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Research Article

Agro-Pedological Characterization of Cashew Plantations (*Anacardium occidentale L.*) in Casamance, Senegal

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Abstract

In Senegal, the agricultural production system is dominated by rainfed crops, and the tree-crop association is an alternative for sustainable production. The introduction of high value-added woody species into the agricultural space should be one of the solutions for ensuring diversified and sustainable agricultural production. Cashew (*Anacardium occidentale* L., Anacardiaceae), which plays an important role in Senegal's agricultural sector, could be one of the species with high agroforestry potential, but has been little evaluated. The present study aims to contribute to understanding the importance of agroforestry species in agricultural production by characterizing the physicochemical fertility level of soils under cashew tree cover and establishing their cultural aptitudes. To this end, 18 samples were taken from 2/3 of the cashew tree crown radius at two depths, 0-20 and 20-40cm, in different production zones (Kolda, Sédhiou, Ziguinchor) in Casamance, characterized by the presence of poorly developed, ferralitic and hydromorphic soils. The results indicate a silty-clay-sandy texture of the soils in these regions. The texture of the 0-20cm horizon is also silty-clayey-sandy. However, the 20-40cm horizon has a sandy-clay texture. The soils are highly acidic (pH<5), with significant differences between regions and horizons. The highest values for pH, P/Ass, MO, CE, KCl, C, C/N were found in Kolda. A highly significant effect was detected between horizons. The 0-20cm horizon gave the highest values for MO (00.43±0.08%), CE (67.36±1.76), KCL (4.30±0.08), pH (4.69±0.09), P/Ass (2.77±0.45 ppm), C (13.33±0.76%), C/N (13.22±0.72). It appears that variations in pH (water, KCl) are strongly, positively linked to those in EC, C and OM, but negatively linked to clay. These results show that cashew soils are rich in mineral elements. However, it would be interesting to see whether soil properties are influenced by *Anacardium occidentale* L., and to learn more about the species' acidifying properties.

Keywords

Senegal, Casamance, *Anacardium occidentale* L., Soil, Acidity

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1. Introduction

Anacardium occidentale L. is an agroforestry species belonging to the Anacardiaceae family. *A. occidentale* is a tropical tree [1-5] up to 12 m high, generally branched at the base, with a ball-shaped habit [6, 7]. Leaves are simple, alternate, entire, obovate or obovate-oblong, leathery and glabrous on both sides. It has a taproot system that can reach a depth of two meters [8]. Unlike many forest species, cashew has pear-shaped fruits of variable color and morphometric features of variable size [9]. Based on fruit analysis, three morphotypes have been identified (red, pink, yellow) in major producing countries such as Mozambique, Tanzania, India, Brazil, Kenya, Madagascar and the rest of Africa (Côte d'Ivoire, Ghana, Guinea Bissau, Senegal...). The area under cashew in over 32 countries was estimated at around 7.5 million ha in 2002 [10]. A multi-purpose tree, cashew is one of the most important species in the tropics. Its use in reforestation is of interest for its various ecosystem services in the fight against soil erosion [11], against bush fires, as a living hedge, in agroforestry systems [12]. In Senegal, plantations have increased exponentially [9]. Pure / monospecific plantations are more representative in Casamance (Kolda, Sédhiou and Ziguinchor) compared to the Groundnut Basin (Fatick) where association is timid. This association of cashew trees with crops is more beneficial at the juvenile stage [13], because at the adult and senescent stages, the trees would limit the crops' access to light. However, it is important to note that this association makes it possible to obtain an agroforestry system that makes the most of the space left between the trees, maintains the plantation well at lower cost, takes advantage of the interactions between cashew trees and annual crops and obtains additional income from the sale of annual crops [14]. From a pedoclimatic point of view, *A. occidentale* is quite plastic. It is found in a wide variety of tropical and subtropical soils between latitudes 27°N and 28°S [12, 8, 15] and adapts well to arid and semi-arid regions [16-18]. In Senegal, notably in Ziguinchor, Sédhiou, Kolda and Fatick [19], soil and climate conditions are generally favorable for cashew cultivation [20].

