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The Role of *Andropogon Gayanus* Savanna Ecosystems in Increasing CEC and Exchangeable Bases in a Hydromorphic Soil in Western Burkina Faso

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Abstract

The CEC is an indicator of the soil's capacity to retain and exchange nutrient cations with the roots of plants. In the Sudanian savannas with *Andropogon gayanus*, hydromorphic soils exhibit a silty-clay texture and a specific large area, which enables the retention of cations in a manner that differs from that observed in sandy soils. It was hypothesised that the CEC and the exchangeable bases of the arable soil layer in the savannas of western Burkina Faso would display significant increases due to the substantial environmental changes that occur during the fallow period. To test this hypothesis, a comparison was made between the soil fertility of the savanna and fallow areas and that of cultivated plots, which served as control sites for this study. A total of 15 plots were selected for analysis, with five plots allocated to each situation. The vegetation and soil characteristics of the plots have been duly described. Soil samples were obtained from the 0-20 cm depth interval to create composite samples. The laboratory analysis encompassed a range of parameters, including texture, pH-H_2O and pH-KCl, carbon, nitrogen, cation exchange capacity (CEC) and exchangeable bases. The observations led to the classification of the soils as tropical ferruginous hydromorphic with iron and manganese oxides. The original materials displayed a silty-clayey properties. The granulometric study has demonstrated that the superficial horizon of the soil is predominantly composed of silt- and clay-sized particles. This results in a considerable capacity for retention in exchangeable bases. The woody vegetation of savannas exhibits a greater diversity and richness of flora than that of fallows. This has a significant impact on the enhancement of the CEC, due to the beneficial effects of plant debris with diverse organic compositions. The overall pH is weakly acidic, with a range of 6.24 to 6.41 (pH-H2O). The soil of savannas exhibits higher concentrations of carbon (0.67% C) and nitrogen (0.059% N) than that of fallow (0.5% N, 0.04% N) and cultivated fields (0.34% C, 0.03% N). The observation of chemical balances has enabled the identification of savannas as conducive to optimal plant nutrition. Overall, savannas enhance the CEC and the bases exchangeable, despite the values being below the recommended threshold for tropical ferruginous hydromorphic soils. It is therefore necessary to implement measures to promote sustainable agriculture and enhance agricultural productivity in this region, where soils are naturally deficient in nutrients.

Keywords: savanna, fallow, CEC, exchangeable bases, hydromorphic soil

1. Introduction

The Savanna ecosystem plays an indispensable role in the optimal functioning of soil and the regulation of numerous ecological processes. In Sudanian Africa, traditional agricultural practices typically adhere to a five-year cycle comprising a cultivation phase and a subsequent rest phase (Yoni *et al.*, 2018). Following the cessation of agricultural activity, the savanna vegetation is restored through a secondary succession process within a period of approximately twenty to thirty years. This operational system gives rise to a mosaic landscape, which is in a state of perpetual evolution and exhibits varying degrees of complexity and fragmentation contingent on the dimensions and configuration of plots and non-cultivated zones (Fournier *et al.*, 2000). It encompasses a multitude of cultivated fields situated within wooded parks of *Vitellaria paradoxa*, protected or uncultivable areas, and fallow lands. The latter exhibit a variety of stages of succession on different soil types, following various types of cultivation. Among the plant species that characterise these savannas, *Andropogon gayanus*, a perennial grass, is distinguished by its capacity for adaptation and its beneficial effects on soil quality (Yoni *et al*., 2018).

A number of case studies have been published on the restoration of soil fertility (carbon, nitrogen, texture and structure) in plots abandoned after cultivation in the Sudanian regions (Yoni *et al*., 2018; Fournier & Nignan, 1997; Fournier, 1996; Ouadba, 1993; Diatta & Matty, 1993; Zougrana, 1991, 1993). Nevertheless, the role of *A. gayanus* in the reconstruction of CEC and exchangeable bases remains poorly understood, particularly in hydromorphic soils. It is particularly challenging to ascertain the relative importance of the roles played by *A. gayanus*, and thus to prioritise them during the process of plant succession. Indeed, during the initial years of fallow, a variety of herbs flourish in the environment, exhibiting a joint response to soil and anthropogenic factors (Hien, 1996). However, after approximately ten years of abandonment, the perennial grass *A. gayanus* becomes the dominant species in fallow conditions, regardless of soil type. This observation has been documented in multiple studies, including those by Yoni (1995, 1997). In the absence of impediments to succession, it is anticipated that, approximately twenty to thirty years later, other perennial grasses characteristic of savanna ecosystems will have supplanted *A. gayanus*. In the traditional cropping system of Bondoukuy in western Burkina Faso, the presence of *A. gayanus* is also used as an indicator of the return of soil fertility following the fallow period. The primary criteria for determining its presence and dominance in savanna and fallow ecosystems are abundance and prevalence.

The objective of this study is to examine the role of *A. gayanus* savanna ecosystems in enhancing the CEC and exchangeable bases of hydromorphic soils in the Sudanian zone, situated to the west of Burkina Faso. This will facilitate a more comprehensive understanding of the ways in which this plant species contributes to sustainable soil management and the resilience of ecosystems in the context of climate change and anthropogenic pressures. It is hypothesised that the CEC and the exchangeable bases of the soil layer of savanna ecosystems will display a significant increase due to the substantial environmental changes occurring during the fallow period. To test this hypothesis, the fertility of the soil in savanna ecosystems and fallow periods will be compared by taking cultivated plots as controls. The findings of this research will prove invaluable for those engaged in land management in areas characterised by strong edaphic constraints. They will contribute to the advancement of ecological restoration practices and enhance the fertility of hydromorphic soils.

2. Material and Methods

2.1 Study Area

The research was conducted in the Bondoukuy region of western Burkina Faso (11 °51'N, 3 °45'W) (Figure 1), which is situated on a gneissic basement. The geomorphological scheme is that of a system of polygenic batteries (Kaloga, 1997). The climate is classified as Sudanian, with a dry season spanning seven to eight months and an average annual rainfall of 800–900 mm. The natural vegetation corresponds to the limit between the Sudanian clear forest of *Isoberlinia doka* in the south and the Sudanian undifferentiated forest in the north (White, 1986). The population engages in the cropping of cotton and food cereals, as well as the rearing of cattle and small ruminants. The human impact is significant, with a population density exceeding 60 inhabitants per km ^{2}and approximately 15 cattle per km ^{2}.

Despite the region's rapid transformation through human intervention, particularly in the form of cultural and pastoral activities, older ecosystems, characterised by the presence of *A. gayanus*, remain relatively abundant. Furthermore, the species is ubiquitous across the entire landscape, occurring in approximately a third of unclear environments without necessarily dominating (Devineau *et al*., 1997). Two predominant ethnic groups, the Bwaba and Mossi, coexist with a few others, including the Gurounsi, Samo, and Lobi. Each of these groups engages in agricultural practices and/or livestock breeding, though there is minimal integration between these activities. In less than four decades, anthropogenic pressure has increased considerably, resulting in profound modifications to both natural and human environments and a notable alteration of plant landscapes.

