). Unfortunately, these areas, which are useful for the survival of all biological communities, are becoming increasingly threatened worldwide (Ramsar, 2015). Agricultural exploitation is among the main causes of the threats that currently influence the survival of wetland resources (IUCN, 1997; Nwamo *et al.,* 2016). In the Republic of Congo, agricultural exploitation is becoming increasingly encouraged in grassland areas because it is imperative to limit the degradation of the forest heritage both at the national level and at the level of the Congo Basin sub-region (De Wasseige *et al.*, 2015). Some data on soils are available in dryland grassland areas (Yoka *et al.*, 2010; Bokatola *et al.*, 2017; Amboua *et al.*, 2019 and Assiala *et al.*, 2019). However, soils seasonally exploited for agricultural activities in grassy wetlands are poorly documented. The physico-chemical parameters of the soils, which give indications for a better valorisation of the grassy wetlands, do not seem to be scientifically studied. The present study follows up on the work of Yoka *et al.* (2020) and Rodrigues *et al.* (2020) in the floodplain of the Mossaka area. It aims to fill in the gaps in scientific knowledge of the soils used in Congolese wetlands. The general objective of the study is to evaluate the physico-chemical characteristics of the soils under the main herbaceous groups exploited for agricultural activities in the wetlands of the Congolese basin. The specific objectives are to (i) to determine the texture of the soils under the main groups exploited, (ii) to chemically characterise the soils under the main groups exploited for agriculture and livestock in the Congolese Cuvette District in Congo.

Material and methods

Study area

The study area is located in the northern part of the Republic of Congo, in the heart of the great central African depression known as the Congolese Cuvette.

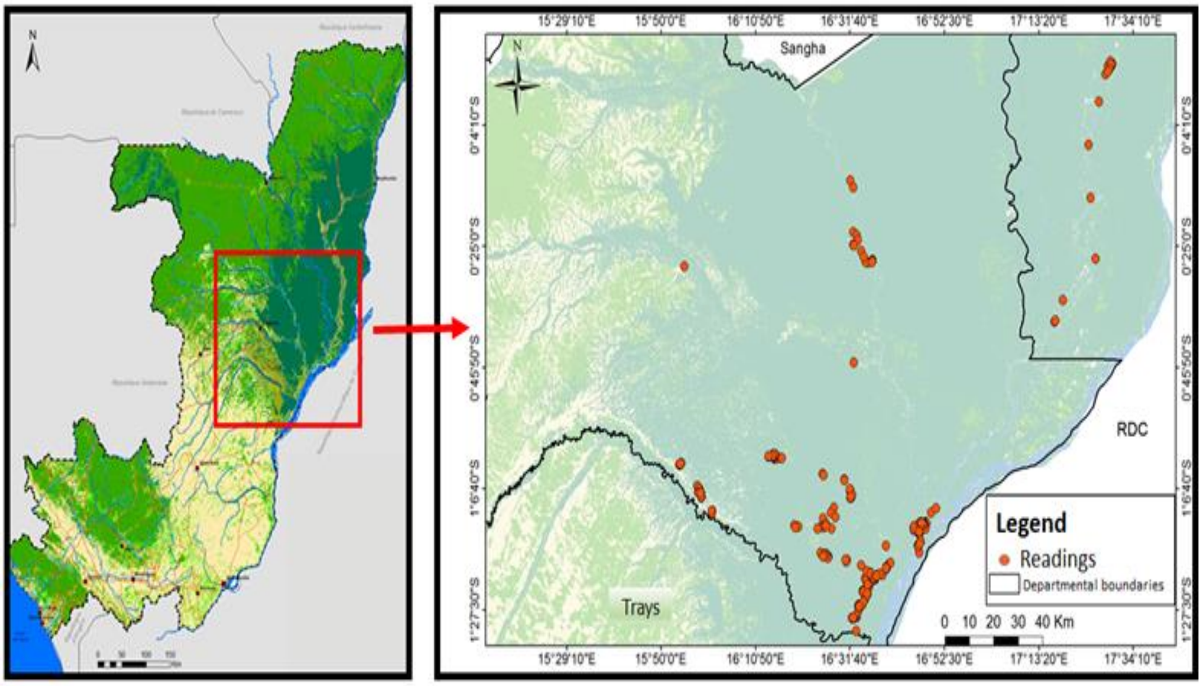


Fig. 1. Geographical location of the study area (CNIAF, 2020).

