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Changes in Soil Physicochemical Properties under Selected Climate-Smart Agricultural Practices in Central African Republic

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Abstract

Soil nutrient depletion as a result of continuous cultivation with insufficient external nutrient replenishment is a major challenge in sub-Saharan Africa (SSA). A trial using the organic and mineral fertilizer was established in the cassava cropping system of the Pissa and Damara areas to address the declining soil fertility. The study aimed to evaluate the effect of cow manure and mineral fertilizer in combination or sole application on soil physico-chemical properties and macronutrients. The experimental trial adopted a randomized complete block design (RCBD) replicated four times. The treatments comprised of; T1 (Control), T2 (Peasant practice), T3 (sole NPK), and T4 (Cow manure + NPK). The data on soil physicochemical analysis was subjected to a one-way analysis of variance in SAS 9.4 and the mean was separated by Tukey's HSD test at $p < 0.005$. The soil pH values ranged from 4.20 to 4.91; and 4.53 to 5.28 in Pissa and Damara respectively. According to the treatments, a low pH value is observed in T3 (4.13) in the Pissa. Combined use of cow manure and the mineral fertilizer resulted in higher Mg K and N in the Pissa region and higher soil pH in Damara. The use of sole NPK (T3) gave a higher soil carbon and CN ratio. In the Pissa region the CEC, Cu, Fe, and Zn were higher in the treatments with mineral fertilizer compared to the control. Conclusively, the use of mineral fertilizer and cow manure can be used with optimum rates to improve soil physico-chemical properties on a sustainable basis.

Keywords

Cow Manure, Physicochemical, Nutrients, Agroecology Nutrient Management

1. Introduction

Sustainable soil nutrient management is an important factor in rainfed agriculture for enhanced food production in sub–Saharan Africa [1]. Deteriorating soil fertility has proven as the main restraint towards attaining good yields in tropical agriculture [2]. Managing nutrient depletion and imbalance is one of the significant challenges that resource-poor farmers face daily to move from an empirical and subsistence-based agriculture to an economical, more rational, and income-generating agriculture. Soil nutrient imbalance in some areas contributes significantly to the yield gap [3]. Nutrient depletion, stagnating agricultural productivity, and rising food insecurity continue to escalate due to climate change [4]. Therefore, there is a dire need to improve soil nutrient imbalances for increased agricultural productivity and resilience if we want to get out of the poverty that the rural population faces constantly [5].

Soils in Sub-Saharan African countries have a low level of inherent fertility [6] associated with specific natural constraints for each agroecological zone. Overall, nutrient losses due to intensification of land use through reduced fallow periods [7] increased from 24 kg/year (10 kg N, 4 kg P, 10 kg K) in 1990 to 48 kg/year (20 kg N, 4 kg P, and 20 kg K) in 2000 [8]. These deficiencies are critical factors in production. Although cassava (Manihot esculenta Crants) is known to grow and produce in poor soils, its cultivation requires minimal soil nutrient richness for acceptable yield.

According to [9], the Central African Republic produces an average of 12,912 tons of cassava (tubers) annually. Each Central African household consumes approximately 75 kg/year of products derived from cassava tuberous roots [10]. Total cassava consumption is 800 g/person/day [11]. Cassava and its products occupy the first place, with 43% of the market share of roots and tubers, 26% for processed products, and 17% for fresh roots [12]. For some decades, cassava tuber production has declined, and prices of cassava derivatives have increased in urban markets [10]. Poor soils and poor dissemination of improved high-yielding varieties resistant to cassava diseases and pests are among the causes of this decline in cassava production. Farmers need support to diagnose, improve soil mineral deficiencies, and increase tuberous root production to cope with climatic risks that pose a significant threat to the environment and long-term agricultural development. Previous studies on cassava have shown that mineral elements (nitrogen, phosphorus, potassium, calcium, and magnesium) can be good indicators of soil quality [13]. It is therefore important to assess the soil nutrient availability in both fallow and cultivated land for the cassava cropping system. Additionally, there is a need to practice crop rotation and progress with a succession of cassava crops on the same plot. This study provides an understanding of the level of restoration of fallowed soils under producers' expectations. The objective of this study is to evaluate changes in soil nutrient availability under fallow conditions and after a cassava cropping season in the study areas.