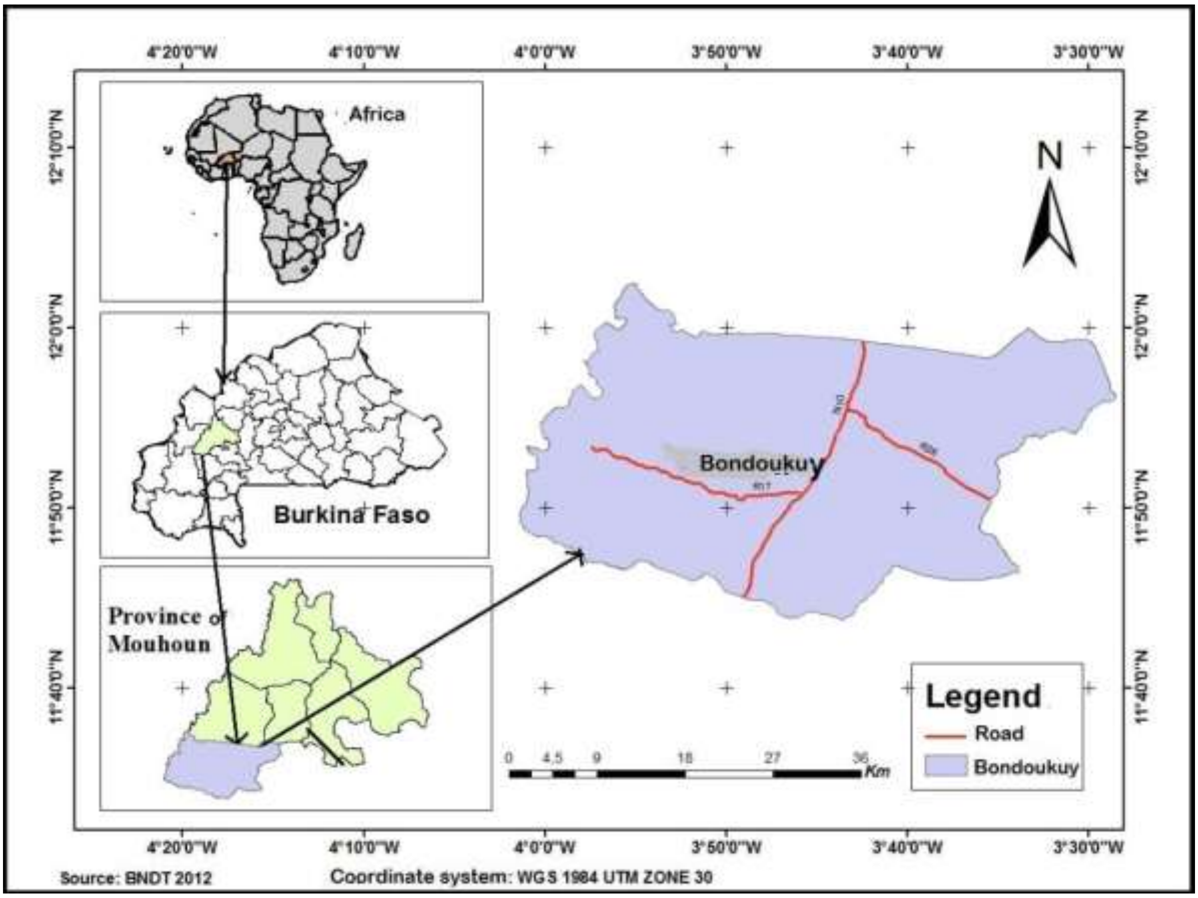

Figure 1. Study area map

2.2 Selection and Description of the Plots Studied

Three scenarios were selected for investigation, namely savannas, 20-year-old fallows and fields. Each scenario was represented by five plots. The witness plots, represented here by the fields, have been in permanent culture for a period exceeding ten years. The old 20-year-old fallows represent the intermediate stage of restoration of fertility, while the Sudanian savannas with *Andropogon gayanus* represent the climax, characterised by the complete restoration of soil fertility.

The diverse circumstances (in cropping or vegetation) and associated activities are delineated through comprehensive observation and investigation. The flora of savannas and fallows was examined through floristic surveys. The floors have been described based on soil profiles and identified according to the French classification system (CSPS, 1967), which has been reinforced by the global reference base (FAO-WRB, 2015) and confirmed by the national directives of Bunasol (2005). This is to facilitate a more nuanced comprehension of the use of the environment and elucidate the disparate values of the physico-chemical parameters obtained.

2.3 Measurement of Physico-Chemical Parameters

The physico-chemical parameters of the soil were analysed from the sample taken from the auger at a depth of 0-20 cm, which is considered to be the arable depth. This layer is of particular interest as it corresponds to the depth mainly explored by the roots, and where changes are perceptible. To account for intra-plot variability, five samples were taken from the plot (four at each end and one in the middle), which were then combined to form a single sample. The following physico-chemical analyses were conducted.

-Particle size analysis by sedimentation, after destruction of organic matter, by the pipette method on an automatic granulometer with 5 fractions according to the Atterberg scale (Clays: 0-2 µm, Fine silts: 2-20 µm, Coarse silts: 20-50 µm, Fine sands: 50-200 µm and Coarse sands: 200 µm-2 mm) (Cirad, 2017). Subsequently, the fine and coarse sands were added, reducing the number of fractions to 4.

-The C analysis was conducted in accordance with the modified Walkley-Black method (CEAE, 2003), while the N determination was performed using the Kjedahl method. The Ca, Mg, Na, K and Mn determinations were carried out by ICP spectrometry (Cirad, 2017). The CEC is obtained by determining the ammonium concentration through continuous flow colorimetry (Cirad, 2017). The exchangeable bases are quantified through percolation (Cirad, 2017), while the pH of the water and KCl solutions are measured using an automated titration chain with a sampler (Cirad, 2017). All of the aforementioned analyses were conducted at the soil biogeochemistry laboratory of the École Normale Supérieure in Paris (ENS).

2.4 Data Analysis

The data collected were subjected to an analysis of variance (PROC ANOVA) and to a simultaneous test of comparison of means by Scheffé (1959) considered to be the most reliable test sensitive to small differences between means (Scherrer, 1989). All tests were performed with an alpha level of 5%. These analyses were performed using the Stat View software (SAS, 2020).

3. Results

3.1 Description of Plots' Soil

In the Bondoukuy region, hydromorphic soils are observed in low-lying areas in proximity to watercourses and in depressions where water accumulates temporarily. The aforementioned lowlands are characterised by a silty clayey texture. In general, no correlation was observed between texture and depth of hydromorphy or induration. The following categories are distinguished.

- Hydromorphic soils (3%) with little humus with shallow gley (< 80 cm) and pseudogley from the surface with a silty tendency. The main constraints of these soils are floods in certain years and grass cover.

- Hydromorphic leached tropical ferruginous soils (16%) at shallow depths (> 10% of red pseudogley spots between 20-40 cm), with a silty tendency. They are present in lowland connections with lower slopes and in secondary thalwegs. The surface of these soils may have damp spots long after showers, suggesting capillary rise (lower slopes and basins, secondary drainage axes). The first two types of soil are damp but not floodable, suitable for shrubby or savannah formations and present a strong constraint on grassing.

- Leached tropical ferruginous soils (18%) with moderately deep hydromorphism (>10% red pseudogley spots between 40-60 cm), possibly with concretions (15-40%) located at the bottom of slopes and basins. These soils correspond to the limit of humid soils. To classify them on the "water reserve" criterion, their more or less silty texture must be taken into account.

- Leached ferruginous soils with deep hydromorphism (5%) (>60 cm), modal ferruginous soils (reddened and without hydromorphism), hydromorphic ferruginous to ferrallitic transition soils, transition from hardened to hydromorphic ferruginous soils. These are sandy-silty soils, with a dry tendency, easy to maintain.

- Ferrallitic soils (23%) weakly desaturated in B, typical modal (ridges and plateaus, piedmont of armoured hillocks). Although classified as moderately dry soils, the better structure of these soils in depth and the richness in iron (especially in the piedmont position of armoured hill) gives these soils a better organic retention capacity than leached ferruginous soils with deep hydomorphy. Farmers also often consider them better.