It is crossed by the equator and is bounded to the North by the department of Sangha, to the north-east by the department of Likouala, to the east by the Democratic Republic of Congo, to the South by the department of Plateaux and to the west by the department of Cuvette-Ouest (Fig. 1). The study area is largely marshy and lies on the border between the great equatorial forest to the North and the savannahs of the Batéké plateaux in the South. The hydrographic network of the study area shows a remarkable convergence of the Congo River and its tributaries. The most important rivers are: the Likouala-aux-herbes, the Sangha, the Likouala-Mossaka, the Oubangui, the Alima, the Ndeko, the Likouba lakes and lagoons and the Boyengué River. As part of the geological plan of the Congolese Cuvette, the study area is covered by a quaternary formation consisting of clay or sandy alluvium deposited by the rivers and their tributaries (De Boissezon *et al.*, 1969). The grassy formations of the wetlands that were the subject of this study can be subdivided into three categories, taking into account the type of wetland that characterises them: floodplains with amphibious savannas, aquatic grasslands and steppe-like savannas or Loussékés.

Soil characterisation

Soil samples were augered from a depth of 0-20 cm. The depth chosen corresponds to the layer colonised by the fasciculated root system of grasses (Cesar, 1990; Yoka, 2009). For each selected survey, a sample was taken at the point where the two diagonals of the survey meeting. Three composite samples, each consisting of a mixture of soils from three samples per plant formation type, were formed. In total, 27 composite samples were formed. The composite samples were air-dried in the field and then dried for 24 hours in an oven at 45°C at the Laboratory of Biodiversity, Ecosystem Management and the Environment (Marien Ngouabi University). They were then taken to the soil science laboratory of the Faculty of Agronomic Sciences of the University of Abomey-Calavi, Republic of Benin, for granulometric and chemical analyses. The particle size analysis was set by using a serial of sieves for the sandy fraction and sedimentation in water with Robinson's pipette for the fine fractions. The chemical analyses concerned pH, total carbon, organic matter, total nitrogen, assimilable phosphorus, cation exchange capacity and exchangeable cations (calcium, potassium and magnesium). The pH measurements were made by potentiometry. Total carbon was determined by the Walkley-Black method. The organic matter content was deduced from the carbon by the multiplying coefficient MO (%) = 1.724 C (%). Total nitrogen was determined by the Kjeldahl method. The BRAY 1 method was used for the determination of assimilable phosphorus.

The cation exchange capacity (CEC) was determined by the Metson method at pH 7. Calcium and potassium were determined by extraction with Acetate NH4 and reading with SAA. Magnesium was determined by flame atomic absorption from the ammonium acetate extract.

Granulometric analysis was used to characterise the texture of the soils. The textural triangle method was performed by the FAO method (FAO, 2020). Statistical processing was applied to data from the granulometric and chemical analyses with R software (R Core Team, 2005) version 3.5.3 (2019-03-11). These treatments included: analysis of variance, Bravais-Pearson linear correlation coefficient and principal component analysis. The results are considered statistically significant at the 5% level.

Results

The particle size analysis of the soils under the eleven plant groups studied revealed that the particle size varied from one plant formation to another (Table 1). The soils under the amphibious savannahs had a clayey texture. In the aquatic grasslands, the soils studied seem to be of silty texture. The steppe-like savannahs developed more on sandy soils.

Analysis of variance of soil physico-chemical parameters

The percentages of clay, sand and silt, pH, nitrogen and potassium contents are the parameters that explain the physico-chemical differences of the soils between the three grass communities. On the other hand, organic carbon, organic matter, assimilable phosphorus, cation exchange capacity, exchangeable calcium and magnesium did not vary considerably within the three communities (Table 2). Overall the soils were acidic, but the most acidic pH was recorded in the amphibious savannahs (3.59±0.59).

Table 1. Particle size composition and texture of the studied soils.

