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Effect of two palms (*Borassus aethiopum* and *Hyphaene thebaica*) on the physicochemical characteristics of the soil of the agroforestry parklands in Gaya (Niger)

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Abstract

The management of soil fertility is a major issue worldwide. The aim of this study was to determine the contribution of *B. aethiopum* and *H. thebaica* to soil fertility in south-west Niger. Using a complete randomized design with three replicates. 45 composite samples of 100 g of soil (36 below canopy and 9 outside) were collected between 0 and 20 cm depth and used to determine organic matter content, total carbon, total nitrogen and total sulfur, macronutrients (Mg, Ca, Na and K), Olsen phosphorus, micronutrients (Fe, Zn, Cu and Mn), pH, hygroscopic moisture, electrical conductivity and texture. The results showed that organic matter, C, N, Mn, Mg, Zn, hygroscopic moisture, P and Fe were significantly higher under the crowns of both species but with a higher effect of *B. aethiopum* canopy. Variations in their levels, with the exception of P, were explained by soil organic matter, to which they were significantly well correlated. This study showed that *B. aethiopum* and *H. thebaica* significantly improve fertility and contribute to soil stability. In view of these results, it is essential to devise policies for the rational management of forest resources as an alternative to the sustainable conservation of stability and crop soil fertility.

Keywords: Agroforestry system, soil fertility, stability index, plam, sustainable land management

Introduction

Agricultural soils are the result of man's transformation of virgin soils for plant production. Agricultural practices can modify or even deplete the physico-chemical properties of soils (Dabin & Segalen, 1977; Vairelles et *al*., 1981). The latter are indicators of soil health and fertility, and determine the sustainability of ecosystems (Dollinger & Jose, 2018). However, there are reciprocal interactions between soil and plant (Liu et *al*., 2021; Zhao et *al*., 2022). Soil is a support and nutrient reservoir for the plant (Moral & Rebollo, 2017). It influences plant growth and development (Mureva & Ward, 2017; Ma et *al*., 2020). Similarly, plants can contribute to improving the physico-chemical qualities of soils (Wu et *al*., 2018; Wu et *al*., 2019; Hou et *al*., 2021).

Indeed, numerous authors have illustrated the role of trees in the conservation of soils physico-chemical parameters. This is the case of Gonçalvez et *al*. (2023), who compared the quantities of carbon and nitrogen stored at different soil depths in an intercropped agricultural area with those in an agroforestry system with 10-year-old (AFS10) and 20-year-old (AFS20) trees. They revealed that the agroforestry system (AFS20) produced significantly higher soil organic carbon (114.97 Mg/ha) up to 1m depth and high nitrogen (7.91 Mg/ha) with the intercropping system. Ramos et *al.* (2017) compared the quantities of carbon stored on the surface and in the soil of an agroforestry system based on oil palm and cocoa with those of another based-on oil palm and grasses in Brazil. The results showed a significantly higher level of organic carbon on the soil surface of the oil palm-cocoa agroforestry system (116.7 Mg/ha against 99.1 Mg/ha). Also, Hoosbeek et *al.* (2018) studied the distribution of soil organic carbon, total nitrogen and phosphorus levels according to distance from tree trunks in a silvopastoral system consisting of grazed open grassland and isolated trees in Nicaragua.

Results showed significantly higher levels of carbon and nitrogen in soils near trees and in areas receiving litter than in open grassland. Alvarez et *al.* (2021) studied the influence of dispersed trees of five species in a grazing area on the physical and chemical properties of the soil in Colombia. They reported that the rate of macroinvertebrates (litter decomposers) was higher under the crown for some species. Similarly, only exchangeable potassium was significantly higher under the crown (0.71 cmol/kg against 0.54 cmol/kg) for some species, while bulk density at 20 cm depth was higher outside the crown (1.19 cm^3 against 1.05 cm^3). Salazar et *al.* (2019) evaluated the *Prosopis pallida* (Humb. & Bonpl. Ex Willd.) Kunth fertility island and its relationship with tree size and leaf traits in dry forest in northern Peru. Results revealed that quantities of most soil nutrients were higher under the canopy. Soil carbon, nitrogen and phosphorus contents were positively correlated with tree size and negatively with leaf structural traits. Abdourahamane et *al.* (2015a) studied the influence of *Guiera senegalensis* clumps on the physicochemical properties of soils in the Guidan Bakoye terroir (Niger). They reported that organic matter, magnesium and potassium levels were significantly higher near than at points far from the clumps. Zoubeirou et *al.* (2013) assessed the effect of *Acacia senegalensis* (L.) Willd trees on the physicochemical parameters of soils under and outside the canopy in gum groves in Niger. Results indicated that pH, organic carbon, nitrogen, cation exchange capacity, assimilable phosphorus and sum of exchangeable bases are significantly higher under the canopy than outside. Abdourahamane et *al.* (2015b) studied the influence of *Hyphaene thebaica* (L.) Mart clumps on soil texture and chemical characteristics in the El Guéza terroir of the Maradi region (Niger). They found that organic matter, exchangeable bases, phosphorus, pH and cation exchange capacity (CEC) were significantly higher near than far from the clumps. They were also higher at the eastern and western positions of the clumps. Moussa (1997) carried out a comparative study of the influence of *Hyphaene thebaica* (L.) Mart and *Faidherbia albida* (Del.) A. Chev species on soil physico-chemical characteristics and the productivity of *Pennisetum glaucum* (L.) R. Br in the semi-arid zone of Niger. He reported that nitrogen, phosphorus, potassium, magnesium, calcium, organic matter and pH levels were significantly higher under the crowns of each species. He showed that the effect depends on the canopy species as they found significantly higher soil parameters content in *Hyphaene thebaica* (L.) Mart than in *Faidherbia albida* (Del.) A. Chev.

