Vol. 21(10), pp. 772-782, October, 2025
DOI: 10.5897/AJAR2025.16981
Article Number: 3C3664873841
ISSN: 1991-637X
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African Journal of Agricultural Research

Full Length Research Paper

Impact of *Faidherbia albida* (Delile) A. Chev. density on soil organic carbon, soil nitrogen, crop yields, and rural livelihoods in Northern Cameroon's Agroforestry parklands

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Received 15 May, 2025; Accepted 17 September, 2025

Trees in parklands can interact with crops positively or negatively based on species, environment, and management. *Faidherbia albida* is an agroforestry tree that can improves soil fertility and provides ecosystem services beneficial to smallholder farmers. This study examined the effects of *F. albida* tree density and pruning on soil organic carbon (SOC), total nitrogen (STN), crop yields, and rural livelihoods in North Cameroon. Parklands were categorized by tree density: low (10 - 30 trees/ha), moderate (40 - 60), and high (≥ 80). Topsoils (0 - 20 cm) were sampled, and agronomic trials were conducted over two years. SOC and STN levels were higher under *F. albida* canopies, especially in high-density, pruned parklands. Sorghum yields were highest (2.269 ± 0.590 t/ha) in pruned, moderate-density plots, while cowpea yields reached 1.854 ± 0.282 t/ha in unpruned plots. Pruning enhanced sorghum yield, whereas cowpea performed better in unpruned conditions. Beyond crops, parklands supported rural incomes through wood fuel, fodder, and timber, contributing 58.7 ± 19.9% of household income in Mambang and 56.1 ± 18.5% in Kodek. The results highlight *F. albida*'s potential to improve soil quality, increase crop productivity, and support livelihoods, reinforcing its value as a climate-resilient agroforestry option for Northern Cameroon.

Key words: *Faidherbia albida*, soil organic carbon, soil nitrogen, North Cameroon, agroforestry, climate change.

INTRODUCTION

Trees-crops interactions in parklands, particularly in agroforestry systems, are crucial for understanding how

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trees and crops coexist and complement each other in rural landscapes (Boffa, 1999). Parklands are areas where trees are integrated with crops, typically in semi-arid and tropical regions (Boffa, 1999). This practice has gained recognition as a land-use strategy to mitigate global climate change while offering additional environmental, economic, and social benefits (Castle et al., 2021; Boffa, 1999; Haskett et al., 2019; Dobhal et al., 2024).

Trees inside croplands limit soil degradation and, at the same time, may contribute to improving their fertility (Basga et al., 2018; Castle et al., 2021). Experiences in some parts of Africa demonstrated their effectiveness in soil amelioration through litter fall and, on the environment, (Roupsard et al., 1999; Gindaba et al., 2005; Mbow et al., 2014; Haile et al., 2021). The main problem impacting this success resides in adapting interactions between trees and cultivated crops. Sometimes, competition between trees and associated crops for light, nutrients, and water limits crop yields. So, the major challenge is situated in the choice of the tree species that can be planted together with crops to optimize the advantages of association (Haile et al., 2021). To deal with these interactions and secure success, farmers sometimes practice tree pruning (Gindaba et al., 2005). However, unsustainable pruning has been documented (Akodewou et al., 2022) and remains a serious threat to the sustainability in parklands of the Fabaceae species *Faidherbia albida* (Delile) A. Chev (*F. albida*).*F. albida* is one of the native tree species in arid and semi-arid rangeland, which has an inverse phenology (Koech et al., 2016; Sileshi et al., 2020a). It sheds its leaves during the rainy season and recovers them in the dry season (Roupsard et al., 1999; Yakubu, 2010; Haskett et al., 2019). This trait causes it to remain physiologically dormant during the cropping season, coupled with its inability to shade crops, making it significantly less competitive with field crops (Akpalu et al., 2020). In Northern Cameroon, agroforestry plots, particularly those featuring this species have played a vital role in enhancing legume production (Akodewou et al., 2024). Studies on cotton productivity revealed a strong connection between improved soil fertility and the presence of the tree, especially in areas where soil quality had previously been poor. In this region, it has had a significant positive effect on cotton yields, establishing itself as a crucial support for farmers. Since 1994, numerous initiatives have supported the restoration and densification of *Faidherbia* in North Cameroon by subsidizing their assisted natural regeneration in the farms (Akodewou et al., 2022). In Ethiopia, both soil fertility and barley yields have been shown to improve in areas closer to *F. albida* trunks (Hadgu et al., 2009; Haile et al., 2021). Similarly, in Niger, an on-farm field experiment demonstrated that millet yields were approximately 36% higher under the tree canopy compared to those in open-field conditions (Kho et al., 2001). However, the optimal density of these trees per hectare for association with annual rainfed crops, as well as the methods of their management, were not established, despite the target of 80 individuals per hectare being commonly adopted. Improving agricultural productivity, enhancing its resilience to climate change need to be addressed by introducing adequate agricultural practices that adapt to changes (Yakubu, 2010; Lasco et al., 2014). Agroforestry is a suitable way to achieve it without negative impact on the environment (Umar et al., 2013; Sileshi et al., 2020b; Akodewou et al., 2022).