Dominant species	E	A (%)	L (%)	S (%)	Texture
flooded savannahs					
Hyparrhenia diplandra (Hack.) Stapf (G1)	E1G1	23	70,4	6	Lsi
	E2G1	57	15,4	27	A
	E3G1	61,8	32,6	5	A
Anadelphia leptocoma (Trin.) Pilg. (G2)	E1G2	57	39,4	3	Asi
	E2G2	57	19,2	23	A
	E3G2	17	30,8	52	Lsa
aquatic grasslands					
Urochloa arrecta (Hack. ex T. Durand & Schinz) Morrone et *Echinochloa pyramidalis* (Lam.) Hitchc. & Chase (G3)	E1G3	9,8	36	54	Lsa
	E2G3	3	54	42	Lsa
	E3G3	17	4	78	Lsa
Anosporum pectinatus (Vahl) Lye et *Nymphaea lotus* L. (G4)	E1G4	37	33,8	29	Lar
	E2G4	33,4	47,2	19	Lsi-ar
	E3G4	1	44	54,9	Lsa
Vossia cuspidata (Roxb.) Griff. (G5)	E1G5	34	52,2	13	Lsi-ar
	E2G5	11,6	55,4	32	Lsi
	E3G5	17	65	17	Lsi
Panicum funaense Vanderyst et *Eleocharis acutangula* (Roxb.) Schult. (G6)	E1G6	25,4	65,2	9	Lsi
	E2G6	17	50,4	32	Lsi
	E3G6	27,8	42,2	29	Lar
Steppe-like savannahs					
Andropogon festuciformis Rendle (G7)	E1G7	12,2	12,8	74	Lsa
	E2G7	5,4	11,6	82	SL
Mayaca baumii Gürke et *Nymphoides forbesiana* (Griseb.) Kuntze (G8)	EG8	7,8	9,2	82	SL
Anadelphia hamata Stapf et *Loudetia vanderystii* (De Wild.) C. E. Hubb. (G9)	E1G9	17	28	54	Lsa
	E2G9	13,4	24,8	61	Lsa
Hyparrhenia wombaliensis (Vanderyst ex Robyns) Clayton (G10)	E1G10	13,2	7,8	78	Lsa
	E2G10	5,6	19,4	74	Lsa
Loudetia simplex (Nees) C. E. Hubb. (G11)	E1G11	17	6,2	76	Lsa
	E2G11	14,2	12,8	72	Lsa

Legend : G : plant groups ; E : sample ; A : clay ; L : silt ; S : sand ; Lsi : Silty silt ; Asi : Silty clay ; Lsa : Sandy silt ; Lar : Clayey silt ; Lsi-ar : Silt-clay silt ; SL : silty sand.

The amphibious savannahs showed the lowest values of total nitrogen (2.92±0.58%). The soils studied indicated a real problem of exchangeable potassium deficiency. The highest deficiencies were found in the steppe-like savannahs. Exchangeable magnesium values were also low in all the grassland formations studied. However, the values of exchangeable calcium seem satisfactory. The (Ca + Mg)/K ratios seemed to be insufficient in the amphibious savannahs and the aquatic grasslands. Optimal values were recorded in the steppe-like savannas. However, the Ca/Mg and K/Mg ratios calculated on all the grassy formations studied would present moderately acceptable values for tropical soils. The median soil organic carbon values vary from 1.36 ± 0.80% in the amphibious savannahs to 1.95 ± 0.34% under the steppe-like savannahs. These results showed that the soils under the grassy formations studied are moderately rich in organic carbon. The soils studied would be fairly rich in organic matter.

Table 2. Medians and standard deviations of analysed physico-chemical parameters.

Elements	Flooded savannahs	Aquatic grasslands	steppe-like savannahs	P-value
Clay	17 ± 12,07	57 ± 19,90	13,20 ± 4,47	0,005
Silt	48,8 ± 16,44	31,7 ± 19,64	12,80 ± 7,65	0,002
Sand	30,5 ± 20,17	14,50 ± 18,92	74 ± 9,37	< 0,001
pH $_{water}$	3,59 ± 0,59	4,32 ± 0,52	5,25 ± 0,77	0,005
pH $_{KCl}$	2,92 ± 0,58	3,73 ± 0,44	4,08 ± 0,42	< 0,001
orgC	1,36 ± 0,80	1,80 ± 0,40	1,95 ± 0,34	0,250
OM	2,34 ± 1,38	3,11 ± 0,69	3,36 ± 0,59	0,255
N	2,92 ± 0,58	3,73 ± 0,44	4,08 ± 0,42	0,026
C/N	16,41 ± 11,53	19,04 ± 5,99	8,83 ± 16,91	0,206
P $_{ass.}$	18,63 ± 6,51	15,24 ± 2,41	18,55 ± 13,30	0,124
N/P	0,005 ± 0,002	0,007 ± 0,003	0,013 ± 0,007	0,019
CEC	13,91 ± 7,68	17,82 ± 8,47	11,56 ± 4,59	0,133
Ca	1,54 ± 0,62	1,41 ± 1,07	2,15 ± 1,69	0,973
Mg	0,54 ± 0,30	0,41 ± 0,52	0,22 ± 0,63	0,420
K	0,33 ± 0,16	0,28 ± 0,10	0,11 ± 0,13	0,009
Ca/Mg	0,33 ± 0,16	0,28 ± 0,10	0,11 ± 0,13	0,336
K/Mg	0,62 ± 0,26	0,88 ± 0,36	0,39 ± 0,33	0,236
(Ca+Mg)/K	6,55 ± 10,58	8,38 ± 3,38	22,19 ± 18,61	0,023