In Niger, the forest area is estimated at nearly 1142000 ha in 2015 (FAO, 2015). It is made up of several physiognomic types of woody field stands or agroforestry parklands that are essentially distributed in the southern strip of the country with densities of 10 to 100 feet/ha (Niger, 2012). These include parks with *Faidherbia albida* (Del.) A. Chev, *Butyrospermum paradoxum* (Gaertner f.), *Parkia biglobosa* (Jacq). R.Br. ex G. Don, *Parinari macrophylla* Sabine, *Borassus aethiopum* Mart, *Hyphaene thebaica* (L.) Mart and *Balanites aegyptiaca* (L.) Del. Stands of *Borassus aethiopum* Mart, the predominant species in the forest resources of Gaya department, and *Hyphaene thebaica* (L.) Mart are very often scattered (Niger, 2012). However, due to energy production, urbanization and the rapid expansion of agricultural land, almost half (50%) of the forest area was lost between 1958 and 1997 (Niger, 2020). Between 1975 and 2013, the area of agricultural land increased by 94.2% (CILSS, 2016). This has led to rapid deforestation and soil degradation, as well as a reduction in cropland (Stone, 1993). Soil erosion and fertility decline are steadily increasing, and nearly 100 t/ha of agricultural soil disappears every year (Stone, 1993; Potts et *al*., 2011). In Tounouga (Gaya), from 1896 to 2019, the surface area of crops grown under roast plantations fell from 2215 ha to 976 ha (SONED-Afrique/MSA, 2020). This situation calls for the identification of management techniques that would enable sustainable land management by restoring and safeguarding the productivity of agricultural soils. Hence the interest of this study, the aim of which is to determine the agroforestry potential of *Borassus aethiopum* Mart and *Hyphaene thebaica* (L.) Mart in south-west Niger in improving soil fertility. It specifically aims to encourage the maintenance and expansion of *Borassus aethiopum* Mart and *Hyphaene thebaica* (L.) Mart stands through their use in combating the decline in soil fertility in the agroforestry systems of the Gaya department.

Material and method

Study area

The study was carried out at two sites in the Gaya department (SW Niger). These were the village of Nadewa, which belongs to one of the three agro-ecological zones of the rural commune of Bengou, and the village of Sabon Birni in the rural commune of Tounouga. The Bengou commune is located 187 km from Niamey (capital of Niger) (3°35'30" E, 11°59'30" N). Its relief is characterized by clayey-sandy soils in the valleys and lowlands, clayey soils in the Dallols, lateritic soils on the plateaus and sandy soils on the dunes (SONED-Afrique/MSA, 2023). The commune of Tounouga is located 299 km from Niamey (3º37'25" E, 11º48'20" N). It is characterized by clay and clay-loam soils in the river and Dallol valleys, sandy soils on the dunes and stony soils in places on the plateau to the east of the commune. Its landscape is characterized by plains, lowlands and a few dune complexes (SONED-Afrique/MSA, 2020).

Sampling and data collection

At each site, a complete randomized block design with three replications was used to determine soil physico-chemical parameters (Dagnelie, 1988). The choice of blocks (fields) was based on the distribution of stands of the two species in relation to the position of the village in each case. Thus, in the case of *Borassus aethiopum* Mart, which is widespread in the locality, three blocks were chosen at random within a radius of around 400 m around the village for the Nadewa site (Figure 1a) and within the stand to the south-east of the village for the Sabon Birni site (Figure 1b). However, in the case of *Hyphaene thebaica* (L.) Mart, due to its low density in the agroforestry parklands, only the Sabon Birni site enabled data to be collected in three blocks, including the agroforestry parkland of the environmental protection department located in the village and two others located outside the village (Figure 1c). In each block, three trees were selected at random. Then, around each one, within a radius of 0.5 m (under the crown) and between 0 and 20 cm depth, four soil samples were taken in the east, west, north and south directions and a control sample (outside the crown) in a bare area of the block (Camara, 2018). A total of 13 soil samples were collected per block, 12 under the canopy (around the 3 trees) and 1 outside the canopy (controls), for a total of 117 samples, 78 from *Borassus aethiopum* Mart and 39 from *Hyphaene thebaica* (L.) Mart. For each block, the samples collected in the same direction were then mixed to form composites, from which 100 g were taken to determine physico-chemical characteristics in the laboratory. For *Borassus aethiopum* Mart, a total of 30 samples of 100 g each, i.e. 24 under-tree samples and 6 controls, were taken, compared with 15 samples of 100 g for *Hyphaene thebaica* (L.) Mart, i.e. 12 under-tree samples and 3 outside-tree samples, for laboratory analysis.