F. albida-based agroforestry offers substantial direct benefits such as improving soil fertility, providing firewood, and offering fodder. It is a woody fodder too important for animal nutrition (leaves and pods are rich in protein and carbohydrates) and a reliable source of wood energy, as almost all households depend on firewood for cooking. Some studies have shown their efficiency in soil organic carbon (SOC) and soil nitrogen restoration (Sanda and Atiku, 2013; Umar et al., 2013; Haskett et al., 2019). Other research papers have documented tree density ranges (Hadgu et al., 2009; Haile et al., 2021) and pruning to increase crop yield (Dilla et al., 2019) with no consensus on the ideal spacing that maximizes crop yield while reducing competition for light, water, or nutrients. Moreover, the interactions of tree density with crop types, soil conditions, and regional climates are insufficiently explored to successfully scaling agroforestry systems with *F. albida*. To contribute toward closing this gap in existing knowledge, this paper aims to assess the impact of *F. albida* density and its pruning on SOC, soil total nitrogen (STN), and the yields of crops like sorghum and cowpea under dryland farming conditions. It also explores its contribution to rural livelihoods and people's well-being.

MATERIALS AND METHODS

Study area

The study was conducted in the semi-arid part of Cameroon, mainly in Kodek, Mambang, and Parkine (Figure 1). The climate of this zone is tropical and characterized by a unique rainy season. The dry season is longer and more severe as you travel northward, moving away from the Mandara Mountains. Annual rainfall fluctuates between 800 and 1000 mm, mainly from May to October (L'Hote, 2000). The highest amount of rain is recorded between August and September. Local variations of the dry season time pose difficulties for the management of natural resources. The mean monthly temperature varies between 16 and 39ºC. The potential evapotranspiration exceeds 2000 mm while the relative humidity is quite low, with an average of 35% in the plains and 30% in the Mandara Mountains.

A summary of the different characteristics of the studied parklands is presented in Table 1. The main land use and natural vegetation are similar across the three study sites. The natural vegetation of North Cameroon is dry savannah characterized by grass cover, scattered shrubs, and a few trees; dominated by *F. albida*, *Guiera senegalensis*, *Balanites aegyptiaca*, *Ziziphus*

Table 1. Characteristics of study sites.

Site	Kodek	Mambang	Parkine
Annual mean rainfall	800 mm	800 mm	1000 mm
Main soil group	Lixisols, Arenosols	Luvisols	Luvisols
F. albida tree age	≥30 years	20-25 years	10-15 years
Natural vegetation	Savannah	Savannah	Savannah
Major land use	Rainfed agriculture and livestock free grazing in the dry season	Rainfed agriculture and livestock free grazing in the dry season	Rainfed agriculture and livestock free grazing in the dry season
Mean altitude	380 m	600 m	379 m
Geology	Alluvial formations	Alluvial formations, plutonic rocks (gabbro), volcano-sedimentary rocks	Plutonic rocks