Legend :orgC : Organic carbon (in %) ; OM : Organic matter (in %) ; N : Total nitrogen (in %) ; Pass : Assimilable phosphorus (in ppm) ; CEC : Cation exchange capacity (in meq/100g) ; Ca : Calcium (in meq/100g) ; Mg : Magnesium (meq/100g) ; K : Potassium (in meq/100g).

The highest values were recorded in the steppe-like savannahs (3.36± 0.59). On the whole, the assimilable phosphorus values were 10 ppm. The soils studied would be fairly rich in available phosphorus. The CEC values were below 20 meq/100g overall. These results indicated that the soils studied have a relatively average CEC. Overall, the C/N ratios seem to be balanced in the amphibious savannahs and the aquatic grasslands. However, the steppe-like savannahs show very variable ratios (8.83±16.91).

Correlation and principal component analysis of soil physico-chemical parameters

The Bravais-Pearson correlation index revealed positive and negative correlations between the different physico-chemical parameters analysed (Table 3). Thus, organic carbon is positively correlated with organic matter. Similarly, there is a positive correlation between clay content and cation exchange capacity (CEC). Potassium is positively correlated with silt percentages. This result allows us to say that silt soils are the best in terms of potassium. However, soils richer in sands would have the least acidic pH. There is a positive correlation between pH and sand percentages. There is also a positive correlation between sand percentages and nitrogen contents. The principal component analysis (PCA) of all the physico-chemical parameters analysed made it possible to separate the three grass communities on the first two axes (Fig. 2). Soil parameters explain 47.2% of the variability of the plant communities studied. Axis 1 positively discriminates steppe-like savannahs and negatively amphibious savannahs and aquatic grasslands. This axis symbolises a gradient of substrate humidity, separating the least humid soils (steppe-like savannahs) from the most humid soils (aquatic grasslands and amphibious savannahs). On the other hand, axis 2 separates, from the bottom to the top, the aquatic groups (aquatic grasslands) from the seasonally flooded plant groups (steppe-like savannahs and amphibious savannahs). This is a gradient of periodic hydromorphy.

Discussion

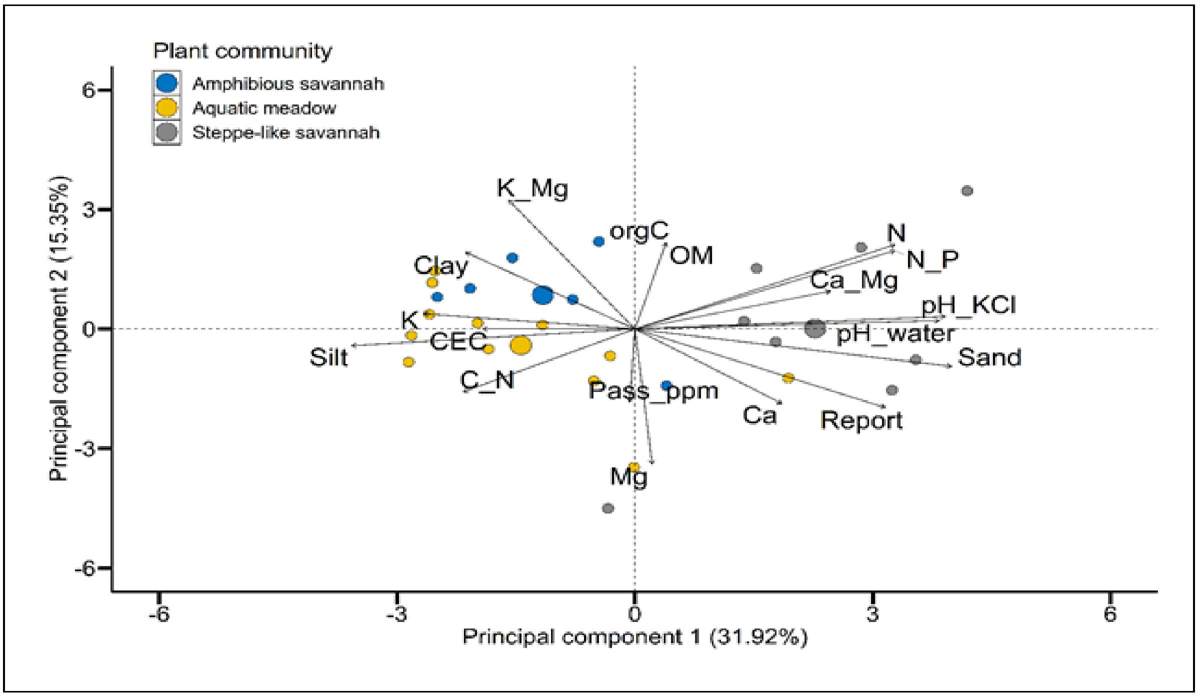
The texture of the soil under these amphibious groups, especially that of *Hyparrhenia diplandra* (Hack.) Stapf (G1) and the grouping with Anadelphia leptocoma (Trin.) Pilg. (G2) is generally clayey. Clay textured soils were also reported by Rodrigues *et al.* (2020) and Yoka *et al.* (2020) in the Mossaka area. Soils under grasslands are reported to be better for farming with a silty texture in general across all samples analysed. Savannahs with a steppe-like appearance tend to develop on soils that are very rich in sand, as has already been pointed out in numerous studies, including those by Yoka *et al.* (2010) in the exundated zone. As is also the case for the adjacent terra firma soils (Yoka, 2009), the soils under the grassy formations of the wetlands of the Congolese Cuvette are also acid.