2. Materials and Methods

2.1. Study Site

Two experimental trials were set up on-farm during the 2018/2019 season at Pissa (4˚20'712 N and 18˚11'022 E, 378 m altitude) and Damara (4˚590622 N and 18˚400442 E, 316 m altitude). The aim is to determine fertilization options for cassava cultivation, conduct physicochemical analyses, and compare them with reference standards for cassava cultivation. In the Pissa area, we established the trial in the plot of the agro-pastoral group of Pissa 2, located 3 km from the city of Pissa on the way to Mbaïki; It has been uncultivated for more than five years. The pissa is situated in the forest zone with an average temperature of 24˚C and a total mean annual rainfall of 1300 mm, with rains mostly occurring from March through November. Another trial was established in Ndara village, located 5 km from Damara city in the savanna zone, and is characterized by a mean temperature of 25˚C with an average rainfall of 1600 mm. Rains mostly occur between May and October. The soil was classified as sandy clay for both study sites.

2.2. Soil Sampling and Analysis

Soil sampling was conducted at the trial sites before and after the experimental setup to know the soil fertility status of the farmland after a cassava cropping season. The Pissa site is a five-year-old fallow dominated by *Imperata cylindrica* (L.), *Chromolaena odorata* (L.), and *Pueraria javanica* (Benth.). The vegetation at the Damara site is dominated by *Chromolaena odorata* (L.). It is an eight-year-old fallow. Samples were taken with an auger before planting cassava at depths of 0 - 30 cm since 70% - 80% of the nutrient supply of annual crops comes from the surface layer [14]. Six sampling locations constituted a composite sample to analyze the different soil elements. At cassava harvest, the soil was sampled from different treatments. Approximately 2 kg of soil was taken and air-dried under shade. Finally, 1 kg of the dry soil was used for analysis.

The particle size analysis of coherent soil was done in two phases: the first one involves the particles of the average diameter of grains higher than 80 μm (granulometry by sieving). The second concerns particles with an average diameter of less than 80 μm (granulometry by sedimentometry). The granulometric analysis consisted of evaluating the particles' size and measuring the relative importance of each soil fraction of well-defined dimensions: sand, silt, and clay [15].

The chemical analysis involved; the soil pH-H_2O (1:2.5 solution) determined using a pH meter in a soil water solution [16] the measurements of the quantitative and qualitative characteristics of the absorbing complex, which are the cationic exchange capacity (CEC) which was extracted using ammonium acetate method [17]. The exchangeable cations (Ca, K, Mg and Na), available micronutrients (Cu, Zn, Mn and Fe) and assimilable phosphorus followed the Mehlich-3 method [18]. The content of the extracts was determined by flame photometry and atomic absorption spectrophotometry (AAS). The total organic carbon followed the Walkley Black chromic acid wet oxidation method. The soil samples were analysed at the Kenya Agricultural & Livestock Research Organization (KALR0).

2.3. Experimental Design and Analysis

The trial was set up in each location at the start of the rainy season in June 2018. The trial setup was conducted in a participatory and cohesive approach with the members of the agro-pastoral groups of Damara and Pissa to allow them to appropriate the endorsed modern cultural techniques. The groups participated actively in the various farming works, from the choice of land to the harvest and the various post-harvest processing works. We designed and established the experimental plots in Pissa and Damara in 2018. The experimental design adopted a randomized complete block design with four treatments replicated four times. The plot dimension was 7 m by 7 m with a 1 m wide alley separating plots within a block and a 2 m wide alley between blocks. The block size was 49 × 4 m, and the whole experiment covered an area of 196 × 4 m per study site. The cassava "Gabon" variety was the test crop as the main annual crop in the two areas. The treatments included; T1: Control (no input), T2: Peasant practice, T3: Sole NPK, and T4: Cow manure + NPK (**Table 1**). The soil physical and chemical analyses were conducted at the end of the trial for both study sites.

2.4. Data Analysis

The soil physicochemical data was subjected to analysis of variance (ANOVA) in SAS version 9.4. Tukey-Kramer Honest Significant Difference Test $P \leq 0.05$. was used to separate the significance means at $p = 0.05$.

3. Results and Discussion

Table 2 shows the initial soil physico-chemical properties before the establishment

Table 1. Combined experimental treatments and fertilization rates used in randomized complete block design in Pissa and Damara areas.

Treatment	Treatment abbreviation	Mineral Fertilizer rate (Kg/Ha)			Manure rate (Kg/ha)
		(Co $(NH_2)_2$	$(H_2PO_4)2$	K_2SO_4	Cow manure
Peasant practices	T1	0	0	0	0
Recommendation of the Ministry of Agriculture	T2	0	0	0	0
Recommendation University	T3	80	40	120	0
IAEA Recommendation	T4	90	30	180	3000

Table 2. Initial soil physicochemical characteristics in Pissa and Damara areas.