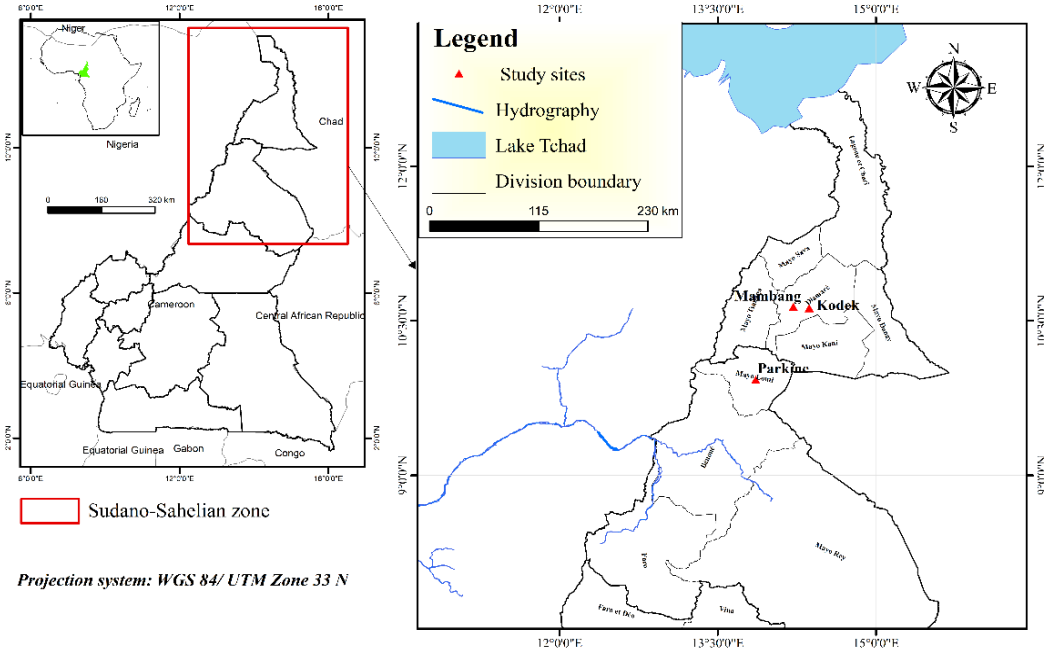


Figure 1. Location of the study sites.

mauritiana (Letouzey, 1985). The geology of the area is made of magmatic, metamorphic and sedimentary rocks. Major soil groups consist of Vertisols, Regosols, Lixisols, Arenosols, Planosols, Luvisols, Fluvisols, and Gleysols (Nanganoa et al., 2020). The landscape is smooth with some gentle slopes. The highlands were represented by the Mandara Mountains, located along the border with Nigeria, where most of the Regosols were developed. The major land uses in this area are for agriculture and grazing. Agriculture is typically rainfed; only some Vertisols are used for dry-season sorghum production; Fluvisols and Gleysols are exploited for market gardening in the dry season. Planosols are usually not used in agriculture but are sometimes allowed for grazing. Erosion and livestock free grazing are the main factors of soil degradation, leading to infertile soils and causing significant negative impacts on woody species.

Parklands delimitation and forest inventory

A forest inventory was conducted in the Kodek and Parkine parklands, as the Mambang parklands exhibited similar characteristics to those of Kodek. These parklands were delineated first and mapped. Kodek parkland was 405 ha, while Parkine parkland was 93 ha. For each site, the coordinates of the boundaries of each field were taken with a Global Positioning System (GPS) to map them. From the map, an inventory plan was defined. The placettes (inventory plots) were carried out. They were circular with a radius of 40 m, while transects were 130 m apart and plots 300 m apart (Figure 2a and b).

In every site, field surveys and target objective of 80 *F. albida* trees per hectare by previous agroforestry initiatives allowed us to distinguish and categorize parklands according to the tree density:

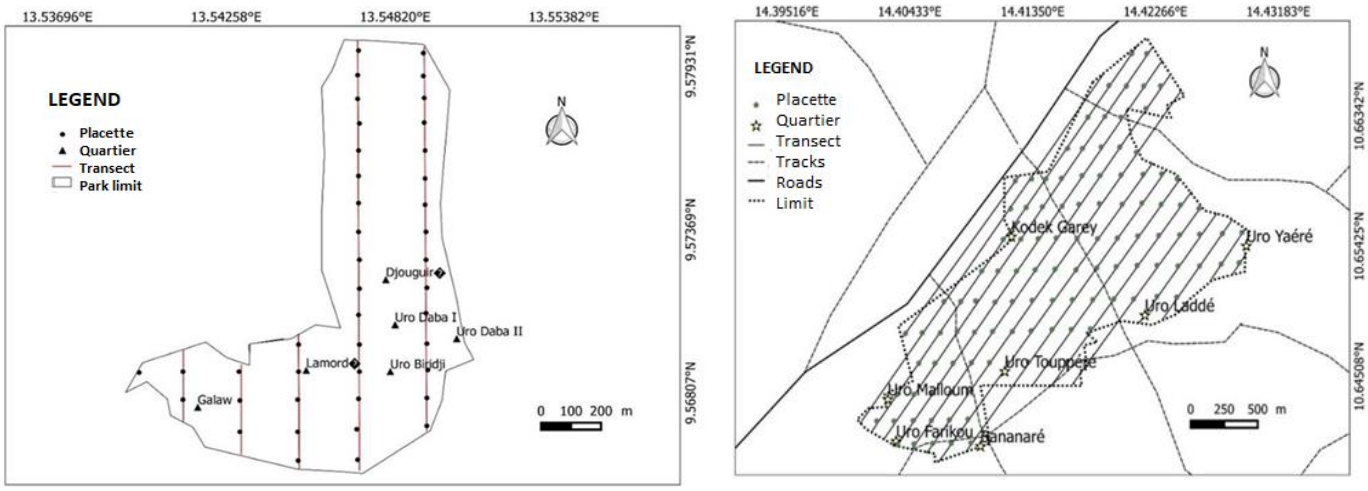


Figure 2. a) Parkine forest inventory plan showing transects and inventory plots, b) Kodek forest inventory plan showing transects and inventory plots.

low (10 - 30 trees/ha), moderate (40 – 60 trees/ha), and high (≥ 80 trees/ha). The trees were pruned in March, before sorghum sowing in June. Pruning involved the removal of all secondary branches, and the pruned material was left in the plots.