Table 3. Bravais-Pearson linear correlation coefficient.

Elements	Clay	Silt	Sand	pH_{water}	pH_{KCL}	orgC	OM	N	C/N	P_{ass}	N/P	CEC	Ca	Mg	K	Ca/Mg	K/Mg	(Ca+Mg)/k
Clay	1																	
Silt	0,049	1																
Sand	-0,68	-0,76	1															
pH_{water}	-0,24	-0,67	0,645	1														
pH_{KCL}	-0,24	-0,74	0,694	0,9	1													
orgC	0,029	0,034	-0,05	-0,04	0,07	1												
OM	0,029	0,034	-0,05	-0,04	0,07	0,99	1											
N	-0,22	-0,53	0,534	0,561	0,55	0,276	0,275	1										
C/N	0,124	0,363	-0,35	-0,31	-0,3	0,219	0,219	-0,63	1									
P_{ass}	-0,16	-0,11	0,184	0,086	0,15	0,065	0,066	-0,11	0,5	1								
N/P	-0,17	-0,49	0,474	0,57	0,51	0,215	0,214	0,95	-0,65	-0,31	1							
CEC	0,511	0,139	-0,43	-0,4	-0,4	-0,04	-0,05	-0,19	0,13	0,07	-0,15	1						
Ca	-0,17	-0,12	0,19	0,29	0,34	0,003	0,003	-0,01	0,09	0,11	0,023	-0,14	1					
Mg	-0,33	0,079	0,162	0,007	-0	-0,19	-0,19	-0,07	0,11	0,25	-0,01	0,088	0,222	1				
K	0,125	0,564	-0,49	-0,38	-0,3	-0,09	-0,09	-0,21	0,07	0,15	-0,32	0,024	-0,11	0,091	1			
Ca/Mg	-0,09	-0,33	0,294	0,41	0,47	0,144	0,144	0,21	-0,15	-0,11	0,225	-0,16	0,599	-0,47	-0,34	1		
K/Mg	0,386	0,166	-0,37	-0,12	-0,1	0,113	0,113	-0,06	-0,01	-0,12	-0,13	-0,01	-0,3	-0,7	0,47	0,19	1	
(Ca+Mg)/K	-0,41	-0,37	0,541	0,432	0,43	0,045	0,045	0,16	-0,11	0,02	0,22	-0,16	0,768	0,228	-0,59	0,6	-0,56	1

Legend **:** orgC : Organic carbon (in %) ; OM : Organic matter (in %); N : Total nitrogen (in %); Pass : Assimilable phosphorus (in ppm) ; CEC: Cation exchange capacity (in meq/100g) ; Ca : Calcium (in meq/100g) ; Mg : Magnesium (meq/100g) ; K : Potassium (in meq/100g).