Parameter	Pissa	Damara	level requirement
pH (water)	5.5	5.8	5.5 - 7
CEC (cmol(+)/Kg)	3.27	3.24	10 < CEC < 20
Organic matter (%)	2.83	2.73	3.6 - 6.5
Organic carbon (%)	0.8	0.99	1.26 - 2.5
Total N (%)	0.06	0.03	1.2 - 2.2
C/N	13.33	33	13.8 - 29
Available P (ppm)	1.54	0	0.20 - 0.23
Exchangeable bases (cmol(+)/Kg)			
Ca	1.64	6.48	8.00
Mg	0.56	1.85	1.5 - 3
K	0.15	0.13	0.15 - 0.25
Na	0.05	0.06	0.3 - 0.7
Total exchangeable base	1.4	8.52	<5
Micronutrients (mg/kg)			
Cu	1.45	1.45	<5
Fe	34	15	<10
Zn	0.5	0.45	<5
Particle size (%)			
Sand	76	62	
Silt	4	16	
Clay	20	22	
Textural class	Sandy clay	Sandy clay	

of the trial. Based on the fertility of fallow soils the silt/clay ratio is 0.3 in the Pissa and 0.8 in the Damara, indicating that these soils are relatively young. The organic matter content of the soils ranged from 2.83% to 2.73% in Pissa and Damara respectively with low total nitrogen content (0.020‰ and 0.30‰). The organic matter was well decomposed in Damara (very high C/N = 33) than in the Pissa site (low C/N = 13.33). The soils are poor in assimilable phosphorus with low cation exchange capacity, with sums of exchangeable basic cations low in the Pissa (1.4 (cmol(+)/Kg) and greater in the Damara (8.52 (cmol(+)/Kg). These findings underscore the widening yield gaps in cassava in the regions. Therefore, there is a dire need for nutrient replenishment. The results of the study revealed a potentially low level of soil fertility. The soils have a sandy-clay texture in the both Pissa and Damara areas (**Table 2**). However, the texture corresponds to the role attributed to each granulometric fraction in expressing various physical characteristics such as ease of heating, permeability, and resistance to farming tools [19]. Studies by [20] and [21] have shown that silty textured soils are excellent for cassava cultivation. This indicates that the soils in the trial sites in this study are not suitable for cassava cultivation, therefore there is a dire need for external nutrient replenishment to improve soil structure and nutrient status. According to [22] and [23], sandy clay soil contributes to the decline in its artistic potential. It can be assumed that cassava growers invest in farming without basic information on the appropriate nature of soil types for cassava requirements. However, they have an empirical approach that guides them in choosing the appropriate soil for their production.

The proportions of sand dominate that of clay and silt in all the study sites, with more than 60% of sand (**Table 2**). Clay rates are less than 25%, which is not likely to promote water retention and nutrients since clay is the element that conditions the fixation of mineral elements on the adsorbent complex. According to [24], the high proportion of sand is linked to the effects of ploughing, which causes soil particle leaching. However, the soils used in this study are fallow land that should generally be restored.

The pH levels between 5.5 and 5.8 are satisfactory for good biological activity and nutritional exchange in the soils. The initial carbon (0.80% in the Pissa and 0.99% in Damara) and nitrogen (0.06% in Pissa and 0.03% in Damara) contents of the soils of the experimental sites are insufficient compared to the low-level cassava requirements proposed by [25] for ferralitic soils; thus, leading to low biomass production. Additionally, the low level of fine particles (clay and silt) associated with the pH justifies the unsatisfactory levels of nitrogen recorded. [26] reported that there is a good correlation between soil nitrogen and clay content based on the regression equation: N (%) = 0.04 clay (%) + 0.215; r = 0.76 (4).

The variations in exchangeable cation content between the Damara and Pissa soils can be explained by soil structure. Organic matter levels ranging from 1.20 to 1.52% are low and below the normal range of 2% to 3% [27] [28] and [29] state that as natural vegetation gives way to agricultural surfaces, there is a decrease in biomass production and soil organic matter due to anthropogenic actions. This confirms that the study area has been heavily exploited and that these fallow soils require soil reconstitution. These low organic matter contents would predispose the soils to acidification and rapid degradation. Clay and organic matter being the basis of the clay-humus complex, their deficiency would largely contribute to the degradation of the fertility of these soils [30].

The C/N ratio is a determining factor in the decomposition of litter. Indeed, litter that decomposes too slowly can block the cycle of mineral elements. The C/N values ranged from 13 and 33 in Pissa and Damara respectively and reflect an excellent biological activity for fallow soils following the low-level requirements for cassava. The C/N ratio in the Damara, which is higher than in the Pissa zone, partly explains the level and speed of organic matter decomposition in the Damara site compared to the Pissa, which has dense vegetation characterized by numerous leaf falls. According to [31] and [32], the mineralization process is more or less expected when $8 \leq C/N \leq 15$. Given these values, although expected, the decomposition of organic matter could be faster in the Pissa than in the Damara. The risk of leaching of mineral elements could be more significant in the Pissa than in the Damara. The slightly slower decomposition of organic matter in Damara makes nutrients available in a gradual and staggered manner, predisposing the mineral elements in the soil for plant development. In another study, [33] reported that although organic matter decomposition is normal, the N content of tropical soils is generally low. For this reason, supplementary supply is always essential for good growth.