Experimental design and data recording

An agronomic field trial was conducted over two consecutive years in Kodek, Parkine, and Mambang to evaluate the effects of *F. albida* density and pruning status on crop performance. In the first year, sorghum was sown, followed by cowpea in the second year. The experiment employed a non-randomized design in which treatments, based on varying *F. albida* tree densities (low, moderate, and high) and pruning conditions (pruned or unpruned), were deliberately selected. Six treatments were applied with 3 control plots adjacent to the low, moderate and high density tree plots each replicated twice, resulting in a total of 18 plots. Each plot measured 100 m², and tree density treatments were defined based on the tertile distribution of tree densities across all plots. Accordingly, low-density plots were influenced by 1 tree, moderate-density plots by 2 trees, and high-density plots by 3 trees. The treatments were as follows:

i) 1= Low density not pruned (10 – 30 trees/ha) = fDNE;
ii) 2= Low density pruned (10 – 30 trees/ha) = fDE;
iii) 3= Moderate density not pruned (40 – 60 trees/ha) = MDNE;
iv) 4= Moderate density pruned (40 – 60 trees/ha) = MDE;
v) 5= High density not pruned (≥ 80 trees/ha) = FDNE;
vi) 6= High density pruned (≥ 80 trees/ha) = FDE;
vii) 7= The control (outside the tree canopy influence) for low-density parkland (TfD);
viii) 8= The control for moderate density parkland (TMD);
ix) 9= The control for high-density parkland (TFD).

The experiment was conducted under a rainfed soil moisture regime. Sorghum is one of the important cereals cultivated in Northern Cameroon and is considered as the main food crop. Cowpea is mainly cultivated in semi-arid part of Cameroon for grains (human consumption) and fodder (animal nutrition). Seeds of sorghum (*Zouaye* variety) and cowpea (*Lori* variety) were sourced from the Institute of Agricultural Research for Development and sown at spacings of 80 × 40 cm for sorghum and 80 × 50 cm for cowpea. The sorghum plants were thinned to 2 plants 2 weeks after planting (62 500 plants/ha). Agronomic data were collected from the central rows of each plot, discarding the border rows.

Soil sampling and analytical procedure

Soil samples were collected from various points within the plots representing different treatments, primarily from the topsoil (0 to 20 cm), before sorghum sowing in the first year of the experiment. At every site, a composite soil sample was obtained by mixing 9 samples collected in each plot, representing each class of density. The same procedure was applied to the control (for every class of density, one plot outside the area of the tree canopy influence was considered as its control plot). Samples were air-dried and passed through a 2 mm sieve to remove coarse fragments. Particle size distribution was determined by the pipette method, after destruction of organic matter and carbonates with hydrogen peroxide (H_2O_2) and then dispersed with sodium hexametaphosphate $(NaPO_3)_6$. Soil pH was measured in water with a pH meter equipped with a glass electrode in 1:2.5 soil-water suspensions. The Walkley-Black procedure (Walkley and Black, 1934) was applied to determine soil organic carbon content (SOC). The total nitrogen was measured by the Kjeldahl method. Available phosphorus was determined by the Bray II method. Exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}) were determined by the ammonium acetate (CH_3COONH_4) extraction method at pH 7.

Household survey

A survey was conducted in Northern Cameroon using a structured questionnaire administered to 60 of the parkland owners, 30 each in Kodek and Mambang where parkland products are commercially utilized. The survey focused on the owners' profiles, including age, primary livelihood activities, income sources, and experience with *F. albida*. It also explored the range of agricultural and non-agricultural products derived from the parklands, their uses, and their contribution to household income.

Data analyses

Collected data from the forest inventory were used to determine the

Table 2. Tree species in the Parkine and Kodek parklands.