3.2 Floristic Characteristics

In Bondoukuy, as in Sudanese ecosystems in general, the vegetation is relatively well provided with woody and perennial herbaceous species (Table 1). As in Sudanese savannas and fallows, three taxonomic groups dominate among woody species: Leguminous, Combretaceae and Rubiaceae. The number of species of Combretaceae increases and that of Leguminous decreases when hydromorphy decreases. The same result is found for herbaceous species. On the other hand, wooded savannas have few leguminous herbaceous plants, which would indicate a preference of leguminous for fallow land. Plant formations are therefore organized according to biotopes and hydromorphy, but not only. Indeed, fire, temporary cropping, selective cutting and grazing are significant factors, likely to strongly influence the physiognomy and flora of plant formations according to the stages of reconstitution after cropping or certain developments.

Table 1. Floristic characteristics of the sites studied (most represented species)

	Plots		
Vegetation	savannas	Fallows	Fields
Woody species	*Terminalia avicennoïdes* *Combretum glutinosum* *Vitellaria paradoxa* *Acacia polyacantha* *A. sieberiana* *Desmodium velutinum* *Pterocarpus erinaceus* *Piliostigma thonningii* *P. reticulatum* *Anogeissus leiocarpus* *Bombax costatum, Lannea acida, L. microcarpa, Mayntenus senegalensis, Feretia apodanthera, Strychnos spinosa, Ximenia americana, Parinari curatellifolia, Sterculia setigera, Entada africana, Pericopsis laxiflora, Daniella oliveri, Isoberlinia doka, Burkea africana Khaya senegalensis* *Xeroderris stuhlmannii* *Cassia siberiana* *Albizzia zygia* *Parkia biglobosa, Mitragyna inermis, Berlinia grandifolia, Raphia sudanica, Diospyros mespiliformis, Tamarindus indica, Capparis corymbosa, Feretia apodanthera, Grewia bicolor, Securinega virosa* *Saba senegalensis, Ziziphus mauritiana*	*Vitellaria paradoxa* *Terminalia avicennoïdes,* *T. macroptera* *Piliostigma thonningii* *P. reticulatum* *Combretum glutinosum* *C. micrantum* *C. nigricans* *C. molle* *Guiera senegalensis* *Swartzia madagascariensis* *Pteleopsis suberosa, Detarium microcarpum* *Parkia biglobosa, Diospyros mespiliformis, Tamarindus indica, Saba senegalensis, Ziziphus mauritiana*	*Vitellaria paradoxa* *Lannea microcarpa* *L. velutina, L. acida* *Parkia biglobosa* *Adansonia digitata* *Bombax costatum*
Perennials herbaceous	*Andropogon gayanus* *Andropogon ascinodis, Hyparrhenia diplandra* *Cymbopogon shoenanthus* *Gladiolus klattianus* *Crinum humile* *Dioscorea dumetorum* *Lippia chevalieri* *Vernonia purpurea* *Cyanotis longifolia* *Costus spectabilis* *Cochlospermum tinctorium* *C. planchoni* *Leptadenia hastata* *Lantana rhodesiensis* *L. camara*	*Tephrosia pedicellata* *Andropogon gayanus* *A. ascinodis* *Borreria stachydea* *Cochlospermum tinctorium* *C. planchoni* *Leptadenia hastata* *Lantana rhodesiensis* *L. camara* *Sporobolus festivus*	*Andropogon gayanus* *A. ascinodis, Cymbopogon shoenanthus*
Annuals herbaceous	*Aspilia helianthoides* *Commelina forskalei* *Cissus gracilis* *Ampelocissus pentaphylla* *Andropogon pseudapricus* *Loudetia togoensis*	*Andropogon pseudapricus* *Rottboelia exaltata* *Loudetia togoensis* *Paspalum orbicurae,* *Bulbostylis filamentosa, Ctenium newtonii*	*Sorghum bicolor* *Gossypium barbadense, G. hirsutum* *Pennisetum typhoïdes* *Zea mays*

In savannas, the woody cover is typically higher, and the woody layer is frequently dominated by large individuals, with a height range of 4 to 6 metres. In contrast, fallows are characterised by a sparser vegetation cover, with a woody layer that is most often dominated by medium-sized woody plants (2 to 4 m). Similarly, the basal cover and the density of clumps of perennial grasses (*Andropogon gayanus* and *A. ascinodis*) are greater in savannas than in fallows. This is a defining feature of savanna vegetation. As evidenced by empirical research, the formation of savannas is a process that has occurred over an extended period of time, originating from ancient fallow lands. Their physical characteristics reflect the evolution of different stages. Such lands are typically utilized by the indigenous population as a land reserve or, on occasion, as a setting for traditional ceremonies. It is documented that these savannas have been cultivated on at least two occasions since 1927. Furthermore, the fallow lands are exclusively owned by the native population, who practise fallow cropping. The fields are preferentially exploited for cotton, corn, and sorghum. These are plots of land that have been continuously cultivated under wooded parkland due to the richness of the soil. Approximately twenty species of woody and herbaceous plants are preserved during the clearing process, with the most notable examples being *Vitellaria paradoxa* and *Andropogon gayanus*.

The vegetation observed in the forests and fallow lands is described in detail in the preceding section.

-Wooded savannas devoid of a grassy layer, with woody cover exceeding 70%. This physiognomy, which was more prevalent in 1927, is currently observed in only a few locations. These include plant formations and sectioned riparian belts, which are protected from fire later by the annual herbaceous plants of the cuirasses, which burn before the rains stop. These humid, fertile environments, protected from fire, represent the closest approximation to the "climax" state. The population of hemi-ombrophilous species and humid environments of these formations is characterised by a rich diversity of fire-sensitive leguminous, including *Pterocarpus erinaceus*, lianas (*Saba senegalensis*) and shrubs (*Capparis corymbosa*, *Ziziphus mauritiana*, *Diospyros mespiliformis*), which flourish in the undergrowth.

-The shrubby savannas are characterised by a low grass layer (35-50% woody cover), which is composed mainly of the following species: *Vitellaria paradoxa*, *Isoberlinia doka*, *Daniella oliveri* and *Burkea africana*. These plants are found on the foothills and hillsides, and on occasion, in the interfluves.

- Floodable grassy savannas: these are characterised by the presence of *Hyparrhenia diplandra* meadows and termite mound thickets.

-The annual savannas are characterised by a distinctive flora and fauna. *Loudetia togoensis* and *Andropogon pseudapricus* exhibit a cuirassed morphology.

-Fallows lands are characterised by the presence of trees and shrubs, with an estimated 35% woody cover. These are observed to be in different stages of reconstitution on various biotopes, or pseudo-climaxes of xeric biotopes. On the shrubby fallow land, species that reject and sucker, such as *Terminalia avicennoides*, *Pteleopsis suberosa*, *Detarium microcarpum*, and seedlings of trees from the wooded park with *Vitellaria paradoxa*, are the dominant species. The herbaceous flora is dependent on the reconstitution stage, with ruderal species giving way to annuals, which in turn are succeeded by *Andropogon gayanus* and *Andropogon ascinodis*. The formation of shrubby savannas, characterised by woody cover exceeding 50% at a low height, is observed in areas subjected to excessive grazing.

3.3 Soil Physical Characteristics

The Anova of the soil data from the three situations revealed a significant effect of the situation on the soil texture (Table 2). It is evident that savannas (22.33% clay, 14.1% fine silt, 25.6% coarse silt and 37.96% fine sand + coarse sand) and fallows (20.27% clay, 14.23% fine silt, 27.76% coarse silt and 37.73% fine sand + coarse sand) exhibit a distinct compositional profile in comparison to fields (9.8% clay, 6.74% fine silt, 15.72% coarse silt and 67.74% fine sand + coarse sand). The proportion of fine elements with a size of less than 20 µm is greater in savannas and fallows than in fields. The sand contents in savannas (37.96%) and fallows (37.73%) are relatively low and statistically different from the contents in fields (67.74%). The proportion of coarse elements (>50 µm) in savannas and fallows is less than that of fine elements (>20 µm), which corroborates the silty-clayey composition of the soil.