Conclusive results have been obtained leading to the dynamic of cashew plantations to the detriment of food crops, industrial crops and forests [9]. The yield of groundnuts grown under the cashew tree crown (width ≤6m) is significantly higher than the control (plots without trees). In view of these multiple uses, *Anacardium occidentale* L. is of definite agroforestry interest. Despite its remarkable presence (0.6% of arable land), little research has been carried out into the influence of organic matter from cashew leaves on soil fertility. A great deal of work has already been done on socio-economics, biophysics, and propagation techniques and so on. However, the study of the species' contribution to soil fertility remains insufficient and patchy. This knowledge seems essential for enhancing soil fertility and proposing sustainable cashew-based agroforestry systems. The agricultural quality of a soil used to be measured in terms of N (Nitogen), P (Phosphorus) and K (Potassium) content, but in-depth research by [21] has shown that in recent decades, the agricultural quality of a soil is measured primarily in terms of color, aggregates and porosity, as well as in terms of the relationship between the root system and the morphology of the soil environment in which they grow.

The present study aims to contribute to understanding the importance of agroforestry species in agricultural production. Specifically, the aim is to characterize the level of physical and chemical fertility of soils under cashew cover.

This study attempts to verify the following hypotheses:

1) Fertilizer content under cashew crown cover varies from region to region;
2) Fertilizer content under the cashew tree crown varies according to soil type;
3) Fertilizer content under the cashew tree crown varies according to soil horizons.

2. Material and Methods

2.1. Presentation of Study Sites and Regions

Casamance lies in southern Senegal, bordering Gambia to the north, Guinea-Bissau and Guinea to the south, and the Tambacounda region bounded by the Koulountou River to the east. It is bordered by the Atlantic Ocean to the west. Casamance covers an area of 28,350 km^2 or 1/7 of Senegal's total surface area. It is made up of three regions Ziguinchor (12°53'00" N, 14°57'00" W), Sédhiou (12°42'29" N, 15°33'25" W) and Kolda (12°33'40" N, 16°17'00" W) with the lower, middle and upper Casamance respectively [22, 23].

Casamance's climate is Sudano-Guinean, with rainfall from June to October, peaking in August and September, and a dry season from November to May. Average annual rainfall ranges from 800 to 1,600 mm. The lowest average monthly temperatures are recorded between December and January and vary between 25 and 30°C, the highest are noted between March and September with values between 30 and 40°C [24].

Ziguinchor has an estimated population of 662,179, Sédhiou 553,005 and Kolda 796,582 [25]. The relief of Kolda and Sédhiou is flat, interspersed with valleys, while Ziguinchor is generally flat [25].

Sédhiou's vegetation consists of open forests characterized by the presence *of Pterocarpus erinaceus, Khaya senegalensis, Daniellia oliveri, Ceiba pentandra, Terminalia macroptera* [26]. Ziguinchor is characterized by the presence of open forests and dense dry forests. Kolda features open forests (*Khaya senegalensis, Pterocarpus erinaceus, Bombax costatum, Cordyla pinnata* and *Daniellia oliveri)* with undergrowth generally composed of Combretaceae [27]. Soils in the regions are diverse and varied. In Ziguinchor and Kolda, the soils are hydromorphic, tropical ferruginous and ferralitic.

Sédhiou, on the other hand, has tropical ferruginous, ferralitic, hydromorphic and halomorphic soils.

2.2. Experimentation Process

Cashew plantations in Casamance cover an area of 190850 ha [9]. Information derived from soil mapping enables us to locate the soil types most suitable for cashew development. The characteristics of the plantation profiles in the study areas correspond to ferralitic, hydromorphic soils with little development [9]. Table 1 highlights the distribution of the 18 survey points according to region and soil type.

Table 1. Distribution of pits by region and soil type.

Zones\ soils	Slightly advanced	Hydromorphic	Ferralitic
Ziguinchor	0	2	4
Sédhiou	1	2	5
Kolda	2	2	0
Total	3	6	9

A total of 18 mini-pits were geolocated at 2/3 of the crown radius, taking into account the cashew tree's root system. After geolocation using a Garmin *etrex* 20 GPS (Global Positioning System), 40cm-deep mini-pits were dug in four directions (east, west, north, south) using a spade at two sampling levels (H1: 0-20cm and H2: 20-40cm). Horizons were measured using a metric tape. Soil samples were taken from each horizon using a knife. The samples were placed in bags, numbered with a marker and weighed with a balance. They were then sent to the soil laboratory of National High School (ENSA) for full analysis. Chemical and physico-chemical parameters such as: pH (pH meter in a solution of soil and distilled water at ½, 5 proportions), exchangeable bases (ammonium acetate extraction), organic matter (organic carbon x 1.724), total carbon (Anne method), total nitrogen (Kjeldhal method) and physical parameters such as: texture (granulometry: Robinson Pipette method). Assimilable phosphorus was determined using the [28] method in [29].