Tree species	Parkine		Kodek	
	Abundance	Percentage	Abundance	Percentage
Acacia hockii De wild.	7	1.0	30	2.4
Acacia nilotica (L). Willd. Ex Dell.	0	0	137	11.1
Acacia ataxacantha DC.	0	0	3	0.2
Acacia seyal Dell.	2	0.3	34	2.8
Acacia sieberiana DC.	16	2.4	54	4.4
Acacia senegal (L.) Will.	-	-	3	0.2
Adansonia digitata L.	2	0.3	3	0.2
Anacardium occidentalis L.	2	0.3	-	-
Annona senegalensis Pers	2	0.3	1	0.1
Anogeissus leiocarpus (DC.) Guill. et Perr.	55	8.2	-	-
Azadirachta indica A. Juss	65	9.7	135	11.0
Balanites aegyptiaca (L.) Del.	24	3.6	101	8.2
Borassus aethiopum Mart.	1	0.1	21	1.7
Boswellia dalzielii Hutch.	5	0.7	1	0.1
Calotropis procera (Ait.) Ait. f.	2	0.3	13	1.1
Carica papaya L.	1	0.1	-	-
Cassia sieberiana DC.	1	0.1	-	-
Celtis integrifolia Lam.	2	0.3	-	-
Combretum aculatum Vent.	5	0.7	57	4.6
Combretum glutinosum Perr. ex DC.	3	0.4	-	-
Combretum micranthum G. Don	19	2.8	2	0.2
Combretum nigricans Lepr. ex Guill. et Perr.	7	1.0	-	-
Cassia singueana (Del.) Lock	7	1.0	-	-
Commiphora africana (A. Rich.) Engl.	13	1.9	-	-
Dalbergia melanoxylon Guill. et Perr.	-	-	10	0.8
Dichrostachys cinera (L.) Wight et Arn.	1	0.1	-	-
Diopirus mespiliformus Hochst.ex A. Rich.	16	2.4	-	-
Eucalyptus camaldulensis Dehnh.	4	0.6	-	-
Faidherbia albida (Del.) Chev.	260	38.7	505	41.0
Ficus gnaphalocarpa (Miq.) C. C. Berg	8	1.2	-	-
Ficus platyphylla Del.	2	0.3	-	-
Ficus thonningii Blume	1	0.1	-	-
Haematostaphis barteri Hook. f.	3	0.4	-	-
*Hexalobus menopetalu*s (A. Rich.) Engl. et Diels	3	0.4	-	-
Hyphaene thebaica (L.) Mart.	-	-	26	2.1
Jatropha curcas L.	4	0.6	-	-
Khaya senegalensis (Desr.) A. Juss.	3	0.4	-	-
Lannea microcarpa Engl. et K. Krause	6	0.9	-	-
Mangifera indica L.	2	0.3	-	-
Mitragyna inermis (Willd.) Kuntze	-	-	2	0.2
Piliostigma reticulatum (DC.) Hochst.	20	3.0	-	-
Piliostigma thonningii (Schumach.) Milne-Redh.	16	2.4	-	-
Psidium guajava L.	6	0.9	-	-
Sclerocarya birrea (A. Rich.) Hochst.	10	1.5	-	-
Senna singueana (Del.) Lock	1	0.1	-	-
Sterculia setigera Del.	3	0.4	-	-
Tamarindus indica L.	16	2.4	-	-
Terminalia avicenoides Guill. et Perr.	1	0.1	-	-
Vitex doniana Sweet	4	0.6	-	-
Ziziphus mauritiana Lam.	39	5.8	82	6.7

Table 2. Cont'd

Ziziphus spina-christi (L.) Desf.	1	0.1	12	1.0
Total	671	100.0	1232	100.0

Shannon-Weaver diversity index (Shannon and Weaver, 1963) for each parkland. The formulas were applied:

$$H' = -\sum_{i=1}^{n} Pi \times \ln(Pi)$$

$$Pi = \frac{ni}{N}$$

With H′ the diversity index, Pi the specific richness or the proportion of individuals belonging to species *i* in the considered parkland, *ni* the number of each species in the parkland, N the total number of individuals for all species in the parkland, and ln(*Pi*) the natural logarithm of this proportion (Shannon and Weaver, 1963). Soil data were analyzed using descriptive statistics (mean and standard deviation) in R software to summarize the results. Analysis of variance (ANOVA) was performed on particle size distribution, SOC, STN and crop yield data. Tukey's post-hoc test was applied to compare the means and identify statistically significant differences at the 5% significance level.

RESULTS AND DISCUSSION

Woody diversity and characteristics of parklands

The woody diversity of the studied parklands is moderate, with the diversity index of 2.99 (Parkine) and 2.98 (Kodek). In Kodek, 21 different tree species were recorded; *F. albida* represented 41% of the total trees in the parkland. It was followed by *Acacia nilotica* (11.1%), *Azadirachta indica* (11%), and *B. aegyptiaca* (3.6%). In Parkine, the parkland was more diversified with 45 different tree species (Table 2). *F. albida* is the dominant tree species (38.7%), followed by *A. indica* (9.7%), *Anogeissus leiocarpus* (8.2%), and *Z. mauritiana* (5.8%). In semi-arid areas, agriculture is a threat to biodiversity conservation. This is why the parklands were less diverse in tree species. The high proportion of *F. albida* density is linked to the agroforestry initiatives, which promoted its conservation in farmlands during the 1994–2002 periods (Akodewou et al., 2022). Farmers were encouraged to assist the growth of their naturally regenerated plants in their farms (Gautier et al., 2002).

Soil physicochemical properties

The soil's clay content was globally low (10.7 to 28.7%). The coarse sand fraction was the dominant particle size, which reached 54.5% in Parkine. Except for the fine sand fraction between Kodek and Mambang, significant differences in soil particle size distribution were observed among the study sites (Figure 3). Parkine soils had a significantly higher sand content ($p < 0.05$), while Mambang exhibited significantly higher clay fraction ($p < 0.05$) compared to the other sites. These differences in particle size distribution can be attributed to the nature of the soils and their parent materials.