Table 2. Soil Physical Characteristics at 0-20 cm depth. Means displaying the same letter per line are not significantly different (n=15, P<0.005), standard error in parentheses

	Plots		
Parameters	Savannas	Fallows	Fields
Clays (%)	22.33a	20.27a	9.8b
	(4.43)	(2.7)	(1.22)
Fine silts (%)	14.1a	14.23a	6.74b
	(4.01)	(2.54)	(1.47)
Coarse silts (%)	25.6a	27.76a	15.72b
	(6.1)	(3.79)	(3)
Coarse + Fine sands (%)	37.96a	37.73a	67.74b
	(3.73)	(4.61)	(5.18)

3.4 The Organic and Acid-Base Status of Soils

The analysis of variance demonstrates a highly statistically significant effect of the situation ($P < 0.0001$) on the distribution of chemical parameters in the 0-20 cm horizons of the soil in the studied situations (Table 3). The Scheffé test enables the differentiation of the situations in terms of organic matter contents (C, N), exchangeable bases and CEC. The results obtained permit an in-depth analysis of the dynamics of soil fertility reconstitution and the enhancement of CEC and exchangeable bases through the examination of the various chemical and organic elements.

Table 3. Results of analyses of variance (ANOVA/SAS) of the effect of situations (savannas, fallows and fields) on the chemical characteristics of the soil at depth 0-20 cm, n = 195

Variables	$F_{8.45}$	P	R^2	CV
C (%)	60.23	<0.0001	0.85	35
N (%)	40.55	<0.0001	0.75	30.2
C/N	30.45	<0.0001	0.50	24.6
pH-H_2O	15.43	0.122	0.22	11.5
pH-KCl	16.67	0.1300	0.15	9.6
Ca^{2+} (meq.100g^{-1})	15.13	0.1200	0.13	8.7
Mg^{2+} (meq.100g^{-1})	22.42	<0.0001	0.73	20.67
Mn^{2+} (meq.100g^{-1})	26.53	<0.0001	0.67	27.32
K^+ (meq.100g^{-1})	40.25	<0.0001	0.77	22.8
Na^+ (meq.100g^{-1})	19.80	<0.0001	0.60	26.7
CEC (meq.100g^{-1})	20.45	<0.0001	0.79	24.5
SEB (meq.100g^{-1})	15.53	<0.0003	0.55	24.2
SEB/CEC (%)	53.13	<0.0001	0.52	31.5

3.4.1 pH-H_2O and pH-KCl

The statistical analyses conducted on the pH values yielded insignificant results. Conversely, the pH of the various scenarios under examination is weakly neutral ($6.24 < \text{pH-H2O} < 6.31$ and $5.23 < \text{pH-KCl} < 5.3$) (Table 4). The findings indicate that despite two decades of fallow land, the savanna has not resulted in an improvement in soil pH.

Table 4. Soil chemical and acid-bases characteristics at 0-20 cm depth. Means displaying the same letter per row are not significantly different (n=15, P<0.005), standard error in parentheses

	Plots		
Parameters	Savannas	Fallows	Fields
C (%)	0.67a	0.5a	0.34b
	(0.1)	(0.05)	(0.02)
N (%)	0.06a	0.042b	0.028c
	(0.01)	(0.01)	(0.01)
C/N	12a	12a	13a
	(1.85)	(1.27)	(3)
pH-H_2O	6.31a	6.24a	6.42a
	(0.5)	(0.42)	(0.9)
pH-KCl	5.27a	5.3a	5.23a
	(0.45)	(0.4)	(1.06)

3.4.2 Carbon

The analyses conducted on the mean carbon contents of the various scenarios yielded statistically significant results ($P < 0.0001$) (Table 3), with a clear distinction between savannas (0.67%) and fallows (0.5%) and fields (0.34%) (Table 4). The carbon content increased by 0.33% from the field samples to the savannah samples and by 0.17% from the fallow samples to the savannah samples. Conversely, a pronounced decline in carbon content is evident when moving from savannas to fields (Figure 2). The recorded carbon losses or gains at the fallows are twice those observed at the fields. The fallow stage, therefore, corresponds to the initial phase of carbon storage, which accumulates sustainably during the savanna.

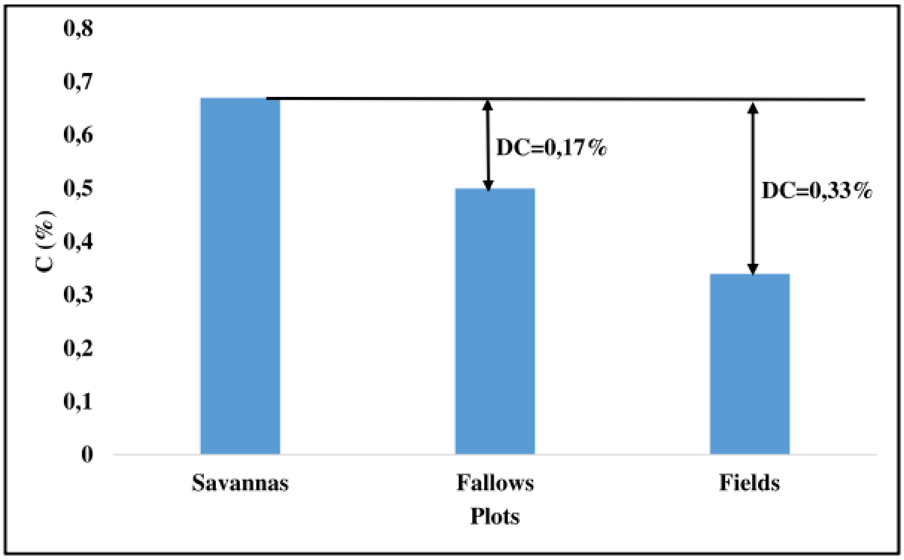

Figure 2. Difference in carbon content (DC)

3.4.3 Nitrogen

The statistical analysis of nitrogen averages revealed a highly significant situation effect ($P < 0.001$) (Table 3), with savannas (0.06%) exhibiting a notable distinction from fallows (0.042%) and fields (0.028%), which demonstrated statistically significant differences (Table 4). A gain of 0.032% is observed from savannas to fields and 0.02% from savannas to fallows. Conversely, the transition from field to savanna results in a loss of 0.032%. The losses or gains in nitrogen observed at the fallow level are approximately double those observed at the field level (Figure 3). It can be concluded that nitrogen is reconstituted during the fallow period and appears to stabilise in the savanna.