2.3. Data Processing

For the factorial map, pH (Hydrogen potential), C (carbon), N, EC (electrical conductivity), organic matter (OM) and texture were considered. Measured variables were subjected to a normality test, followed by an analysis of variance (ANOVA) using XLSTAT 6.9. To determine the existence of significant differences between soil types, horizons (depths) and regions. For parameters that showed differences, the ANOVA (Analysis of Variance) was followed by Fisher's LSD (Least Significant Difference) test. The ANOVA was completed by a principal component analysis (PCA) to determine the typology of soils under agroforestry parks with *Anacardium occidentale* L. Correlations between parameters were established by Pearson's test to clarify and specify the links that might exist between the different physico-chemical characteristics of the soils. Textural classes were developed using the GEPPA triangle.

3. Results and Discussion

Analysis of variance showed no significant effect of soil types_regions, soil types_horizons and regions_soil types_horizons for any of the variables studied. However, a highly significant regions_horizons interaction effect was observed for sand. A significant region difference was observed for silt, KCL, P, pH. A highly significant horizon effect was detected for most variables, except silt, EC, P/Ass and C/N (carbon/nitrogen) ratio (Table 2).

Table 2. Significance test of studied soil physicochemical parameters between regions, soil types, horizons, regions_soil_types, regions_horizons, soil_types_horizons, regions_soil_types_horizon.

Caracteristics	Regions		Types of soil		Horizons		Regions_ Types of soil		Regions_ Horizons		Types of soil_horizons		Regions_ Types of soil_ horizon	
	F	P	F	P	F	P	F	P	F	P	F	P	F	P
Clay	3,026	0,069	1,002	0,383	8,127	0,009	0,027	0,974	2,522	0,103	1,131	0,341	0,378	0,690
Silt	4,333	0,026	1,575	0,23	0,006	0,939	1,360	0,277	0,300	0,744	0,637	0,539	0,374	0,692
Sand	0,228	0,798	0,013	0,987	8,848	0,007	0,988	0,388	4,099	0,031	0,848	0,442	0,016	0,984
MO	1,235	0,310	0,008	0,992	12,85	0,002	0,164	0,85	0,554	0,583	0,077	0,926	1,148	0,335
EC	1,614	0,222	0,807	0,459	1,333	0,261	0,060	0,942	0,591	0,562	0,306	0,739	0,225	0,800
KCL	3,971	0,034	0,874	0,431	4,701	0,041	0,050	0,951	0,821	0,453	0,520	0,601	0,793	0,465

Caracteristics	Regions		Types of soil		Horizons		Regions_ Types of soil		Regions_ Hori-zons		Types of soil_horizons		Regions_ Types of soil_ horizon	
	F	P	F	P	F	P	F	P	F	P	F	P	F	P
pH	8,195	0,002	2,529	0,103	10,08	0,004	0,205	0,817	0,743	0,487	0,418	0,663	1,044	0,369
P/ASS	6,747	0,005	0,391	0,681	0,195	0,663	0,883	0,428	0,004	0,996	0,707	0,504	0,548	0,586
N/TOTAL	2,757	0,085	0,505	0,611	11,66	0,002	2,047	0,153	0,691	0,512	0,138	0,871	1,041	0,370
C/TOTAL	1,237	0,310	0,008	0,992	12,85	0,002	0,163	0,851	0,551	0,584	0,078	0,926	1,148	0,335
C/N	0,439	0,650	0,526	0,598	0,111	0,742	1,411	0,265	0,094	0,911	0,039	0,962	0,360	0,701

3.1. Variations in the Physical and Chemical Properties of Soil Depending on the Region

Analysis of physical parameters showed that the texture of soils under cashew tree cover is predominantly silty-clay-sandy in all regions and at the 0-20 cm horizon (H1). At the 20-40 cm horizon (H2), the texture is clay-sandy. The texture is silty-clay-sandy. These results do not corroborate those of [23], which show that in southern Senegal, the soil texture of Anacardium plantations is sandy-silty. The differences observed could be relatedto the choice of study sites and soil heterogeneity. The dominance of sand could be due to climatic factors (wind, rainfall) [30]. The highest values for pH, P/ASS, N, MO and Kcl were found in Kolda (Table 3).