Specifically, Lixisols and Arenosols are found in Kodek, whereas Luvisols dominate in Parkine. The soils in Kodek and Mambang are derived from alluvial materials, while those in Parkine are formed from plutonic rocks.

The pH_w of the soils ranges from slightly acidic to slightly basic (Table 3). Similar soil pH has been reported by Nanganoa et al. (2020) in Northern Cameroon. The slightly basic pH values were observed mainly in high-density *F. albida* plots. Available P, exchangeable Ca, Mg, and K were also above the critical level in these plots (Nanganoa et al., 2020). The high standard deviation (SD) and variance (V) observed for available phosphorus and coarse sand indicate considerable variation across the different plots (Table 3).

Effect of *F. albida* density and pruning on SOC

SOC results showed that values from the control plots differed from those under the *F. albida* tree canopy of (Figure 4a). The control plots recorded the lowest SOC levels compared to the plots influenced by tree canopies. However, only the high tree density plots (FDE and FDNE) had significantly higher SOC than the control plots ($p < 0.05$). The SOC levels in the high-density plots were not significantly different from those in the moderate and low tree density classes ($p > 0.05$).

Across all tree density classes, pruned plots exhibited higher SOC than their corresponding unpruned plots, though the differences were not statistically significant ($p > 0.05$) (Figure 4a). This suggests that prunings (leaves, stems, etc.) may have contributed to increase SOC. The contribution of *F. albida* to SOC has been documented by several authors (Umar et al., 2013; Haskett et al., 2019; Akpalu et al., 2020). Pruning appeared to be the most effective management practice for improving soil organic matter under these trees. However, Sida et al. (2018a) reported that complete pruning prevented seed production for up to six years, posing a significant risk to the species' conservation. Overall, soil organic carbon was lowest in low tree density areas and highest in plots with high tree density.

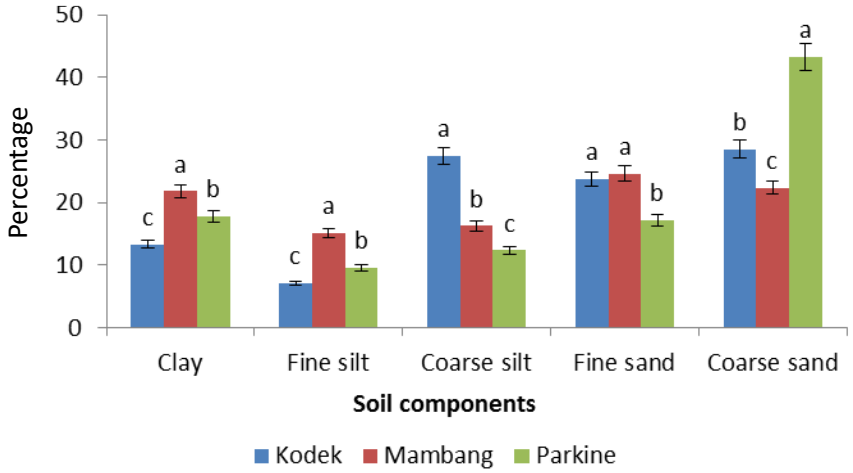


Figure 3. Variation in particle size distribution between sites (Means without the same letter are significantly different ($p < 0.05$) according to Tukey's test).

Effect of *F. albida* density and pruning on soil total nitrogen

STN content in the different parklands was generally low, ranging from 0.28 to 2.27 g kg^{-1}. The mean STN values in the control plots were the lowest compared to all tree density classes (Figure 4b). However, no significant differences were observed among the treatments ($p > 0.05$). Among the plots under tree canopies, STN decreased with decreasing tree density: the lowest values were recorded in the low tree density unpruned plots (FDNE), while the highest values were observed in the high-density pruned plots (FDE) (Figure 4b). Overall, pruned plots exhibited higher total nitrogen levels across all tree density classes, suggesting that pruning may enhance soil total nitrogen content. Similar results were obtained in other semi-arid environments (Gindaba et al., 2005; Mbow et al., 2014; Sida et al., 2018b; Akpalu et al., 2020). Woody tree legumes are N_2 fixing trees and their ability to improve soil nitrogen through their root system symbiosis with rhizobium are highly documented (Gindaba et al., 2005; Yakubu, 2010; Basga et al., 2018; Sida et al., 2018b). Kho et al. (2001) noted that the nitrogen availability under *F. albida* tree was more than 200% higher than outside the canopy. Furthermore, through the litter falls and pruning, N is released to the soil and improves the STN (Mubarak et al., 2012; Sanda and Atiku, 2013; Haskett et al., 2019; Akpalu et al., 2020). The level of improvement is highly dependent on soils characteristics and local environment. It is well known that organic matter mineralization in the sudano-sahelian zone is affected by local temperature and the duration of dry season (Tsozué and Yakouba, 2016).