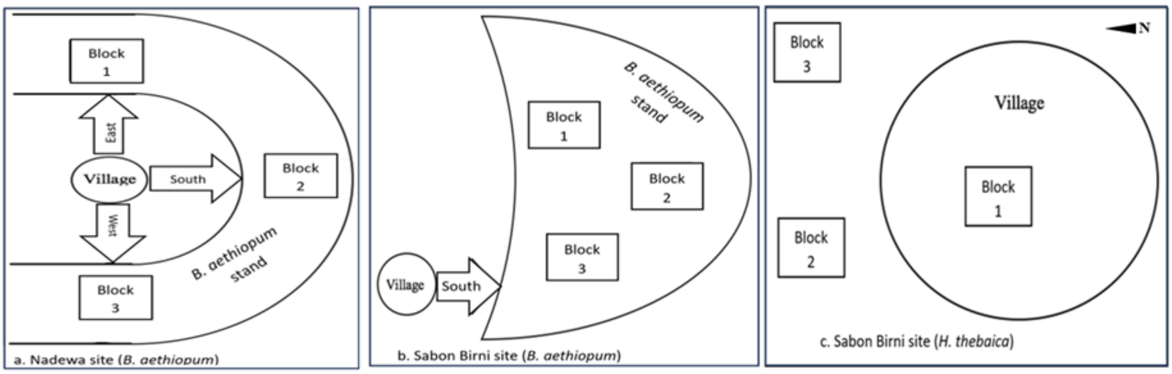

Figure 1: Data collection system

Determination of soil physico-chemical parameters

To determine physico-chemical parameters, soil samples were air-dried at room temperature in the laboratory. Then, those containing a few aggregates were lightly crushed before analysis. Soil samples were sieved using a 2 mm sieve. The parameters determined were hygroscopic moisture by oven drying at 105°C, hydrogen potential (pH) measured in aqueous suspensions at a dilution of 1/2.5 using a basic 20 pH meter, electrical conductivity (EC) measured in aqueous suspensions at a ratio of 1:5 using a GLP 31 conductivity meter, total organic matter from organic carbon determined by the method of Walkley and Black (1934), micronutrients (Fe, Cu, Zn and Mn) by flame atomic absorption using the method of Lindsay and Norvell (1978), available phosphorus in 0.5 M $NaHCO_3$ solution adjusted at a pH of 8.5 using the method of Olsen et *al.* (1954), assimilable potassium, magnesium and sodium with ammonium acetate by flame atomic absorption, soil texture using the Robinson pipette method, and total nitrogen, sulfur and total carbon were determined using a combustion elemental macroanalyzer (Leco Series 928, LECO Corporation, St Joseph, Michigan, USA).

Determining the stability index

The soil stability index (St) is used to determine the soil's degree of vulnerability to degradation agents. It ranges from 9.1 to 14.0 % for stable soils. It is calculated using the following formula (Soro et *al*., 2011):

$$St = \frac{OM}{clay + silt} \times 100$$

where St is the stability index (%); OM, clay and silt are respectively the percentages (%) of organic matter, clay and silt in the soil.

Data analysis

The experimental data obtained were subjected to statistical analysis to determine the influence of *Borassus aethiopum* Mart and *Hyphaene thebaica* (L.) Mart on the physico-chemical characteristics of the soil in the study area. But first, a logarithmic transformation with the log10 function was applied to variables whose distribution did not follow the normal distribution previously checked using the Shapiro-wilk test recommended for small sample sizes. Transformed variables (with a normal distribution) for which the influence of the site factor was not significant at the 0.05 threshold with the Mann-Whitney test were subjected to the two-factor ANOVA test (species and position) at the 5% threshold and three-factor ANOVA test (species, position and site) those (pH and P) for which the Mann-Whitney test was significant (Appendix: Table 1). In the event of a significant difference, in Post Hoc, Bonferroni's test was used to compare group means with each other when equality of variances was confirmed by Levene's test at the 5% threshold, otherwise Dunnett's T3 test was applied to this effect. Variables (CE, Mg and Ca) that did not show a normal distribution after logarithmic transformation were subjected to Friedman's non-parametric test to detect significant differences between the medians of the different groups at the 5% threshold. In addition, a Spearman correlation test and a principal component analysis (PCA) were performed to determine the various interactions between soil physical and chemical parameters and the forest species (*Borassus aethiopum* Mart and *Hyphaene thebaica* (L.) Mart) under study. SPSS software version 29.0.2.0 was used for descriptive statistics, logarithmic transformation of variables and application of the analysis of variance. R software version 4.4.2 was also used to perform the Friedman test, Spearman correlation test and principal component analysis on untransformed variables (origins). The results reported in the tables below are mean values calculated on the original values for variables with a normal distribution with logarithmic transformation, and medians for those whose distribution does not follow the normal distribution even with transformation.

Results

Soil stability index

Table 2 shows the results of the soil stability index according to site, position (under and outside the crown) and species.

Table 2: Descriptive statistics for soil stability index

Factors	Modalities	Means	CV (%)	SE	Min	Max	P-value
Site	Sabon Birni	6.0a	54.6	0.6	1.6	15.5	0,074
	Nadewa	7.8a	44.1	0.9	2.8	15.3	
Position	Below	7.3b	46.1	0.6	2.1	15.1	0,001
	Outside	3.8a	43.1	0.5	1.6	6.8	
Species	*B. aethiopum*	8.1b	39.3	0.6	2.8	15.5	0,000
	H. thebaica	3.7a	35.7	0.3	1.6	6.1	
Means		6.6	51.5	0.5	1.6	15.5	

CV (%): coefficient of variation; on the rows, SE: standard error, the averages of factors with different letters are significantly different

The results in Table 2 show a low stability index of 6.59% for the soil in the study area. In fact, at the 0.05 threshold, it is significantly higher than average under the crowns (7.29%) and with the *Borassus aethiopum* Mart species (8.05%), whereas outside the crowns (3.77%) and with the *Hyphaene thebaica* (L.) Mart species (3.67%), which are characterized by below-average indices.