Phosphorus (1.54 ppm in the Pissa and 0 ppm in the Damara) and potassium (0.15 cmol/kg in the Pissa and 0.13 cmol/kg in the Damara) levels are insufficient for good crop nutrition. The CEC is also low in both cases about the required standard proposed by [25]. Based on the results, the nutrient levels of these soils are exhausted. Even though cassava is considered an undemanding plant, additional organo-mineral fertilizer is essential to improve production.

3.1. Soil pH

The soil pH ranged from 4.2 to 4.9 and 4.53 to 5.28 in Pissa and Damara respectively (**Table 3**). Treatment with organic manure and mineral fertilizer (T4) had the highest soil pH value (5.28). Soil pH is a measure of the hydrogen concentration of the soil solution. The pH is essential for nutrient availability and toxicity problems. The pH of the soil in the trials before cultivation was weakly acidic (5.5 to 5.8). The values observed are favorable for better biological activity. Most of the mineral elements present are available for the plants and thus favorable to their excellent development, the mineral elements are easily dissolved. The pH was more acidic in the Pissa than in the Damara site. The low pH values indicate uprises in soil acidity. They are attributable to the presence of acidic anions NO_3^- and SO_4^{2-} primarily due to the use of fertilization input, the release of Al^{3+} and H^+, and the decomposition of the organic amendment. Weakly acidic soils (5.5 in the Pissa and 5.8 in the Damara) became slightly more acidic after the experimental trial. These anions mobilized Aluminum, which replaced calcium

Table 3. Residual effect of treatments on soil pH, calcium, magnesium, and potassium in Pissa and Damara areas.

	pH water		Ca		Mg		K	
	Exchangeable (Cmol/kg)							
Treatment	**Pissa**	**Damara**	**Pissa**	**Damara**	**Pissa**	**Damara**	**Pissa**	**Damara**
T1	4.91^{a}	4.93^{ab}	2.6^{a}	3.40^{a}	0.53^{b}	1.28^{a}	0.02^{b}	0.048^{b}
T2	4.50^{ab}	4.92^{ab}	1.65^{b}	2.84^{ab}	0.42^{c}	1.20^{ab}	0.02^{b}	0.062^{ab}
T3	4.20^{b}	4.53^{b}	1.62^{b}	2.82^{ab}	0.31^{d}	1.19^{ab}	0.03^{b}	0.11^{a}
T4	4.71^{ab}	5.28^{a}	1.45^{b}	2.43^{b}	0.69^{a}	1.05^{b}	0.07^{a}	0.011^{a}
	0.04	0.04	0.002	0.002	0.0001	0.04	0.01	0.0003

T1 = Control; T2 = Peasant practice; T3 = Sole NPK and T4 = Cow manure + NPK. Means with same letter in each column, are not statistically different at $P < 0.05$.

and other non-acidic cations in the complex, facilitating their leaching by the intense rainfall that fell in the area during the study period [27] [34]. Therefore, the absorbing complex could be saturated in Al^{3+} ions. The decreases in K, Ca, and Mg under different treatments would be due to the utilization of the nutrients by cassava plants and leaching, particularly for Ca and Mg. Concerning phosphorus, the results showed a high content that could come from plant debris residues. [35] confirmed that cultivation increases the phosphorus content of the soil. However, a decrease of more than one-third in phosphorus content was observed under natural fallow. The findings of this study corroborate the reports of other studies [36]. Which reported increases in soil pH with the use of organic and inorganic sources. The pH increases under manure treatment could be attributed to the reduction of exchangeable aluminum in these acidic soil's pH (5.5 - 5.8) [37].

3.2. Available Primary Macronutrients (N, P, K)

Nitrogen is a fundamental compound of living matter. It is necessary to elaborate on organic plant compounds: amino acid, nucleic acid, protein, and chlorophyll. It enters the composition of enzymes that direct the metabolism of plants. The total nitrogen in fallow soils was very low (0.03% - 0.06%). However, it is high in the Pissa compared to the Damara areas. After harvesting, there is an increase in nitrogen under treatments, which is still below the low-level requirement for cassava (**Table 4**). The highest nitrogen content (0.15%) was in the Pissa under T1 treatment which did not receive any fertilization input.