Also, the amount of shed leaves per year strongly influences the rate of nitrogen release in the soil (Akpalu et al., 2020). Soil phosphorus content is well known for its positive effect on N_2 fixation rate by leguminous trees and STN (Isaac et al., 2011). The high variation of available P and diversity of tree species present in the parklands is another fact that might explain differences in SOC and STN between the studied parklands (Saha and Jha, 2012).

Effect of pruning and *F. albida* density on crop yields

The mean yields of rainfed sorghum across treatments are presented in Figure 5a. Although no statistically significant differences were detected among the treatments ($p > 0.05$), higher yields were consistently observed under the tree canopy plots compared to the control plots. Among these, pruned plots outperformed unpruned ones. The highest mean sorghum yield (2.269 ± 0.590 t ha^{-1}) was recorded in the pruned moderate tree density treatment, while the lowest yields occurred in the control plots. Similarly, no significant differences were found in cowpea yields among treatments (Figure 5b). However, the highest cowpea yields (1.854 ± 0.282 t ha^{-1}) were observed in the unpruned moderate tree density plots. The positive influence of *F. albida* on crop yields has been well documented in previous studies (Kho et al., 2001; Abasse et al., 2021; Roupsard et al., 2020). Both tree pruning and litter fall facilitate nutrient transfer from trees to crops via the soil. Specifically, prunings (leaves and stems) decompose in situ, releasing nutrients that improve soil fertility (Saha and Jha, 2012; Haskett et al., 2019; Akpalu et al., 2020), thereby enhancing crop productivity. In the Sahel zone, the beneficial effects of *F. albida* on crops are also attributed to the microclimate it creates on farms. This microclimate protects crops from extreme weather conditions such as high temperatures, drought, and heavy rainfall; and helps maintain soil moisture for extended periods (Kalinda et al., 2015; Sida et al., 2018b; Dobhal et al., 2024).

Table 3. Summary statistics of physico-chemical characteristics of composite topsoil (0-20 cm).

Statistic	Clay	Fine silt	Coarse silt	Fine sand	Coarse sand	Humidity	pH_w	OC	Total N	P av	Ca^{2+}	Mg^{2+}	K^{+}
Unit				**%**				**g/kg**	**g/kg**	**mg/kg**		**cmol/kg**	
N	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00	27.00
Min	10.70	2.90	8.00	4.90	0.60	0.50	6.00	2.72	0.28	4.86	4.07	0.12	0.00
Max	28.70	24.80	57.00	30.00	54.50	5.71	7.97	16.83	2.27	59.68	10.79	9.18	13.25
Median	18.30	10.30	14.80	22.40	35.20	1.73	6.90	8.29	0.84	19.33	5.51	1.32	1.55
Mean	17.63	10.53	18.67	21.82	31.36	1.77	6.86	9.06	0.86	20.47	5.72	1.84	2.48
V	21.48	29.57	115.96	39.60	194.55	1.11	0.20	12.27	0.21	196.20	2.24	4.16	9.96
SD	4.63	5.44	10.77	6.29	13.95	1.05	0.45	3.50	0.46	14.01	1.50	2.04	3.16
CV	0.26	0.51	0.57	0.28	0.44	0.58	0.06	0.38	0.53	0.67	0.26	1.09	1.25
SDm	0.89	1.05	2.07	1.21	2.68	0.20	0.09	0.67	0.09	2.70	0.29	0.39	0.61
SDv	5.96	8.20	32.16	10.98	53.96	0.31	0.06	3.40	0.06	54.42	0.62	1.15	2.76

n= Number of observations, V=Variance, SD=Standard deviation, CV=Coefficient of variation, SDm=Standard deviation of the mean, SDv=Standard deviation of the variance.

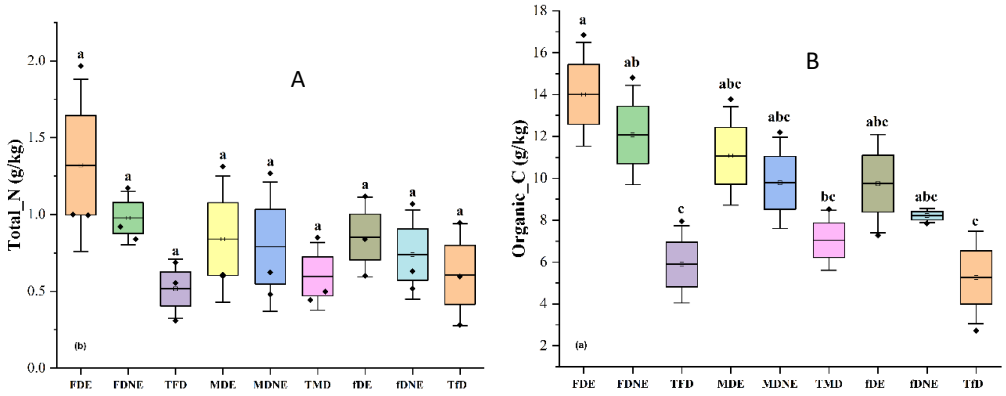


Figure 4. Soil organic Carbon (A) and soil total nitrogen (B) contents.
(Means without the same letter are significantly different ($p < 0.05$) according to the Tukey's test).