Effect of *B. aethiopum* and *H. thebaica* on soil nutrient levels

Figure 2 (A, B, C and D) shows the means and standard error of some essential soil nutrients by species, depending on the position (under and outside the crown) of the samples in relation to the tree.

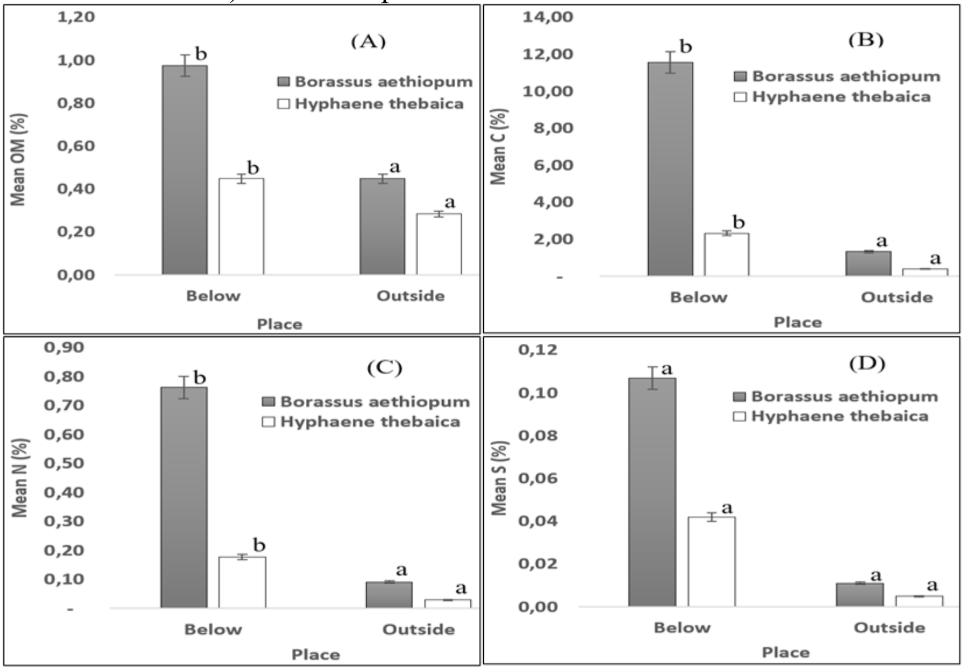

Figure 2: Distribution of concentrations of organic matter "OM" (A), total carbon "C" (B), total nitrogen "N" (C) and total sulphur "S" (D). The graphs for each species in relation to the position bearing different letters are significantly different

Figure 2 shows a significant variation in essential soil nutrient concentrations according to position and species. Nutrient concentrations are significantly higher in soils under palm tree crowns than in control soils for organic matter (P-value 0.000), total carbon (P-value 0.006) and total nitrogen (P-value 0.002) in contrast to sulphur levels (P-value 0.323), which is not significantly different according to position. They are also significantly higher for *Borassus aethiopum* Mart than for *Hyphaene thebaica* (L.) Mart, with P-values below the 5% threshold. With P-values greater than 0.20 at the 5% threshold, no significant interaction was revealed between position and species for any of these nutrients.

Table 3 shows the results of the chemical analysis of exchangeable bases such as magnesium (Mg), calcium (Ca), sodium (Na) and potassium (K) in the soil, according to species and sample position at each study site.

Table 3: Results of soil exchangeable base analysis.

Site	Species	Mg (cmol/Kg)		Ca (cmol/Kg)		Na cmol/Kg)		K (cmol/Kg)	
		Below	***Outside***	***Below***	***Outside***	***Below***	***Outside***	***Below***	***Outside***
Sabon Birni	*BA*	0.019b	0.010a	3.22a	2.81a	0.09a	0.82a	0.48a	0.37a
	HT	0.018b	0.010a	3.01a	2.91a	0.09a	0.60a	0.39a	0.06a
Nadewa	*BA*	0.026b	0.010a	3.15a	3.33a	3.45a	0.001a	2.41a	0.75a
Means		0.019b	0.012a	3.07a	3.03a	1.21a	0.47a	1.09a	0.39a
CV (%)		-	-	-	-	222.5	201.4	157.6	114.2

BA: Borassus aethiopum; HT: Hyphaene thebaica; CV (%): coefficient of variation; on the rows, the under-tree and out-of-tree averages for each soil element bearing the letter are not significantly different

Overall, the results in Table 3 show that exchangeable soil base (Mg, Ca, Na and K) rates are higher below the canopy. It can also be seen that, with the exception of Na at the Sabon Birni site and Ca at the Nadewa site, which are higher outside the tree crowns, soil nutrients are at higher levels below the palm's crowns. They also reveal that the highest rates under tree crowns are observed with *Borassus aethiopum* Mart, especially at the Nadewa site. The differences observed were only statistically significant for magnesium at the 5% threshold, in relation to position. Also, no significant interaction between position and species was found to be positive for these different exchangeable base rates, with P-values greater than 0.60.