The soil organic carbon was significantly higher in the treatment with animal manure and mineral fertilizer (T3). The carbon content ranged from 0.68 to 1.26; and 0.91% to 1.33% in Pissa and Damara respectively (**Table 4**). These results corroborate with the findings of [36]. Who observed upsurges in organic carbon with the use of animals? Manure. There was a significant treatment effect on total carbon ($p = 0.0001$), C/N ratio, and Na ($p = 0.0001$) in both the Damara and Pissa areas. The carbon content was in the increasing order of T1 (0.91), T4 (0.93), T2 (1.08) and T3 (1.33).

Table 4. Residual effect of treatments on total nitrogen, carbon and Sodium (N, C and Na) in Pissa and Damara areas.

	Total N		C		Na	
	%				(Cmol/kg)	
Treatment	**Pissa**	**Damara**	**Pissa**	**Damara**	**Pissa**	**Damara**
T1	0.15^a	0.06^a	1.26^a	0.91^c	0.01^a	3.00^a
T2	0.07^a	0.007^a	0.94^b	1.08^b	0.0025^b	0.01^c
T3	0.06^a	0.077^a	0.93^b	1.33^a	0.01^a	0.03^c
T4	0.05^a	0.072^a	0.68^c	0.93^c	0.01^a	0.84^b
	0.06	0.79	0.0001	0.0001	0.0021	0.0001

T1 = Control; T2 = Peasant practice; T3 = Sole NPK and T4 = Cow manure + NPK. Means with same letter in each column, are not statistically different at $P < 0.05$.

Sodium (Na) plays a role in osmotic regulation, helping to control water flow into and out of the plant. In some plants growing in potassium-poor soils, sodium can perform some of the functions of potassium. **Table 2** shows that the fallow soil is low in sodium, except for T1 (3.00), which is above the established norms.

After harvest, the soils showed an increase in phosphorus. The increase in phosphorus is attributable to the use of organic and inorganic inputs. The highest phosphorus level was observed in T3 (23.05 ppm). Low Potassium (K) levels were observed in the treatments compared to the fallow soils. Concerning phosphorus, the results showed a high content that could come from plant debris residues. [35] confirmed that cultivation increases the phosphorus content of the soil. However, a decrease of more than one-third in phosphorus content was observed under natural fallow.

Copper plays a role in chlorophyll production, acts as a catalyst for enzymes, and assists in iron utilization by the plant. Copper levels are similar at both sites for the fallow soils and high values were recorded at the end of the experimental trial in the Damara area compared to the Pissa site (**Table 5**). Overall, the recorded levels meet the reference standards of less than 5. Iron has several functions in plants. It acts as a catalyst in the formation of chlorophyll, is required for plant respiration, and plays a role in forming specific proteins. Iron levels at the fallow and harvest sites exceeded the reference standard (**Table 5**). However, they are higher in the Pissa than in the Damara. Zinc plays a vital role in the plant's biochemical processes, including chlorophyll production, and contributes to the formation of growth hormones. The zinc levels in the fallow soils, as well as after the experimental period, were within the normal range (**Table 5**).

There was a significant treatment effect on organic matter content, CN ratio, exchangeable bases, and the available phosphorus (**Figure 1**). The exchangeable bases ranged from 1.0 (T3) to 3.18 (T1) in Pissa and from 3.07 (T2) to 7.7 (T1) in the Damara areas. The highest organic matter content was observed in TI treatment in both the study areas. The C/N ratio significantly varied with treatments

Table 5. Residual effect of treatments on cation exchange capacity, copper iron, and zinc (CEC, Cu, Fe, and Zn) in Pissa and Damara areas.

	CEC		Cu		Fe		Zn	
	Cmol(+)/kg		mg/kg					
Treatment	**Pissa**	**Damara**	**Pissa**	**Damara**	**Pissa**	**Damara**	**Pissa**	**Damara**
T1	4.24^{b}	5.41^{a}	0.57^{b}	1.36^{b}	19.20^{b}	10.84^{b}	0.36^{b}	1.54^{b}
T2	4.66^{ab}	5.15^{a}	0.69^{ab}	1.01^{c}	35.5^{a}	11.20^{b}	0.66^{a}	0.88^{b}
T3	4.45^{ab}	5.23^{a}	0.75^{a}	1.62^{a}	40.5^{a}	17.28^{a}	0.50^{ab}	1.20^{b}
T4	5.67^{a}	4.44^{a}	0.57^{b}	1.42^{b}	35.51^{a}	15.35^{a}	0.43^{b}	3.55^{a}
	0.03	0.09	0.005	0.0001	0.0001	0.0001	0.003	0.0004

T1 = Control; T2 = Peasant practice; T3 = Sole NPK and T4 = Cow manure + NPK. Means with same letter in each column, are not statistically different at $P < 0.05$.