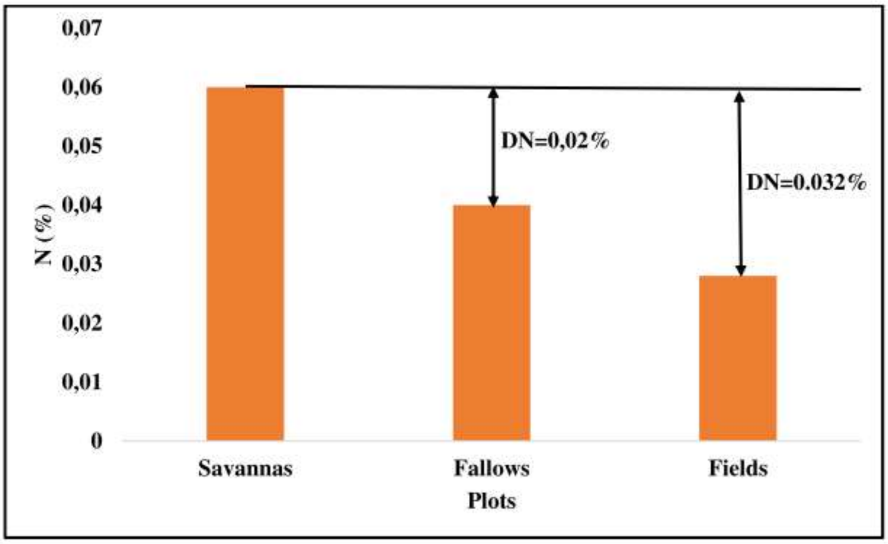

Figure 3. Difference in nitrogen content

3.4.4 C/N Ratio

The C/N ratio is an indicator of the degree of decomposition of organic matter. The ratio varies from 12 to 13 and is not statistically significant (Table 4). The low C/N ratios observed in the three scenarios suggest that mineralisation is occurring rapidly.

3.5 Nutrient Status According to Exchangeable Bases

Table 5 shows the level of soil fertility based on average CEC values and exchangeable bases.

3.5.1 Exchangeable Bases and Cation Exchange Capacity (CEC)

The mean calcium values obtained ranged from 3.41 to 2.63 meq.100 g^{-1}. The statistical analysis of the Ca^{2+} contents yielded insignificant results. The three scenarios exhibit statistically comparable values.

The mean magnesium content varies from 1.8 to 0.84 meq/100 g^{-1}. A significant effect of the situation on magnesium content was observed. It can be observed that the savanna and field situations exhibit the highest calcium contents, at 1.8 and 1.054 meq.100g^{-1}, respectively, in comparison to the fallow land situation, which has the lowest calcium content at 0.84 meq.100g^{-1}.

The mean values of potassium observed in the samples ranged from 1.64 to 0.13 meq.100g^{-1} (Table 5). A highly significant situation effect ($P < 0.0001$) is evident, with fallows (0.13 meq.100g^{-1}) and fields (0.18 meq.100g^{-1}) exhibiting deficiencies in K compared to savannas (1.64 meq.100g^{-1}).

The results of the analysis revealed a highly significant situation effect on the mean sodium values. The savannas and fallows exhibited the highest rates, at 0.022 and 0.024 meq.100g^{-1}, respectively, in comparison to the fields, which demonstrated a rate of 0.016 meq.100g^{-1}.

The mean manganese values range from 0.03 to 0.01 meq.100g-1 (Table 5). The results of the statistical tests demonstrate a highly significant situation effect. The data indicate that, in this situation, savannas are characterised by manganese deficiency, in contrast to fields.

The CEC (Cation Exchange Capacity) represents the total exchangeable cations present in the soil. The mean CEC values obtained in the different situations are between 9.23 and 4.14 meq.100g^{-1} (Table 5). The statistical analyses revealed a highly significant situation effect ($P < 0.00001$) on the observed values. The savannas exhibited the highest values (9.23 meq.100g^{-1}), followed by the fallows (4.49 meq.100g^{-1}) and fields (4.14 meq.100g^{-1}), which demonstrated a statistically similar distribution.

Table 5. Characteristics of nutrient status at 0-20 cm depth of soil in the studied situations. The means displaying the same letter per line are not significantly different (n=24, P<0.005), standard error in parentheses

	Plots		
Parameters	Savannas	Fallows	Fields
Ca^{2+} (meq.100g^{-1})	3.41a	2.63a	2.66a
	(0.69)	(0.59)	(0.89)
Mg^{2+} (meq.100g^{-1})	1.8a	0.84b	1.05a
	(0.3)	(0.14)	(0.25)
K^{+} (meq.100g^{-1})	1.64a	0.13b	0.18b
	(0.15)	(0.04)	(0.06)
Na^{+} (meq.100g^{-1})	0.022a	0.024a	0.016b
	(0.02)	(0.01)	(0.02)
Mn^{2+} (meq.100g^{-1})	0.03a	0.02ab	0.01b
	(0.03)	(0.04)	(0.01)
Sum of exchangeable bases (SEB) (meq.100g^{-1})	6.89a	3.64b	3.92b
	(2.72)	(1.34)	(1.4)
CEC (meq.100g^{-1})	9.23a	4.49b	4.14b
	(2.06)	(1.35)	(1.45)
Bases saturation SEB/CEC (%)	74.65a	81.16ab	94.78b
	(2.1)	(2.08)	(2.08)

3.5.2 Bases Saturation Rate

The saturation rate is defined as the ratio of the sum of exchangeable bases to the cation exchange capacity. The value ranges from 94.78% to 74.65% (Table 5). A highly significant situation effect was observed. The saturation rate serves as an indicator of the chemical richness of the soils and the cationic lining of the adsorbent complex. The saturation rate is notably elevated in agricultural fields, reaching 94.78%, in comparison to fallow land, which exhibits a lower value of 81.16%, and savannas, which demonstrate a saturation rate of 74.65%.

3.6 Nutrient Status According to Chemical Balances

In order to diagnose mineral balances and assess the relative deficiency of exchangeable bases in soils, specific values are calculated (Figure 4).

3.6.1 Ca/Mg Balance

The Ca/Mg ratio values obtained in the different situations exhibit a range of 3.14 to 1.9 (Figure 4). The statistical analyses yielded a significant contrast between the fallows (3.14), the fields (2.52), and the savannas (1.9).

3.6.2 Mg/K Balance

The Mg/K ratios observed ranged from 6.25 to 1.1. The results of the statistical analyses indicated a statistically significant effect of the situations under consideration on the Mg/K ratio. The savannas (1.1) with low ratios are in contrast to the fallows (6.25) and fields (5.73), which have high ratios (Figure 4).

3.6.3 K/CEC Ratio (%)

The values of the percentages of saturation of potassium (K) in the various scenarios span a range of 18 to 3%. The results of the statistical analyses indicated the presence of a significant difference and a situation effect. The Savannas (18%) are in opposition to the fields (4%) and fallows (3%), which have statistically identical rates (Figure 4).

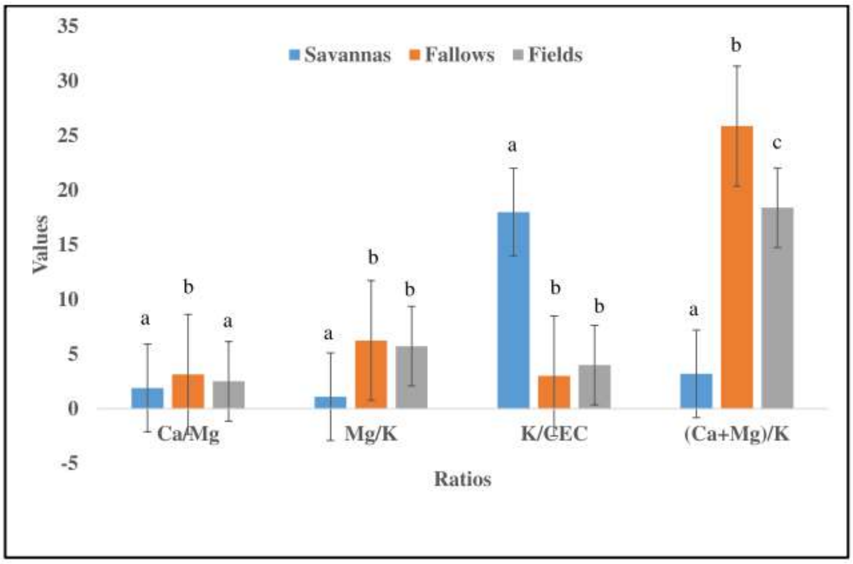

Figure 4. Chemical balance of soil in different situations

3.6.4 (Ca+Mg)/K balance

The mean values of the (Ca+Mg)/K ratio from the various experimental conditions exhibited a range of 25.87 to 3.2. The results of the statistical analyses clearly demonstrated a highly significant situation effect. The low ratios observed in savannas (3.2) are in stark contrast to those seen in fallows (25.87) and fields (18.4), which are statistically distinct (Figure 4).