The results in Table 4 show the distribution of (total) mineral elements such as iron (Fe), copper (Cu), manganese (Mn), zinc (Zn) and Olsen phosphorus (P) in the soil, according to species and soil position in relation to trees of both species at each site.

Table 4: Results of soil nutrient analysis.

Site	Species	Fe (mg/kg)		Cu (mg/kg)		Mn (mg/kg)		Zn (mg/kg)		P (mg/kg)	
		Below	***Outside***	***Below***	***Outside***	***Below***	***Outside***	***Below***	***Outside***	***Below***	***Outside***
Sabon Birni	*BA*	37.7b	29.92a	0.35a	0.36a	18.5b	11.46a	0.89b	0.49a	1.81b	1.30a
	HT	7.68b	4.90a	0.38a	0.37a	5.50a	6.08b	1.10b	0.60a	2.23b	0.66a
Nadewa	*BA*	34.8b	27.90a	0.49a	0.33a	9.59b	3.03a	0.96b	0.78a	7.14b	2.70a
Means		26.7b	20.91a	0.41a	0.36a	11.22b	6.86a	0.99b	0.62a	3.73b	1.55a
CV (%)		57.73	98.08	30.30	21.38	64.08	85.39	64.76	49.04	106.3	69.78

BA: Borassus aethiopum; HT: Hyphaene thebaica; CV (%): coefficient of variation; on the rows, the below-tree and outside-tree averages for each soil element bearing the letter are not significantly different

Analysis of the results in Table 4 shows that for all soil nutrients, the proportions are high below the palm crowns for each species. It can also be seen that at each site, Fe, Zn and P contents are higher below the crowns for both species. For manganese, the proportions are low under the canopy (5.50 mg/kg) for *Hyphaene thebaica* (L.) Mart and high for *Borassus aethiopum*

Mart. As for Cu, the proportions are similar between positions (below and outside the canopy) for both species at the Sabon Birni site. With p-values below the 0.05 threshold, the results of the statistical analysis showed that these differences are significant between species and position for Fe, between sites and position for P and only in relation to position for Zn and Mn. Statistical analyses at the 5% threshold revealed no significant interaction between factors, with P-values greater than 0.08.

Effect of *B. aethiopum Mart* and *H. thebaica Mart* (L.) on physical properties

Table 5 shows soil particle size composition by species and position relative to the tree at both sites.

Table 5: Physical characteristics of the soil

Site	Specie	Clay (%)		Silt (%)		Sand (%)	
		Below	*Outside*	*Below*	*Outside*	*Below*	*Outside*
Sabon Birni	*BA*	2.7a	3.5a	6.9a	6.7a	90.4a	89.8a
	HT	5.0a	7.2a	6.3a	6.4a	88.7a	86.4a
Nadewa	*BA*	6.3a	2.9a	12.1a	6.9a	81.7a	90.1a
Means		4.6a	4.6a	8.4a	6.7a	86.9a	88.8a
CV (%)		66.1	50.0	60.8	23.2	8.6	3.4

BA: Borassus aethiopum; HT: Hyphaene thebaica; CV (%): coefficient of variation; on the rows, the below-tree and outside-tree averages for each soil nutrient bearing the letter are not significantly different

The results in Table 5 show that, overall, the soil texture in the study area is predominantly sandy. Statistical results also indicate that the average percentages of physical soil elements are not significantly different between positions (under and outside crowns) and species, with P-values above the 5% threshold. %. At the 5% threshold, statistical analyses showed that there was no positive interaction between the species and position factors for all the parameters studied, with P-values greater than 0.20.

Table 6 shows the distribution of hygroscopic moisture (HM), pH and electrical conductivity (EC) as a function of species and soil position at both sites.

Table 6: pH, hygroscopic moisture and electrical conductivity

Site	Species	HM (%)		pH		EC (dS/m)	
		Below	*Outside*	*Below*	*Outside*	*Below*	*Outside*
Sabon Birni	*BA*	0.44a	0.54a	5.6a	5.5a	0.07a	0.06a
	HT	0.28a	0.28a	5.3a	5.5a	0.06a	0.04a
Nadewa	*BA*	0.98a	0.28a	6.8a	6.4a	0.10a	0.09a
Means		0.57a	0.37a	5.9a	5.8a	0.07a	0.06a
CV (%)		87.83	70.96	16.8	11.7	-	-

BA: Borassus aethiopum; HT: Hyphaene thebaica; CV (%): coefficient of variation; on the rows, the below-tree and outside-tree averages for each soil element bearing the letter are not significantly different

The results in the table 6 shows that, overall, hygroscopic moisture, pH and electrical conductivity are a bit higher below palms crowns, at 0.57%, 5.91 and 0.07 dS/m respectively. They are higher under *Borassus aethiopum* Mart trees, especially at the Nadewa site. Nevertheless, these differences were only found to be significant at the 5% level by statistical tests for HH for position factor with a P-value of 0.03. Also, they indicate that these differences are significant between species and sites with p-values below 0.001 for EC and only between sites for pH with a p-value of 0.00. No positive interaction was revealed for any of the parameters studied, with P-values greater than 0.20.

Relationships between soil physical and chemical parameters

The table 7 shows the correlation coefficients (Spearman correlations) between soil parameters.