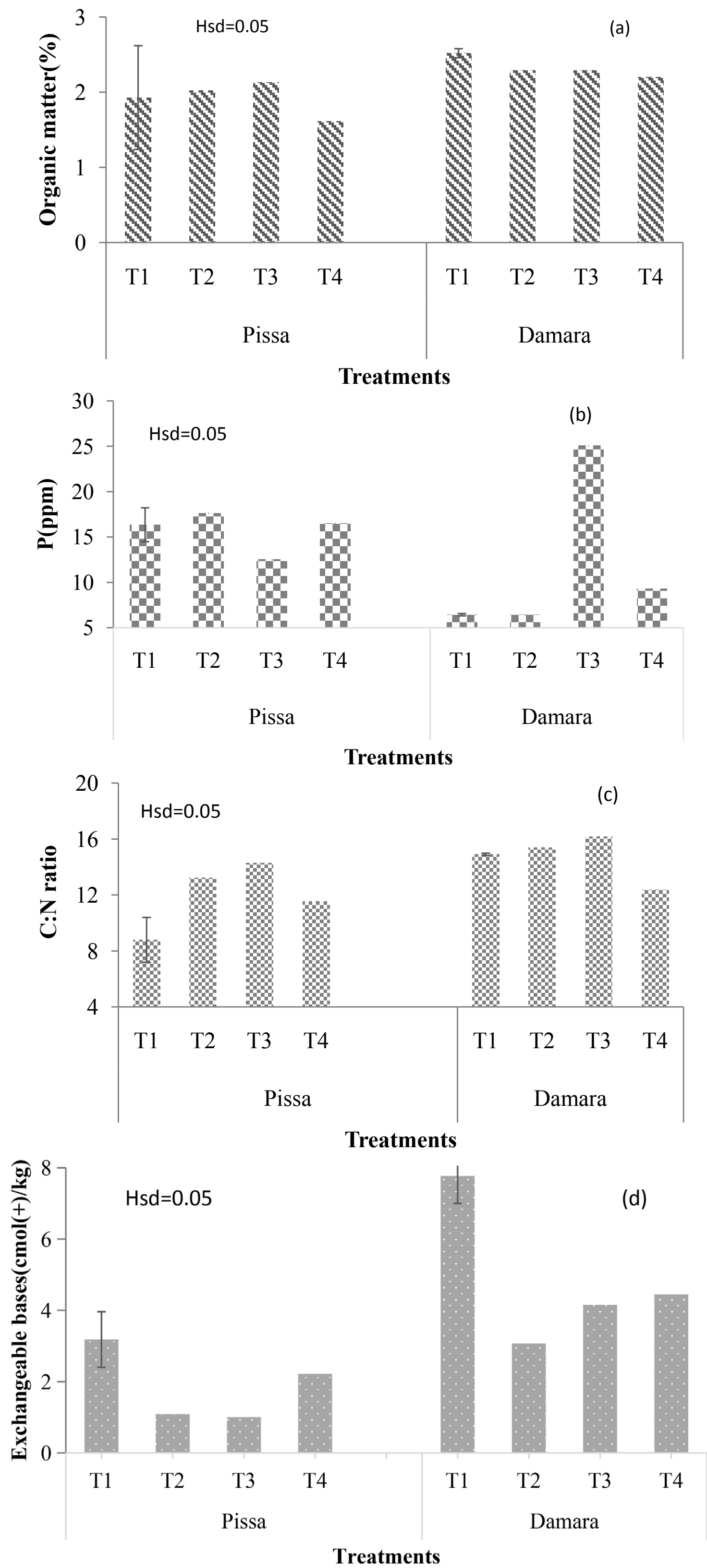

Figure 1. Treatment effect in Pissa and Damara areas on (a) organic matter content; (b) phosphorus (P); (c) C: N ratio in Pissa and Damara; (d) Exchangeable bases T1 = Control; T2 = Peasant practice; T3 = Sole NPK and T4 = Cow manure + NPK.

with T3 registering the highest C/N ratio 14.3 and 16.17 in Pissa and Damara respectively. Organic matter plays a crucial role in soil fertility. It is essential for nutrient retention, moisture, and structure and serves as a shelter for soil microorganisms. Previous studies [38] [39] have shown that the clay and organic matter rate explains the fixation of exchangeable cations on the clay-humus complex. These results confirm those obtained by [40]. And [41]. Indeed, these different authors have shown that CEC is intimately linked to the soil's organic matter rate and the clay rate. According to [42], the higher the organic matter content of the soil, the more nutrients the soil retains to make it available to plants for growth. According to [43], organic farmers should strive for at least 4% organic matter and consider stable or increasing values indicative of good soil management.