4. Discussion

4.1 Role of Texture

The upper layers (0-20 cm) of soil in the various situations under consideration are characterised by a silty-clayey texture. This texture confers upon the soil a high degree of structural stability and a large specific surface area for the retention of nutrients. The clay content is notably high in these surface horizons, with values ranging from 9.8% to 22.34%. The elevated clay content of these soils renders them highly chemically reactive. It is notable that the clay content of savannas is approximately twice that of fields, with a value of 22.34% compared to 9.8%. This suggests that the clay fraction undergoes reconstitution during fallow periods (20.28%), which then stabilises in savannas. The significance of the clay fraction has been elucidated in the context of CEC dynamics in hydromorphic soil (Brady & Weill, 2017; Pezeshki, 2001; Sedogo, 1993; Ponnamperuma, 1984; Thomas, 1982). Baize (2000) posits that clay is the most active particle size fraction due to its multifunctional nature, which encompasses association with organic matter, cohesion of aggregates, fixation of cations and anions on exchange sites, water retention, and other properties. However, the capacity of clays to store cations and enhance the CEC is more contingent on their intrinsic characteristics than on their relative abundance in the soil. In hydromorphic soils, the specific type of clay present is a significant factor. In particular, smectites, illites and montmorillonites, which are negatively charged, are capable of attracting and retaining a greater number of cations. This directly contributes to an increase in the CEC (Brady & Weil, 2017; Lal & Shukla, 2004; McBride, 1994; Sedogo, 1993). The provenance of the low-humus substrate, characterised by a shallow gley (<80 cm) and pseudogley, is also a contributing factor in enhancing the CEC. Indeed, hydromorphic tropical ferruginous soils are often the site of certain processes, such as the reduction of metal oxides (Fe, Mn), which can influence the reactivity of clays and the availability of cations (Pezeshki, 2001; Ponnamperuma, 1984; Thomas, 1982; Reddy & Patrick, 1977). Due to their coarser texture, fine silts also participate in water storage, thereby influencing the accessibility of nutrients during periods of excess water or drainage. This ultimately enhances the CEC (Kaiser *et al*., 2002; Pezeshki, 2001; Ponnamperuma, 1984; Reddy & Patrick, 1977). Furthermore, coarse silts exert an additional influence on soil structure and water distribution, which can indirectly affect cation dynamics in hydromorphic soils by facilitating or limiting water and nutrient movements (Kaiser *et al*., 2002; Pezeshki, 2001; Schwertmann & Taylor, 1989). Our findings have been corroborated by several authors in similar studies (Brady & Weil, 2017; Sanchez, 2019; Lal, 2006; Dubroeucq & Volkoff, 1998; Niskanen & Jaakkola, 1986). The texture and cation exchange capacity (CEC) of a soil may be influenced by the presence of vegetation and other factors.

4.2 Role of Vegetation

The vegetation of western Burkina Faso is characterised by a high degree of diversity in terms of its morpho-structural types, which are adapted to the specific environmental conditions of the region. The physiognomy of the Sudanian savanna is therefore representative of a succession of intermediate states between young and old fallows. These fallows are the consequence of local agricultural practices that ensure their preservation throughout the crop cycle, as their function is to restore soil fertility (Serpantié, 2003; Yoni *et al*., 2018). The biodiversity of this region is considerable, though not particularly distinctive to savanna ecosystems. The dynamic equilibrium achieved in the soil of savannas and fallows thus permits the restoration of soil fertility to a significant extent. This contributes to an improvement in the cation exchange capacity (CEC) and exchangeable bases of hydromorphic soils. Boyer's (1978) research demonstrated that the concentration of specific cations (Ca^{2+} and Mg^{2+}) in the surface layer of the soil is influenced by vegetation. In savannas on hydromorphic ferruginous soils, the woody layer exhibits greater coverage and larger individuals than in fallows. Furthermore, the perennial herbaceous layer is observed to occur in more uniformly sized tufts, with greater density in savannas than in fallows. As a result, wet savannas produce a considerable quantity of organic matter, including dead leaves and plant debris, which decomposes at a relatively slow rate due to the high humidity. The organic matter improves the CEC, as organic colloids (humus) have a high cation exchange capacity. The vegetation of savannas, which is richer in woody plants compared to that of fallows, thus provides the opportunity to restore soil fertility through the deposition of plant matter. It can be seen that woody plants play an important role in the storage of mineral salts and the provision of energy to the soil through the processes of litter and exudate production. Indeed, woody plants serve as agents for the storage of mineral salts, thereby providing energy to the soil through litter and exudates (Manlay, 2001). The installation of these plants prioritises their ability to survive, which is achieved by the formation of a tuberous pivot (storages of photosynthates and water) supplied by seasonal aerial parts (Alexandre, 2008). In some cases, woody plants are negatively impacted by fires, which can result in the selection of certain species over others. Conversely, fallow vegetation is characterised by the dominance of perennial grasses (hemicryptophytes), which have evolved to thrive in environments subjected to fire and grazing. As a result, the tillering plateaus, buds and young stems, which are used for survival and regrowth following fires, are located underground or protected at the base of the tuft by a tight mass of dead tissues (Fournier, 1991). The role of *Andropogon gayanus* fallows has been the subject of extensive study (Yoni *et al*., 2018; Serpantié, 2003, Fournier *et al*., 2001), yet there has been limited discourse on its contribution to the dynamics of the CEC. The *A. gayanus* fallow allows for the restoration of savannah biodiversity, which plays a multitude of roles in compensating for poorly structured, poor and semi-arid soil. Therefore, the *A. gayanus* fallow, like the savanna, is economically efficient in the utilisation of mineral salts. Furthermore, *A. gayanus*, due to its substantial biomass and its capacity to interact with the soil, plays a role in enhancing certain physicochemical properties of soils. It is important to note that erosion under *A. gayanus* fallow is negligible (Roose, 1993). The low nitrate leaching resulting from the presence of perennial roots serves to conserve nitrogen and bases, thereby maintaining the pH. Only the residual nitrogen from the leaves is released into the atmosphere as a result of combustion. Microbial activity, including free nitrogen fixation in macro-aggregates (Chotte *et al*., 2001) and symbiotic fixation (although nodulating Rhizobium species are rare in fallows), contributes to the capitalisation of atmospheric contributions or those brought by runoff. In contrast, fallows with *A. gayanus* are subject to significant withdrawals by livestock and humans. This fallow system, through its biomass growth, capitalises on atmospheric contributions and those of the extraction of poorly assimilated forms of the root zone

(K, P). *A. gayanus* fallows situated downstream of crops act as traps for runoff water and solid loads (Fournier *et al*., 2000), thereby contributing to the accumulation of organic matter. Subsequently, these fallows will evolve into *A. gayanus* savannas, maintaining the same plant characteristics to enrich the soil and thus improve the CEC and exchangeable bases. The results demonstrate that the clearance of a savanna would result in the introduction of 10 times more potassium, approximately 2 times more sodium and manganese into the soil in comparison to that of a fallow. The diverse flora of savannas may be a contributing factor to the relatively high levels of exchangeable bases obtained. It is therefore crucial to highlight the importance of savannas in the restoration of soil fertility.