Table 7: Correlation matrix between soil physical and chemical parameters

	C	Ca	CE	Clay	Cu	Fe	HM	K	Mg	Mn	OM	N	Na	P	pH	S	Sand	Silt	Zn
C	1.00																		
Ca	0.05	1.00																	
CE	0.44	-0.22	1.00																
Clay	0.04	0.05	-0.21	1.00															
Cu	0.45	0.26	0.11	0.42	1.00														
Fe	0.69	0.24	0.29	-0.32	0.05	1.00													
HM	0.70	0.15	0.28	0.11	0.33	0.60	1.00												
K	0.52	-0.37	0.71	0.05	0.12	0.25	0.36	1.00											
Mg	0.52	-0.17	0.52	0.09	0.28	0.13	0.27	0.57	1.00										
Mn	0.67	0.11	0.16	-0.01	0.23	0.56	0.48	0.22	0.25	1.00									
OM	**0.82** ***	0.02	0.42	-0.06	0.22	**0.70** ***	**0.68** ***	0.43	**0.52** *	**0.61** **	1.00								
N	0.93	-0.01	0.45	0.06	0.38	0.62	0.61	0.55	0.55	0.69	**0.78** ***	1.00							
Na	0.41	-0.40	0.54	0.17	0.23	0.09	0.45	0.52	0.52	0.11	0.38	0.39	1.00						
P	0.51	-0.09	0.52	0.10	0.15	0.28	0.49	0.60	0.41	0.25	0.39 ns	0.56	0.48	1.00					
pH	0.37	0.06	0.62	0.09	0.13	0.16	0.19	0.50	0.53	-0.07	0.33	0.34	0.36	0.47	1.00				
S	0.25	-0.08	0.15	0.42	0.27	-0.12	0.25	0.30	0.34	-0.03	0.14	0.30	0.33	0.41	0.26	1.00			
Sand	-0.17	-0.14	0.05	-0.79	-0.60	0.13	-0.27	-0.10	-0.08	-0.14	0.01	-0.16	-0.23	-0.17	0.01	-0.32	1.00		
Silt	0.41	0.04	0.45	0.01	0.39	0.28	0.42	0.40	0.18	0.30	0.24	0.34	0.32	0.32	0.16	0.05	-0.52	1.00	
Zn	0.45	-0.10	0.25	0.21	0.31	0.22	0.30	0.51	0.25	0.31	0.41 ns	0.50	0.31	0.48	0.27	0.32	-0.16	0.10	1.00

Boldface indicates soil parameters with significantly elevated levels below palm crowns; *indicates a significant correlation at 0,05; ** indicates a highly significant correlation at 0,01; *** indicates a big highly significant correlation at 0,001 and ns: indicates non-significant correlation

The results in the table 7 show that the dependency relationships between the soil physicochemical parameters are characterized by positive correlations for some and negative correlations for others. However, in the particular case of organic matter content, it is positively correlated with all soil parameters and negatively correlated with sands. Correlations are highly significant with total carbon (r=0.82; p<0.0001), total nitrogen (r=0.78; p<0.0001), iron (r=0.70; p<0.0001) and hygroscopic moisture (r=0.68; p<0.0001), highly significant with manganese content (r=0.61; p<0.0001) and significant with magnesium content (r=0.52; p=0.0375). However, the test results revealed that the correlations were not significant for phosphorus (r=0.39) and zinc (r=0.41), with p-values of 0.81 and 0.63 respectively.

Relationships between soil parameters and both species of palms

Figure 3 (A and B) shows the results of the distribution of physical and chemical parameters (left) and that of individuals (position of soil samples under and outside the crown for each species) with multivariate analyses (PCA) in the two-dimensional plane. This model showed a good fit to the data, as evidenced by the KMO value of 88%, suggesting the existence of a good factorial solution. Also, it showed a determinant of $5.971.10^{-16}$ and a P-value of 0.00 for Bartlett's test indicating that the model is well suited to present the interactions between the different variables in the model.

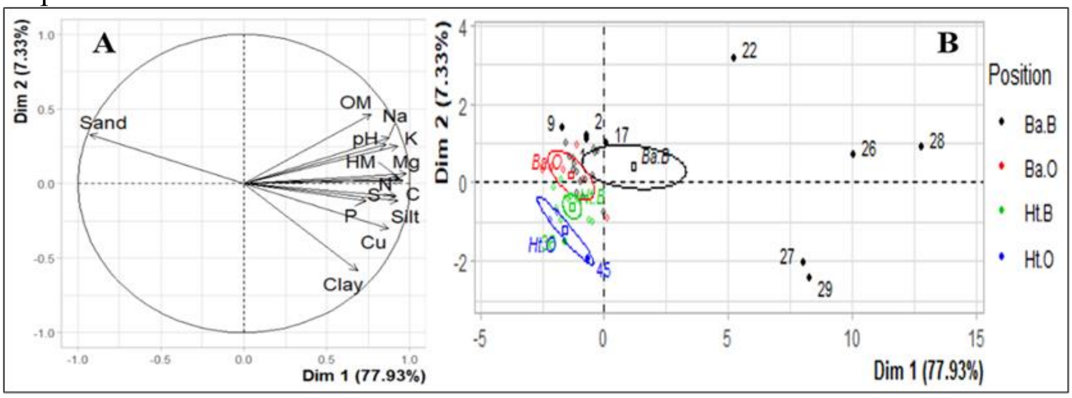

Figure 3: Distribution of soil parameters (A) and positions according to species (B) in the PCA factorial plane. Ba.B : below the crown of Borassus aethiopum, Ba.O: outside the crown of Borassus aethiopum, Ht.B: below the crown of Hyphaene thebaica et Ht.O : outside the crown of Hyphaene thebaica