This high acidity of the soils limits the bioavailability of some important elements such as iron (Fe2+); Calcium (Ca2+) and potassium (K+) and increases the risks of aluminium toxicity Al3+ (Comptour, 2017). The soils studied are believed to be rich in carbon and organic matter. These high levels of carbon and organic matter are probably linked to the regular input of organic sediments transported by the Congo River and its tributaries. Under the amphibious savannahs and aquatic grasslands of the study area, the soils were moderately low in total nitrogen. Seasonal flooding and leaching by the water current may be among the causes of this deficit in total soil nitrogen. In the steppe-like savannahs, the total nitrogen content varies with the sampling points. This variation would probably be due to the presence of circular and elongated mounds that dot the steppe-like savannahs and that allow the soils to escape prolonged flooding and leaching caused by the water current. The assimilable phosphorus levels of the studied soils were above the minimum average of 10 ppm accepted by Riquier (1966) in tropical soils. However, in wetlands, the mobilisation of this phosphorus by agricultural activities can lead very quickly to eutrophication situations since soil nitrogen deficiencies can easily be made up by atmospheric nitrogen. This means that the two essential elements for plant nutrition can be found in overabundance in the environment and very quickly lead to the proliferation of especially lower plants (Barroin, 2003). The soils under the grassy formations studied had a relatively average cation exchange capacity. Cations such as K+, Mg2+ and Ca2+ were not easily exchanged or retained by the soils as described by Doucet (2006). The C/N ratios revealed that the rate of mineralisation of organic matter is either too slow or too fast, depending on the site. These ratios would indicate the agronomic deficiencies that these soils may have in relation to some crops.



Legends : PH_water : pH water ; PH_KCL : pH KCl ; Corg : Organic carbon ; OM : Organic matter ; N : Total nitrogen ; C_N : Carbon to nitrogen ratio ; Pass_ppm : Available phosphorus in ppm ; N_P : Nitrogen to phosphorus ratio ; CEC: Cation exchange capacity ; Ca : Calcium ; Mg : Magnesium ; K : Potassium ; Ca_Mg : Calcium to Magnesium ratio ; K_Mg : Potassium to Magnesium ratio ; Report : ratio Calcium plus Magnesium on Potasium.

Fig. 2. Principal component analysis of the physico-chemical parameters.

The grassy formations studied have calcium contents exceeding the critical threshold of 1meq/100g admitted by Guinaudeau *et al.* (1963). The magnesium content ranged between 0.59 and 0.69 meq/100g overall. Again, compared to the threshold of Guinaudeau *et al.* (1963), the soils studied would be moderately rich in exchangeable magnesium.

The potassium content was below the threshold of 0.4 meq/100g. These soils are therefore deficient in potassium. Indeed, overall, exchangeable cations present significant risks of loss through leaching, given that the CEC remains moderately low overall (UNIFA, 2019). Under these conditions, it is important to take into account the ratios between the bases, as the influences of one and the other can be very pronounced in this type of soil (Jutras, 2019). Thus, the ratios calculated between the different bases on all the grassy formations studied revealed that the Ca/Mg and K/Mg ratios seem to be balanced on all the soils studied. However, the (Ca+Mg)/K ratios revealed values either below the limit, i.e., insufficient to guarantee good crop growth, or above the threshold, i.e., too high to maintain the availability of exchangeable cations at equilibrium (Boyer, 1978 and Doucet, 2006). These undesired values of the ratios between exchangeable bases reveal ed antagonisms and blockages of absorption, especially when the content of one of the bases, and in particular potassium in our case, was lower.

Conclusion

The soils under the grassy formations of the wetlands of the Congolese Cuvette are relatively unfertile. They are rich in clay in the amphibious savannahs, rich in silt in the aquatic grasslands and rather rich in the sand in the steppe-like savannahs. These soils are acidic on the whole, have a fairly average cation exchange capacity and are fairly rich in assimilable phosphorus. The rate of mineralisation of organic matter is fairly normal in amphibious savannas. However, this rate appears to be very irregular in aquatic grasslands and steppe savannas. There are points with a very low C/N ratio and places with a very high C/N. The soils studied would be deficient in potassium. Intensive cultivation would require large amounts of soil amendments to make up for the nutritional deficiencies of the soil in certain essential elements. Therefore, the populations should already be moving towards more responsible practices that consume less fertiliser in order to hope for sustainable agriculture in the area. Moreover, sustainable development and effective protection of the wetland ecosystems of the Congolese Cuvette would require management strategies that encourage participatory actions by local populations. A mixed system integrating livestock, agriculture and fishing would be much more effective and would allow the balance of the habitat to be maintained without degrading it.

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