The C/N ratios found are low (13). These low C/N values would indicate well-decomposed organic matter. A C/N ratio between 15 and 18 would indicate insufficiently decomposed organic matter.

The results showed that the soils under cashew trees in the study area are poor in clay, which, together with organic matter, forms the basis of the clay-humic complex. Their deficiency contributes significantly to the degradation of soil fertility [31].

***Table 3**. Variations in soil characteristics by region.*

Regions	OM	EC	KCL	pH	P/ ASS	N
Ziguinchor	0,08±0,09^{a}	64,33±2,16^{a}	4,08±0,10^{a}	4,16±0,11^{b}	1,91±0,55^{b}	6,50±1,65^{c}
Kolda	0,37±0,12^{a}	69,00±2,65^{a}	4,50±0,13^{a}	4,87±0,13^{a}	4,75±0,67^{a}	19,50±2,02^{b}
Sédhiou	0,18±0,09^{a}	64,68±1,87^{a}	4,12±0,09^{a}	4,43±0,09^{a}	1,06±0,48^{b}	27,0±1,43^{a}

Regions	C	C/N	Sand	Silt	Clay
Ziguinchor	13,25±0,93^{a}	13,25±0,89^{a}	78,37±3,08^{a}	13,62±2,9^{a}	6,75±3,16^{a}
Kolda	13,37±1,15^{a}	13,37±1,10^{a}	76,06±2,17^{a}	9,06±2,0^{a}	13,43±2,23^{a}
Sédhiou	12,68±0,81^{a}	12,68±0,77^{a}	78,83±2,51^{a}	4,41±2,38^{a}	15,25±2,58^{a}

The results indicate that soils in cashew-growing regions are low in phosphorus (1.9; 4.7). Exchangeable bases, and phosphorus in particular, are on average much higher in humus horizons. This is linked to biotic uplift [32]. Furthermore, research by [33] emphasise that soil is formed when plant and animal life settles in the debris from the decomposition of parent rock. When these living organisms die, their matter is incorporated into the soil, mixing with mineral substances. Organic matter plays an important role in the overall functioning of soil through its physical, biological and chemical components, which have major consequences for soil fertility. However, the importance of phosphorus for flowering and fruiting has been highlighted by [34]. If plants lack phosphorus, flowering is sparse.

3.2. Variations in the Physical and Chemical Properties of Soil Depending on the Horizons

Our results reveal the existence of a fertility gradient depending on the depth of sampling. The MO, total carbon, total nitrogen, EC and P levels are significantly higher at H1 (Horizon 1), while sand, clay and the C/N ratio are higher at H2 (Horizon 2) (Figure 1). Fertiliser content (organic matter, EC, pH, KCl, pH, P/ASS and C) is higher in the upper layer and decreases from the surface to the deeper layers (Table 4). The pH values (4.8 and 4.87) clearly demonstrate the acidic nature of the soils under cashew trees. However, further consideration should be given to the acidifying nature of the species. Acidifying species have leaves with the following characteristics: high C/N ratio (> 50). In Senegal, [35] found that Acacia albida had no significant effect on soil pH. In Zimbabwe, [36] noted that the pH was the same under and outside the tree canopy. The pH values found under *Cordyla* are significantly higher than those found in our research. This acidity could be linked to the mineralisation of litter (organic matter) but also to the artisanal processing of apples into drinks under the trees. The beneficial influence of organic matter on microbiological processes and microbial activity in general has been demonstrated.

Table 4. Variations in soil characteristics by horizons.