4.3 Role of pH

The pH of the soil serves to determine the type of activity (acidic or basic) that exists or is predominant. In general, the pH values of savanna soil (6.31), fallow land (6.24) and fields (6.41) are slightly neutral. It has been demonstrated that the pH value increases gradually over time during the long-term storage of organic matter across plant succession, as evidenced by Falkengren-Grerup (1995). In the studies conducted by Bationo *et al*. (2006) and Baize (2000), the pH threshold for optimal activity was identified as 5.5. The pH values observed in our study are higher than the aforementioned threshold, indicating that the chemical and microbiological reactions in our soils are occurring in a manner that is conducive to optimal nutrient bioavailability. In general, cultivated plants grow harmoniously in neutral or slightly acidic soil, with a pH of 5.5 to 7 (Landon, 1991; Baize, 2000). A reduction in soil pH has been demonstrated to impede plant growth by inhibiting nitrification. Nevertheless, it is not possible to attribute the enhancement in CEC to pH alone. The effect is indirectly linked to the content and nature of the clays. Hydromorphic soils have a tendency to accumulate H^+ ions (resulting in acidification), which can lead to a reduction in CEC over time due to competition with other cations. A soil with a higher acidity level will exhibit a reduced CEC, due to the diminished retention capacity of soil colloids for nutrients. In particular, acidic hydromorphic soils have been observed to exhibit a lower CEC (Sedogo, 1993). This is not the case in the present study, in which the soils are weakly neutral. Furthermore, it is notable that the CEC (9.23 meq.100g^{-1}) of the savannas is approximately twice that of the fallow land (4.49 meq.100g^{-1}) and fields (4.14 meq.100g^{-1}). The combination of a weakly neutral pH and a high clay content therefore renders the savanna an ecosystem conducive to an increase in CEC. As with texture and vegetation, pH exerts an influence on CEC. Nevertheless, it would be beneficial to ascertain the role of organic matter in enhancing CEC.

4.4 Effect of Soil Organic Matter (C, N)

The presence of organic matter (C, N) in tropical ecosystems has been demonstrated to enhance soil fertility. It is an effective indicator of optimal plant health. In the context of our study, concentrations of carbon (C) and nitrogen (N) are higher in savannas (0.67% C, 0.06% N) than in fallows (0.5% C, 0.042% N) and fields (0.34% C, 0.028% N). The high organic matter content in savannas serves to protect the soil from degradation by water erosion during periods of heavy rainfall (Mulaji *et al*., 2016). Furthermore, the high silty-clayey texture of savannas, coupled with the high organic matter content, accentuates the gain of soil nutrients and the increase in CEC. Conversely, a comparison of the contents of savannas with those of fallow land and fields demonstrates a gradual increase in organic matter during the fallow period. It can be demonstrated that a significant gain of 0.33% of carbon is recorded when one considers the transition from permanent crop situations to savannas via fallows. The latter transition allows for a gain of 0.17% of carbon. In terms of nitrogen, the transition from fields to savannas results in a gain of 0.032% N, while the transition from fallows to savannas gives a gain of 0.02% N. Fallow practices have been demonstrated to considerably improve the organic matter content of soil, which then stabilises in the savannas. This is attributable to the deposition of substantial quantities of plant debris in the savannas, in comparison to fallows. At the field level, the low organic matter content can be attributed to the practice of growing permanent crops, given the inherent richness of the soil, and in some cases, the absence of crop residue restitution. It is generally acknowledged that in the context of hydromorphic soil of Bondoukuy, the improvement of CEC is strongly correlated with organic matter. Indeed, soil hydromorphism facilitates the accumulation of organic matter in the upper layer, as decomposition is slowed down in anaerobic conditions (Munkholm *et al*., 2008). The presence of organic matter in the soil results in a negative charge, which enables the retention of cations, thereby increasing the CEC (Lehmann & Kleber, 2015; Six *et al*., 2002). However, if soils are excessively saturated and poor in oxygen, incomplete decomposition can also result in the formation of recalcitrant organic compounds, which are less effective for cation retention (Van den Akker *et al*., 2013; Lal, 2004; Sedogo, 1993). Our observations are corroborated by several studies (Ranger *et al*.; 2007; Sparks, 2003; Six *et al*., 2002; Kätterer & Andrén, 1999; Batjes, 1996; Rowell, 1994). It can be concluded that organic matter plays an essential role in improving the CEC of hydromorphic soils. It permits the retention and release of cations that are essential for plant nutrition, enhances soil structure and water retention, and fosters superior long-term fertility.

4.5 Dynamics of the CEC and Exchangeable Bases

CEC is defined as the capacity of a soil to retain and exchange cations, which are positive ions such as K^+, Ca^{2+}, Mg^{2+}, and Na^+. A soil with a CEC of 10 to 20 $meq.100g^{-1}$ is regarded as moderate and acceptable for crops, whereas a soil with a CEC exceeding 20 $meq.100g^{-1}$ is considered conducive to the retention of nutrients, as observed in hydromorphic soils (Brady & Weil, 2017; McBride, 1994; Duchaufour, 1982). The CEC of savannas was found to be 9.23 $meq.100g^{-1}$, which is double that of fallows (4.49 $meq.100g^{-1}$) and fields (4.14 $meq.100g^{-1}$). The CEC of the hydromorphic savanna soil evinces stability and nutrient richness for plants. Furthermore, it is important to acknowledge the correlation between the CEC and the clay-humic complex, as well as the organic matter content. The elevated CEC observed in savannas can be attributed to the combination of a high silty-clayey texture and a high organic matter content. At the level of fallows and fields, the CECs are lower than those of savannas but nevertheless remain within acceptable limits, thus allowing the establishment of crops in hydromorphic soils. The findings of Fang *et al.* (2017) indicate that the CEC is significantly influenced by climatic conditions, precipitation levels, topographical features and human activities. This is exemplified by our hydromorphic soils. A comparison has been made between the CEC of savannah and fallow soil and that of fields under permanent cropping. The functional particularity of the CEC precludes its storage in cultivated soils. This is indicative of the low value obtained, despite the favourable nature of the soil in terms of increasing the CEC.

Exchangeable bases represent the essential cations that are available to plants. An enhancement in these bases directly enhances soil fertility (Kopittke *et al*., 2007; Donahue *et al*., 1990). The results of our study indicate that savannas possess values of 6.89 $meq.100g^{-1}$, which are twice as high as those observed in fallows (3.64 $meq.100g^{-1}$) and fields (3.92 $meq.100g^{-1}$). The values observed in savannas exceed the threshold (2 <SEB< 15 $meq.100g^{-1}$ soil) for hydromorphic tropical soils (Chesworth, 2008; Landon, 1991; Boyer, 1982). It should be noted that these values may fluctuate in response to temporary waterlogging associated with hydromorphy. Consequently, the relative abundance of certain cations may be enhanced at the expense of others. The elevated levels of exchangeable bases in savanna soils provide compelling evidence of enhanced CEC in these ecosystems. These values increased from those observed in fields to those observed in savannas through intermediate fallow situations. Notwithstanding the fact that the soil in question has been subjected to permanent cultivation, the values observed therein fall within the threshold range established for hydromorphic tropical soils. This therefore permits the continuation of permanent agricultural activity. Nevertheless, the results of our study indicate that the conversion of a savanna to agricultural use would result in a soil with twice the cation content of the soil in the fields. The saturation rate is an invaluable environmental indicator of the chemical richness of the soil, which determines the biological activity, quality and reserves of fertilising elements. The mean saturation rate values indicate that the three scenarios are situated on highly fertile soils, with the savannas exhibiting a saturation rate of 74%, the fallows a rate of 81%, and the fields a rate of 94%. Therefore, the succession from fallows to savannas has not resulted in a significant alteration in the saturation rate of the bases. These soil fertility states under savannas and fallows may be attributed to the previous cultivation practices that occurred prior to the fallow period. The work of Serpantié (2003) on hydromorphic soil has demonstrated that fallow soil from animal-drawn cultivation regenerates rapidly, in contrast to that from motorised cultivation. The soil conditions in the fields, which are identical to those in savannas and fallow lands, can be readily explained by the fact that heavy soil work is preferentially carried out with a plough by the indigenous population, who are highly conscious of the need to preserve the fertility of the soil.