The first two factorial axes of the PCA for soil physical and chemical characteristics express 85.26% of the total inertia of the dataset. This suggests that 85.26% of the total variability in the distribution of physico-chemical parameters is explained by these two dimensions. The first component (PC1) presents the impact of palm species crown on the distribution of soil physicochemical characteristic groups. Soils under the crown of *Borassus aethiopum* Mart species are characterized by high levels of Mg, C, N, HM, K, silt, S, Na, Cu, pH, OM, P and clay in the positive part of the axis, compared with high levels of sand in the negative part of the axis associated with soils outside the *Borassus aethiopum* Mart crown and under the crown of *Hyphaene thebaica* (L.) Mart species. The separation of positions for the two palm species according to groups of physical and chemical characteristics is significant with the Wilks test indicating the impact of crowns on edaphic parameters (P-value = 0.0012).

Discussion

Results on particle size composition showed that soils in the study area have a sandy texture, with 88.8% sand, 6.9% clay and only 4.3% silt. Although these physical parameters were slightly elevated under tree crowns, and especially with *Borassus aethiopum* Mart species, statistical analysis showed that these differences were not statistically significant at the 5% threshold. According to Camille et *al*. (2021) in a study on the contribution of plants in agroforestry systems to fertility of soil in France, the increasing rates of sand, clay and silt from the soil to the trees were not statistically significant. Similar results are reported by Samba (1997) in a study carried out in a traditional *Cordyla pinnata* (Lepr. Ex A. Rich) Milne-Redh agroforestry system in Senegal. He reported that the trees of this species were not linked to any variation in the soil physical properties studied, such as texture, bulk density and moisture.

Trees with two palms improve soil stability by increasing cohesion between solid soil particles. According to Soro et *al*. (2011), a soil is all the more vulnerable to erosion and degradation if its destructuration index is below the standard range of 9.1 to 14.0%. Thus, the soil in our study area is relatively more stable under the canopy of *Borassus aethiopum* Mart and *Hyphaene thebaica* (L.) Mart trees, with an index of 7.3% compared with 3.8% outside the canopy, but with a significantly higher incidence of *Borassus aethiopum* Mart plants (8.1%) than *Hyphaene thebaica* (L.) Mart species (3.7%). These results show that stands of *Borassus aethiopum* Mart and *Hyphaene thebaica* Mart (L.) contribute well to improving the structure of agroforestry parklands soils and reducing their vulnerability to degradation and erosion. This is linked in particular to the accumulation around palms trunks of organic matter from organ residues (leaves, fruit and flowers) or from plant micro-biodiversity developed in the vicinity of the trees. It could also be linked to the level of organic matter from animal droppings attracted by palms organ residues or plant micro-biodiversity developed around trunks. The high contribution of *Borassus aethiopum* Mart to soil stability is linked to compliance with the conservation and protection policies developed for this species, unlike *Hyphaene thebaica* (L.) Mart. This would explain an increase in human pressure to exploit *Hyphaene thebaica* (L.) Mart organs, such as the leaves, which are especially prized for handicrafts, and the fruits, which are sold commercially, thus reducing the species' contribution to the soil's organic matter They are also linked to the high density of the *Borassus aethiopum* Mart species in the area that is its distribution zone in Niger. According to the results of a study by Feller (1995) carried out in West Africa, the level of organic matter is closely linked to the physical characteristics of the soil, such as texture and structural instability in the surface horizons (0 to 20 cm).

Results on chemical characteristics showed that these palms influence soil nutrient concentrations. In fact, soil mineral content is higher overall below the canopies of these two species, and especially in the soils below *B. aethiopum's* canopy, as also indicated by the results of the distribution of soil physical and chemical elements in the factorial plane associated with that of the positions for the two forest species under study, and statistical analyses at the 5% threshold for concentrations of iron, zinc, phosphorus, magnesium, manganese, total nitrogen, total carbon and organic matter significantly higher under the palm canopy. Similar results are reported in a study by Breman & Kessler (1995) in agroforestry parks with *Faidherbia albida* (Del.) A. Chev, *Acacia auriculiformis* A. Cunn. and *Cassia siamea* Lam in Senegal. According to their results, soil carbon and nitrogen concentrations are higher under the tree crowns of these forest species. However, they were higher under trees of the species *Acacia auriculiformis* A. Cunn. and *Cassia siamea* Lam. Similarly, the results of Soumaré's (1996) study in Mali revealed that total carbon, nitrogen and phosphorus contents are higher under the canopies of *Acacia seyal* Del. and *Sclerocarya birrea* subsp. caffra (Sond). However, they are higher under *S. birrea* trees and lower under *Acacia seyal* Del. Our results corroborate those of Kater et *al*. (1992) obtained in a study carried out in *Vitellaria paradoxa* C.F Gaertn and *Parkia biglobosa* (Jacq) R.Br ex G. Don agroforestry parks in southern Mali. They reported that soil carbon and nitrogen levels are higher under tree crowns than outside. The importance of trees in increasing soil chemical parameters has also been reported by Camille et *al*, (2021) in France. The results revealed that the closer one gets to the trees, the higher the organic carbon content of the soil. Soil phosphorus and nitrogen levels, although not significantly different, are higher in soils near trees. Also, according to Samba (1997), organic carbon, total nitrogen, assimilable phosphorus, exchangeable calcium and soil cation exchange capacity are higher under the canopy than outside the canopy of trees in a *Cordyla pinnata* (Lepr. Ex A. Rich) Milne-Redh agroforestry system. Nevertheless, our results differ from those reported by Kouyaté et *al*, (2007) in a study assessing the fertility of *Detarium microcarpum* Guill. & Perr soils in different agroforestry environments in Mali. They reported that nitrogen, total organic carbon and phosphorus contents were not significantly different between soils sampled under the crown and outside the crown.