Horizons	OM	EC	KCL	pH	P/ASS	N
0-20cm	0,43±0,08ᵃ	67,36±1,76ᵃ	4,30±0,08ᵃ	4,69±0,09ᵃ	2,77±0,45ᵃ	17,37±1,35ᵃ
20-40cm	0,00±0,08ᵇ	64,65±1,76ᵃ	4,16±0,08ᵃ	4,29±0,09ᵇ	2,37±0,45ᵃ	17,95±1,35ᵃ

Horizons	C	C/N	Clay	Sand	Silt
0-20cm	13,33±0,76ᵃ	13,22±0,72ᵃ	7,88±2,10ᵇ	8,70±1,94ᵃ	8,20±2,05ᵃ
20-40cm	12,87±0,76ᵃ	12,83±0,72ᵃ	15,73±2,10ᵃ	9,36±1,94ᵃ	7,47±2,053ᵇ

3.3. Under and Outside Canopy

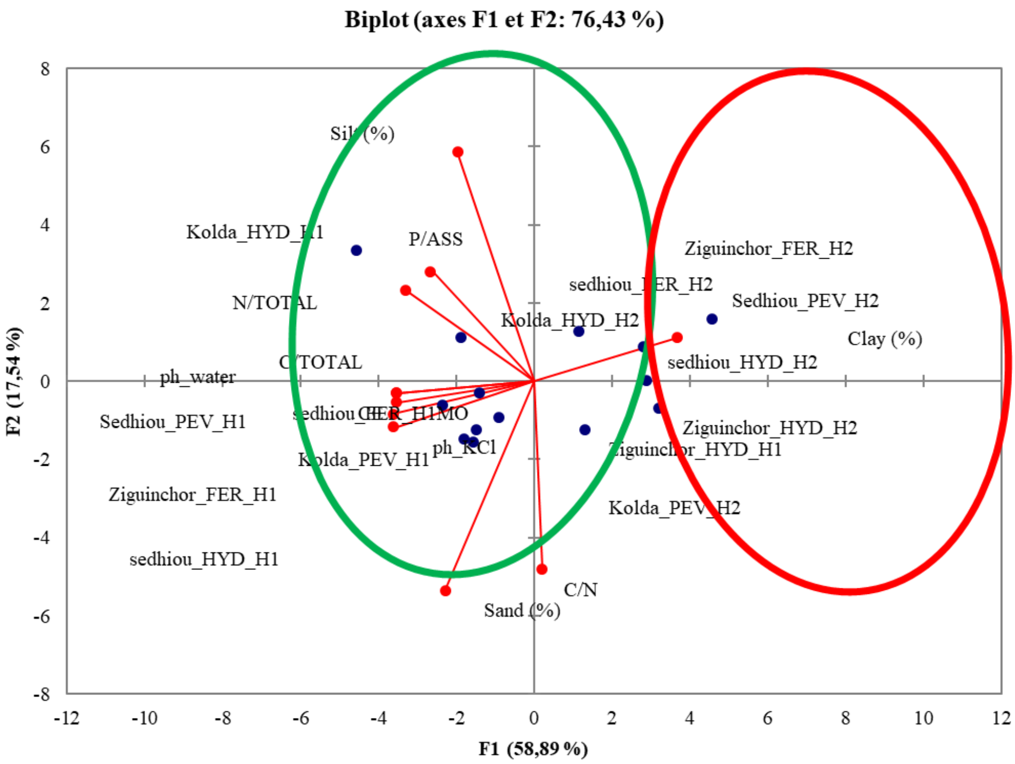

Figure 1. Multivariate analysis of soil characteristics by horizon.

The C and N values found are higher than those found by [37] at R/2; 1R to 2R of *Cordyla pinnata*. A higher organic carbon content generally leads to greater microbial activity, better soil structure through the formation of more stable aggregates, and better water and mineral retention capacity. As for organic carbon C, its higher values under the canopy compared to the controls could be due to the action of soil microorganisms on the organic matter found under *A. senegal* [38]. Indeed, the higher concentration of microorganisms found under the canopy at depths of 0-25 cm [39] would explain these results. Quantitative and qualitative measurements of certain soil fertility parameters (pH, C, N, CEC, P, and S) have shown that the soil under the tree canopy is rich in minerals [38].

Principal Component Analysis (PCA) was performed on the basis of the parameters evaluated (Figure 1). Analysis of Figure 1 shows that the F1 and F2 axes absorb 76.43% of the variability studied, providing a good graphical representation of the information contained in the matrix. The F1 axis explains the distribution of information better (58.89%). PCA enabled us to distinguish two groups based on horizons. The first group comprises the H1 horizon, characterized by its high content of silt, N/Total, C/Total, P/Ass, pH water, pH Kcl, OM and EC. The second group consists solely of the H2 horizon, distinguished by its high sand, clay and C/N content.