4.6 Influence of Chemical Balances

The equilibrium of chemical balances between diverse cations (Ca^{2+}, Mg^{2+}, K^+) and soil CEC is a pivotal factor influencing soil fertility and plant nutrition in general. The Ca/Mg ratio is frequently regarded as a crucial factor in maintaining optimal soil structure and balanced nutrient availability (Brady & Weil, 2017). However, the presence of excess of calcium can result in reduced magnesium availability, while the accumulation of excess of magnesium can lead to soil compaction, which in turn reduces aeration and water infiltration (Brady & Weil, 2017; Dorlodot *et al*., 2005; Cox, 1979). The optimal Ca/Mg ratio for tropical hydromorphic soils is between 2 and 4.5 (Sedogo, 1993; Landon, 1991). The values of the ratios obtained in the present study range from 1.9 to 3.14. This suggests the potential for inhibition of Mg and a deficiency of Ca in our soils. The occurrence of waterlogging for part of the year may or may not favour the presence of one of the two elements. Such consequences would be detrimental to plant nutrition, resulting in soil compaction or poor aeration. The ratios observed in savanna soils (1.9) and fields (2.5) are lower than those recorded in fallow soils (3.14). This indicates that, in the initial two scenarios, plant nutrition is deficient in calcium, in contrast to fallow soils where it is optimal.

The Mg/K ratio plays a significant role in plant nutrition and cation balance within the soil. An excess of magnesium can result in competition with potassium for exchange sites on the soil matrix (Brady & Weil, 2017). This may result in a limitation of potassium uptake by plants. In the case of these two cations, which are antagonistic, the optimal value of the Mg/K ratio is between 2 and 4 for hydromorphic soils (Boyer, 1982). With the exception of savannas, which exhibit a Mg/K ratio of 1.1, the Mg/K ratio for fallows and fields is 6.25 and 5.73, respectively. This suggests that magnesium deficiency may occur in savannas. A low ratio may indicate the presence of excess potassium, which could potentially lead to magnesium deficiency in some plants. This imbalance in nutrition may result in a reduction in the cation exchange capacity (CEC) of the soil. As demonstrated by Dognin *et al*. (1981), achieving an optimal Mg/K ratio maximises the use of cation exchange sites and facilitates balanced nutrient absorption by plants. Conversely, in hydromorphic soils, the conditions of water saturation and low oxygenation result in a greater alteration of primary minerals, which is likely to be the case for savanna soils. It can be stated that this situation presents permanent vegetation, in contrast to fallow land and cultivated fields. It can be inferred that the excess of potassium is linked to the constant fallowing of plant debris, which undergoes slow decomposition due to the hydromorphic conditions.

The K/CEC ratio represents the proportion of potassium relative to the total cation exchange capacity of the soil. In hydromorphic Sudanian soil (40% fine elements), a K/CEC ratio of 2 to 5% is considered satisfactory for the majority of plants, as outlined by Brady and Weil (2017). The ratio may be influenced by the retention of water and the potential leaching of potassium during periods of heavy rainfall. Values that are too high indicate potassium saturation, which can result in the inhibition of the absorption of other cations. As stated by Fallavier and Olivin (1988), potassium is preferentially exchanged in hydromorphic soils, with the consequence that other cations are displaced. However, this process is limited by the saturation of the CEC, which should not exceed 30%. Notwithstanding the elevated clay and organic matter concentrations, the effective availability of nutrients may be diminished by water saturation. In the present case, the savannas exhibit a ratio of 18%, while the fallows (3%) and fields (4%), which serve as controls, display relatively low ratios. The low ratios observed in the fallows and fields indicate a limited availability of potassium in the soil, which could potentially impact plant nutrition. Conversely, the elevated levels of potassium present in savanna soils have the potential to disrupt the absorption of other cations. The surplus of potassium in savanna soils can be attributed to the continuous replenishment of K-rich plant litter.

The (Ca+Mg)/K ratio represents the overall relationship between calcium, magnesium and potassium and is employed to assess the overall cation balance in the soil. It ensures an optimal balance between these major cations, thereby enhancing soil fertility. An optimal ratio of (Ca+Mg)/K of 10 to 20 is typically recommended for hydromorphic soils (Brady & Weil, 2017). A ratio that is too low can result in soil structure issues and restrict the uptake of calcium and magnesium. Conversely, a ratio that is too high can restrict the availability of potassium. The ratio of 3.2 observed in Savanna soils indicates that the availability of Ca and Mg is a significant challenge in natural vegetation situations, despite the continuous replenishment of plant matter. The ratio for fallow lands is 25.87, while that for fields is 18.4, which reflects a limited supply of potassium. This is justified at the field level, where organic amendments are restricted to crop residues for certain crops (Dakouo, 2012), and potassium is preferentially taken up by crops. In fallow lands, which represent a transitional phase prior to the establishment of the savannah, this phenomenon can be attributed to the restitution of plant matter from species with low K content and the removal of certain useful plants. The nature of the vegetation and its management by the local population therefore have an impact on the renewal of the cation stock and on the improvement of the CEC in general.

6. Conclusion

The findings of this study highlight the importance of *Andropogon gayanus* savanna ecosystems and fallows in the restoration of soil fertility. This was demonstrated through a comparative analysis of the enhancement of CEC and the exchange of exchangeable bases. In Sudanese hydromorphic soils, cation exchange capacity (CEC) dynamics are enhanced by the presence of clay minerals, which possess a large surface area and cation retention capacity. The contribution of fine silts is comparatively limited, whereas coarse silts play a more prominent structural role. Furthermore, hydromorphic conditions exert an influence on soil chemistry, modifying the reactivity of clays and the availability of essential cations. The high organic matter content associated with a weakly acidic pH creates a suitable environment for CEC enhancement in savanna soils. Furthermore, the presence of *Andropogon gayanus* savanna vegetation is of significant consequence. Indeed, *A. gayanus*, a perennial grass, produces a considerable quantity of biomass. The decomposition of this biomass, particularly through the fall of leaves and dead roots, serves to promote the accumulation of organic matter in the soil. The organic matter plays a fundamental role in the enhancement of cation exchange capacity (CEC), as it provides supplementary cation exchange sites. Furthermore, it facilitates the release of exchangeable bases for plants. The measurement of a range of chemical and physical soil parameters has enabled a comparison of savanna soil with fallow and field soil. It is evident that fallow, which represents the intermediate stage of fertility reconstitution, does not play a significant role in enhancing CEC and exchangeable bases. It is essential to allow sufficient time for the establishment of the savanna ecosystem before expecting significant increases in CEC and exchangeable bases.

The increase of the CEC and exchangeable bases of a hydromorphic Sudanian savanna soil in western Burkina Faso must therefore be based on integrated soil management with innovative approaches, such as the implementation of adapted cultural practices. The objective of these approaches is twofold: firstly, to enhance the soil's capacity to retain nutrients, and secondly, to improve the availability of exchangeable bases that are essential for plant growth. These approaches also facilitate the promotion of sustainable agriculture and enhance agricultural productivity in this region, where soils are naturally deficient in nutrients. However, the present study did not consider agronomic aspects in order to estimate losses due to the export of crops at the level of permanent fields.

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