After harvesting, C/N ratios in the Damara were high compared to those in the Pissa site, reflecting a more rapid decomposition and a greater risk of leaching of mineral elements in the Pissa than in the Damara. The ratio (C/N) reflects the soil's condition and the overall biological activity level of the humus. The mineral level is satisfactory for high C/N values (13.8 to 29). Soils in fallow were high in carbon levels, hence the high C/N ratios (33) in the Damara zone. After the experimental trial, biological activity was low in the Pissa for treatments T1 (8.4) and T4 (11.55). The highest C/N ratio was observed under T3 in the Damara area (**Figure 1**).

The levels of exchangeable soil bases (Ca^{2+}, Mg^{2+}, and K^{+}) improved in the Pissa with T1 (3.18 mi/100g) and T4 (2.2 mi/100g). This can be attributed to nutrient content in the cow manure. Animal manure supplies vital plant nutrients either directly or indirectly by lessening aluminum toxicity or by provision of organic acids which complex with aluminum, thus enhancing nutrient availability [42]. The work of [44] [45] and [46] respectively confirmed that the decomposition of organic residues improves exchangeable base content. A single insufficient element causes the yield to drop, even if all the others are satisfactory [47]. Fertilization must therefore be balanced by correcting all soil deficiencies.

4. Discussion

4.1. Fertility Status of the Fallow Soils

Analyses of the fallow soil samples selected for this study revealed a potential decline in fertility. The soils in the study area have a sandy-clay texture in the forest and a sandy-clay texture in the savanna. However, the texture corresponds to the role attributed to each granulometric fraction in expressing various physical characteristics such as ease of heating, permeability, and resistance to farming tools [19]. Studies by [20] and [21] have shown that silty textured soils are excellent for cassava cultivation. This indicates that the soils of the trial sites in the study area are not suitable for cassava cultivation, which requires additional organic inputs to improve soil structure. According to [22] and [23], sandy clay soil contributes to the decline in its artistic potential. It can be assumed that cassava growers invest in cultivation without basic information on the appropriate nature of soil types for cassava cultivation. However, they have an empirical approach that guides them in choosing the appropriate soil for their production.

The proportions of sand largely dominate that of clay and silt in all localities, with more than 60% of sand. Clay rates are less than 25%, which is not likely to promote water retention and nutrients since clay is the element that conditions the fixation of mineral elements on the adsorbent complex. According to [24], the high proportion of sand is linked to the effects of plowing, which causes the leaching of fine particles. However, the soils used in this study are fallow land that should generally be reconstituted.

The pH levels between 5.5 and 5.8 are satisfactory for good biological activity and nutritional exchange in the soils. The initial carbon (0.80% in forest and 0.99% in savanna) and nitrogen (0.06% in forest and 0.03% in savanna) contents of the soils of the experimental sites are meager compared to the test values proposed by [25] for ferralitic soils; thus, leading to low biomass production.

The low level of fine particles (clay and silt) associated with the pH justifies the unsatisfactory levels of nitrogen recorded. The work of [26] states that there is a good correlation between soil nitrogen and clay content according to the regression equation: N (%) = 0.04 clay (%) + 0.215; r = 0.76 (4).

The variations in exchangeable cation content between the savanna and forest soils can be explained by soil structure.

Organic matter levels ranging from 1.20% to 1.52% are low and below the normal range of 2% to 3% [27] [28] and [29] state that as natural vegetation gives way to agricultural surfaces, there is a decrease in biomass production and soil organic matter due to anthropogenic actions. This confirms that the study area has been heavily exploited and that these fallow times are insufficient for soil reconstitution.

These low organic matter contents would predispose them to acidification and rapid degradation. Clay and organic matter being the basis of the clay-humus complex, their deficiency would largely contribute to the degradation of the fertility of these soils [30].

The C/N ratio is a determining factor in the decomposition of litter. Indeed, litter that decomposes too slowly can block the cycle of mineral elements. The C/N values are respectively 13 and 33 in forest and savanna and reflect an excellent biological activity for fallow soils following the standards. The C/N ratio in the savanna zone, which is higher than in the forest zone, partly explains the level and speed of organic matter decomposition in the savanna site compared to the forest, which has dense vegetation characterized by numerous leaf falls. According to [31] and [32], the mineralization process is more or less expected when $8 \leq C/N \leq 15$. Given these values, although expected, the decomposition of organic matter could be faster in the forest than in the savanna. The risk of leaching of mineral elements could be more significant in the forest than in the savannah. The somewhat slower decomposition of organic matter in savannahs makes nutrients available in a gradual and staggered manner, predisposing the mineral elements in the soil for plant development. According to [33], although organic matter decomposition is normal, the N content of tropical soils is generally low. For this reason, an additional supply is always essential for good growth. Phosphorus (1.54 ppm in the forest and 0 ppm in the savanna) and potassium (0.15 cmol/kg in the forest and 0.13 cmol/kg in the savanna) levels are low to ensure good crop nutrition. The CEC is also low in both cases about the standard proposed by [25]. Based on the results and following the standards indicated for cassava, the nutrient poverty of these soils is deduced. Even though cassava is considered an undemanding plant, additional organo-mineral fertilizer is essential to improve production.