3.4. Correlation Matrix

Table 5 and Figure 2 highlight the links between the various physical and chemical elements of the soil. It appears that variations in pH (water, KCl) are strongly and positively correlated with those of EC, C and OM, but negatively correlated with clay. The relationship is moderate with sand, poor with silt and almost non-existent with the C/N ratio. Variations in EC are moderately and positively correlated with those in sand, P/ASS, C, N and OM, but strongly and negatively correlated with clay. The relationship is weak with silt and non-existent with the C/N ratio. The relationship between P/ASS and the other elements is moderate to weak. Variations in C are strong with OM and N, moderate with clay and weak with sand, silt and C/N. The relationship between N and C and OM is very strong. It is moderate with clays and silts but weak with sands and C/N. OM is moderately negatively correlated with clay and positively and weakly correlated with C/N, silts and sand. The links between C/N and sand and clay are almost non-existent. Clay has a weak, negative link with silt and sand. The link between sand and silt is weak and negative. However, these elements could be influenced by the cashew tree canopy. The values of physical, organic and chemical characteristics are always higher under HI but are influenced unevenly. Organic matter, which is an important source of phosphorus in organic form, contributes to the reversible storage of nutrients through mineralisation/mobilisation by microorganisms [40]. It would be important to assess the contribution of the cashew tree.

Table 5. *Pearson matrix correlation.*

Variables	pH_water	pH_KCl	CE	P/ASS	C	N	MO	C/N	Clay	Silt	Sand
pH_water	1										
pH__KCl	0,933	1									
CE	0,796	0,859	1								
P/ASS	0,567	0,535	0,586	1							
C	0,725	0,702	0,596	0,467	1						
N	0,635	0,589	0,577	0,511	0,905	1					
MO	0,725	0,702	0,596	0,467	1	0,905	1				
C/N	-0,01	0,089	-0,099	-0,048	0,085	-0,309	0,085	1			
Clay	-0,822	-0,822	-0,906	-0,541	-0,699	-0,634	-0,699	0,071	1		
Silt	0,357	0,36	0,411	0,665	0,343	0,567	0,343	-0,412	-0,376	1	
Sand	0,575	0,573	0,622	0,069	0,461	0,233	0,461	0,225	-0,743	-0,342	1