The results obtained in this study showed that soil organic matter content has a significant influence on nutrient concentrations. This indicates the importance of the contribution of these species in increasing soil nutrient concentrations through the organic matter they return to the soil. Better still, with a positive correlation coefficient of 0.68, it is significantly linked to the amount of hygroscopic water in the soil. This indicates that organic matter content also influences soil water retention capacity. Similar results have been reported by numerous authors, such as Feller (1995), who indicated that organic matter content correlates very well with chemical parameters such as mineralized nitrogen and the sum of exchangeable bases in soil surface horizons. According to the results of work by Zoubeirou et *al*. (2013) in Niger, chemical elements such as soil nitrogen and phosphorus are derived from the decomposition of organic matter of plant origin or from soil microflora. The results of the study by Rene et *al*. (2021) carried out in Côte d'Ivoire in an agroforestry system at Cocoa reported similar findings indicated that organic matter content is significantly correlated with the levels of soil nutrients studied.

Conclusion

The results of this study showed that both palms (*Borassus aethiopum* Mart and *Hyphaene thebaica* (L.) Mart) contribute to improving the physicochemical characteristics of agricultural soils, but with a strong contribution from *B. aethiopum* species. Specifically, these two forest species increase the quantities of carbon (organic and total), iron, manganese, magnesium, phosphorus and total nitrogen, perfectly correlated with the level of organic matter they bring to the soil. They also improve the soil's hygroscopic water content and electrical conductivity. Thanks to their organic matter content, these palms enhance soil protection against erosive agents. In view of the improved agroforestry potential of *B. aethiopum* and *H. thebaica* revealed by these results, this study would enable the development of inclusive policies on the protection and regeneration of forest resources with a view to their involvement in sustainable land management and the restoration of agricultural soil fertility.

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Declaration of authors' contributions

All co-authors contributed fully to the critical revision and validation of the intellectual content of the draft article. More specifically A.G.S drew up the data collection protocol, conducted the operations in the laboratory and drew up the first draft of this manuscript. A.N monitored the various physico-chemical analyses of soil samples in the laboratory. V.B checked and validated the experimental results obtained from the laboratory analyses. H.O contributed to the implementation of the field data collection protocol and the physico-chemical soil analyses in the laboratory. R.V monitored the implementation of the analysis protocol in the laboratory, contributed to the statistical analysis and interpretation of the results obtained and to the design of the draft article and H.A.M contributed fully to the use of R software in the processing of the data collected.

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Disclosure statement

The lead author declares that there are no conflicts of interest between the various authors and that all accept responsibility for all aspects of this work.

Data availability statement

All the data from this study have been processed and included in this manuscript and supplementary file. But they are available from the corresponding author, who can share them on request.

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Appendix

Table 1: Test for the effect of the site factor on soil parameters

Variables	Rank Sum Site 1	Rank Sum Site 2	U	Z	p-level	Z adjusted	p-level	Valid N Site 1	Valid N Site 2	2*1 Sided exact p
pH	22	23	1.0	-2.06	**0.03***	-2.06	**0.03***	6	3	**0.04***
HM	32	13	7.0	0.51	0.60	0.51	0.60	6	3	0.71
CE	24	21	3.0	-1.54	0.12	-1.54	0.12	6	3	0.16
OM	33	12	6.5	0.64	0.51	0.64	0.51	6	3	0.54
C	32	13	7.0	0.51	0.60	0.51	0.60	6	3	0.71
N	31	15	8.5	0.12	0.89	0.12	0.89	6	3	0.90
S	36	10	3.5	1.42	0.15	1.45	1.45	6	3	0.16
Fe	27	18	6.0	-0.77	0.43	-0.77	0.43	6	3	0.54
Cu	31	14	8.0	0.25	0.79	0.25	0.79	6	3	0.90
Mn	37	8	2.0	1.80	0.07	1.80	0.07	6	3	0.09
Zn	24	21	3.0	-1.54	0.12	-1.54	0.12	6	3	0.16
P	22	23	1.0	-2.06	**0.03***	-2.06	**0.03***	6	3	**0.04***
Clay	35	10	4.0	1.29	0.19	1.29	0.19	6	3	0.26
Silt	27	18	6.0	-0.77	0.43	-0.77	0.43	6	3	0.54
Sand	26	19	5.0	-1.03	0.30	-1.03	0.30	6	3	0.38
Mg	24	21	3.0	-1.54	0.12	-1.57	0.11	6	3	0.16
Ca	25	20	4.0	-1.29	0.19	-1.29	0.19	6	3	0.26
Na	33	12	6.0	0.77	0.43	1.06	0.28	6	3	0.54
K	24	21	3.0	-1.54	0.12	-1.57	0.11	6	3	0.16

* Indicates significant effect of site factor on soil parameters at 5%.