4.2. Effect of Different Treatments on Soil Properties

The low pH values reflect an increase in soil acidity. They are attributable to the presence of acidic anions NO_3^- and SO_4^{2-} primarily due to mineral fertilization, the release of Al^{3+} and H^+, and the decomposition of the organic amendment. Weakly acidic soils (5.5 in the forest and 5.8 in the savanna) became slightly more acidic with cultivation. These anions mobilized Aluminum, which replaced calcium and other non-acidic cations in the complex, facilitating their leaching by the intense rainfall that fell in the area during the test period [34]; [27]. Therefore, the absorbing complex could be saturated in Al^{3+} ions. The decreases in K, Ca, and Mg under different treatments would be due to exports by cassava plants and leaching, particularly for Ca and Mg. Concerning phosphorus, the results showed a high content that could come from plant debris residues. [35] confirmed that cultivation increases the phosphorus content of the soil. However, a decrease of more than one-third in phosphorus content was observed under natural fallow.

The treatments generally impacted the CEC of the soils in the trials; this is more important with T1 in the savanna and T4 in the forest, which corroborates those of [48], who showed that cocoa bean husks used as fertilizers produced significant effects on degraded soils in Côte d'Ivoire by improving the CEC. [34], in a similar approach in Kinshasa (DRC), showed that the contributions of dolomite and coffee parchment led to a variation of the CEC. It is the same in [27] in Congo, who proved that the compost of household biowaste has the same effects. The improvement of CEC under organo-mineral fertilization (T4) could be explained by the fact that the organic input (cow dung) affected the phenomenon of exchangeable cations fixation on the absorbing complex [49]. However, the low level of CEC observed compared to the standards can be explained by the low proportions of organic matter and clay. Organic matter plays a crucial role in soil fertility. It is essential for nutrient retention, moisture, and structure and serves as a shelter for soil microorganisms. Previous studies [38] [39] have shown that the clay and organic matter rate explains the fixation of exchangeable cations on the clay-humus complex. These results confirm those obtained by

[40] and [41]. Indeed, these different authors have shown that CEC is intimately linked to the soil's organic matter rate and the clay rate. According to [50], the higher the organic matter content of the soil, the more nutrients the soil retains to make it available to plants for growth. According to [43], organic farmers should strive for at least 4% organic matter and consider stable or increasing values indicative of good soil management. After harvesting, C/N ratios in the savannah remain high compared to those in the forest site, reflecting a more rapid decomposition and a greater risk of leaching of mineral elements in the forest than in the savannah.

The levels of exchangeable soil bases (Ca^{2+}, Mg^{2+}, and K^{+}) improved in the forest with T1 (3.18 mi/100g) and T4 (2.2 mi/100g) but still below the reference standard. In T4, for example, the availability of exchangeable cation in the soil is ensured by the cow dung initially introduced into the decomposing soil. The work of [44] [45] and [46] respectively confirmed that the decomposition of organic residues improves exchangeable base content. On the savannah site, however, the contents decrease following the application of treatments that the assimilations of the plants could still justify.

Production is limited by the factor that is furthest from its optimum. Actions on the other factors are not very effective as long as correcting the most limiting factor is not achieved. Furthermore, if it is corrected, another one takes its place. A single insufficient element causes the yield to drop, even if all the others are satisfactory [47]. Fertilization must therefore be balanced by correcting all soil deficiencies.

5. Conclusion

The objective of this study was to evaluate the level of fertility of soils in the fallow land in the Pissa and Damara regions and to assess the fertility status of the soils after the use of climate-smart agricultural practices. The results show that the soils remain relatively poor after the fallow period relative to the cassava's production requirements. After the trial period with the use of organo-mineral fertilization, some nutrients were still low, following the required standards. A scrutiny of the data indicated that the influence of cow manure combined with mineral fertilizer was more prominent on the pH of the soil. The highest organic carbon and phosphorus availability was observed under treatment with animal manure and inorganic fertilizer. There is a need for more studies on other climate-smart technologies that have shown the potential of enhancing soil fertility status. This will avail several technologies for farmers disposal to choose from hence correcting deficits in nutritive elements for production in the Pissa and Damara regions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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