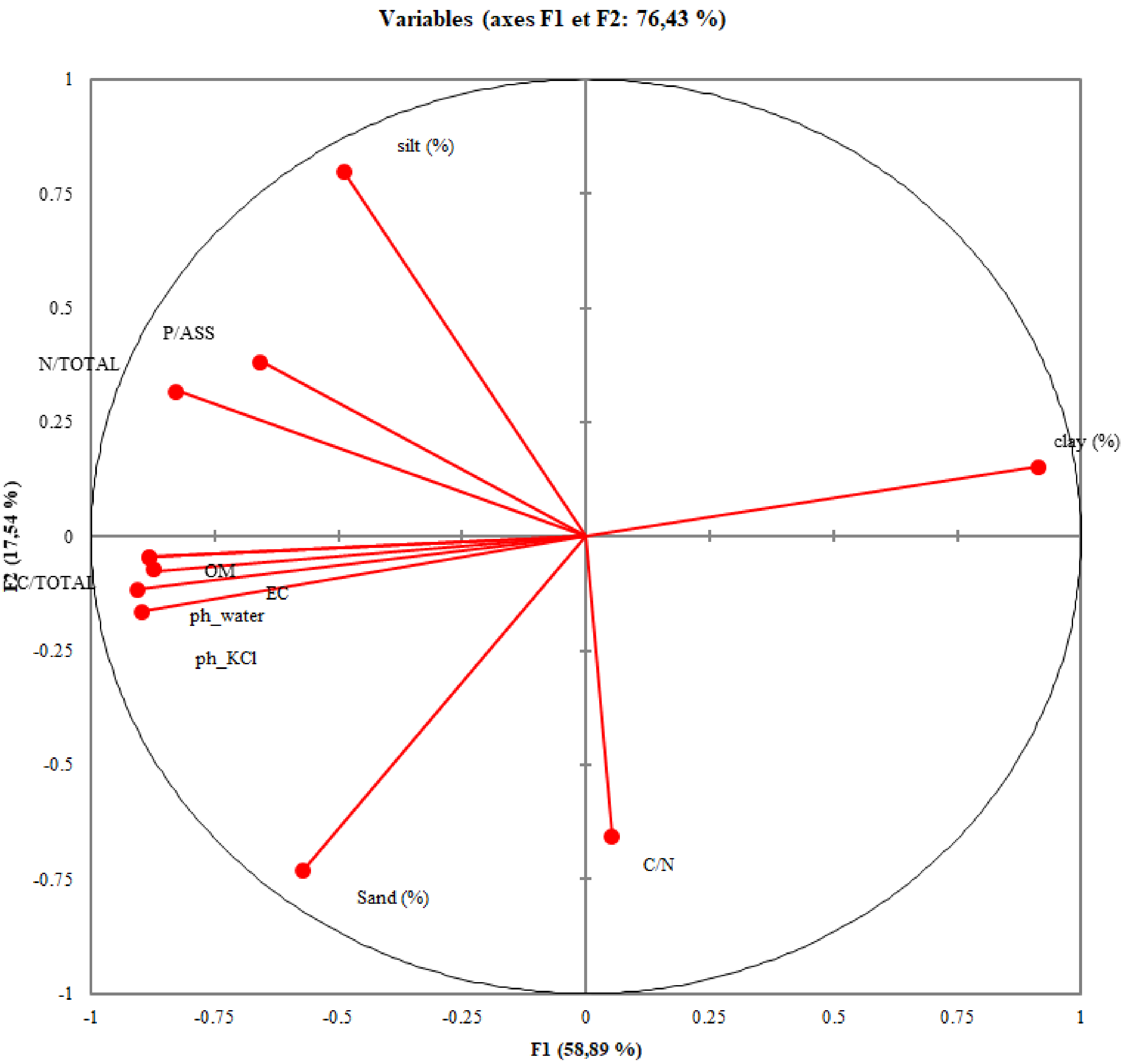

Figure 2. Correlation circle for soil physico-chemical parameters.

4. Conclusion

The study on the agro-pedological characterization of cashew plantations in Casamance revealed variations in nutrient content. Soil constituents are essentially dependent on region and sampling depth, as hypothesized. Significant differences were noted between regions for silt, pH-Kcl, pH-water, P/Ass and horizons for clay, sand, silt, OM, pH-Kcl, pH-water, N, C. PCA revealed that H1 stands out for its high content of silt, N, C, P/Ass, pH-water, pH-Kcl, OM, EC and H2 for its high sand, clay and C/N values. The physico-chemical characteristics of H1 are strongly and positively correlated, but strongly and negatively correlated with those of H2. Overall, pH values (regions and horizons) are low in soils covered by the species. Depending on sampling depth, pH values are lower in the H2 horizon (20-40cm) than in the H1 horizon (0-20cm). These results indicate that the soil under cashew trees, which is richer in OM at the surface, is highly acidic. This acidity is strongly linked to organic matter (r= 0.725). The high values of organic carbon C under cashew are linked to the action of soil microorganisms on organic matter (litter). The improvement in soil constituents from depth to surface could be explained by the presence of OM. The place of *Anacardium occidentale* L. in the agricultural landscape is fully justified. These results confirm hypotheses 1 and 3 and invalidate hypothesis 2. Soils under cashew would be a valuable model for the study of OM evolution. However, the study must be continued to quantify precisely the species' real contribution to soil fertility, and to see whether the physical and chemical characteristics of the soil are relatively unaffected by the presence of *Anacardium occidentale* L.

Abbreviations

ANOVA	Analysis of Variance
C	Carbon
C/N	(Carbon / Nitrogen) Ratio
EC	Electrical Conductivity
GPS	Global Positioning System
H1	Horizon 1
H2	Horizon 2
K	Potassium
LSD	Least Significant Difference
N	Nitogen
OM	Organic Matter
P	Phosphorus
PCA)	Principal Component Analysis
pH	Hydrogen Potential

Author Contributions

Cheikh Oumar Samb: Conceptualization, Formal Analysis, Funding acquisition, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing

Ndeye Marietou Sidibe: Data curation, Formal Analysis, Software, Visualization, Writing – original draft

Amsatou Thiam: Formal Analysis, Methodology

Alioune Badara Diop: Data curation, Methodology, Software

Elhadji Faye: Supervision, Validation

Conflicts of Interest

The authors declare no conflicts of interest.

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