Farmer's experiences and benefits from *F. albida* agroforestry systems

Maintaining these trees in the farms is an old practice in Northern Cameroon. It has been driven for a long time by indigenous knowledge. Farmers usually conserve trees that provide some benefits to soil fertility. Some species with high medicinal values or which are good livestock fodders are also well managed in farms. Farmers usually protect sprouts and young plants during agricultural operations such as tillage and mechanized weeding. While *F. albida* has been adopted successfully in agroforestry by farmers in Northern Cameroon, other agroforestry practices might not have been as widely embraced due to factors like economic incentives, labour requirements, ecological suitability, or simply a

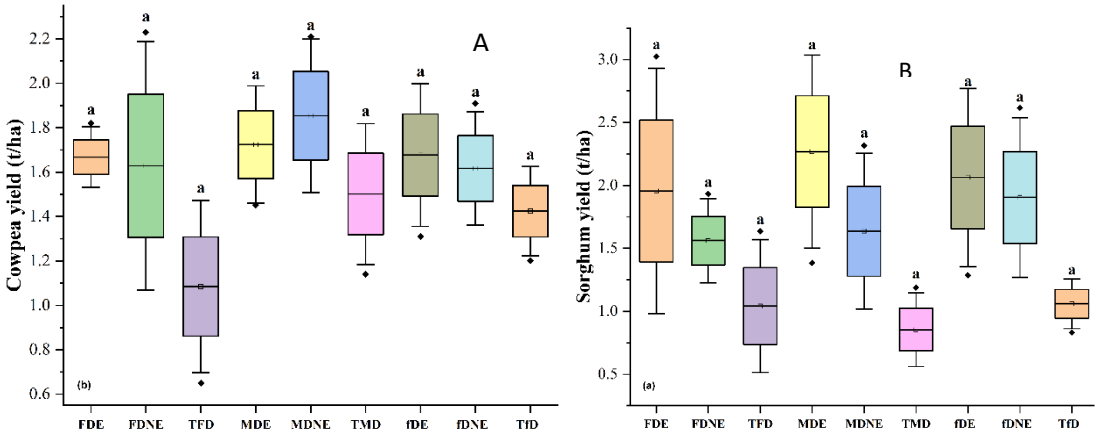


Figure 5. Sorghum (a) and cowpea (b) yield according to treatments.
(Means without the same letter are significantly different ($p < 0.05$) according to the Tukey's test).

lack of awareness. This success is also related to the fact that this system matched well with their indigenous knowledge (Gautier et al., 2002). Agroforestry provides some environmental and social benefits as part of farmer's livelihood in rural areas (Mbow et al., 2014; Castle et al., 2021; Dobhal et al., 2024). *F. albida* in North Cameroon is considered as a multipurpose species. In addition to its nutrient enhancement on soils, it usually provides wood fuel and remains a good fodder (pods and leaves) for animals and timber for building houses (Gautier et al., 2002; Akodewou et al., 2022). Pruning trees provides wood for which 81.67% is used as fuel wood and 18.33% as utility wood. About 3,000 kg of firewood per year is sold on average for 5,840 XAF (around 9 $) in Kodek, while in Mambang, the parkland generated an income of about 5,625 XAF (Table 4). Firewood is the main accessible source of energy for the population of the Sahelian part of Cameroon and constitutes a flourishing activity in Maroua, the regional capital city near Kodek and Mambang, yielding income to the modest households (Folefack and Sale Abou, 2009; Gautier and Van Santen, 2014; Akodewou et al., 2024). The tree provides pods, which are another commercial non-timber product with high local commercial value. Wood obtained by pruning and collected pods provided an average income of 21,090 XAF/household (around 33.5 $/household) in Kodek and 9,625 XAF/household (around 15 $) in Mambang. Altogether, agricultural and non-agricultural products from the parklands contributed on average 58.7 ± 19.9% (Mambang) and 56.1 ± 18.5% (Kodek) to the annual total household income (Table 4).

Implications of the study on climate-smart agriculture (CSA)

F. albida is a crucial tree species for climate-smart agriculture because of its multifaceted benefits that align with CSA's goals of improving agricultural productivity, enhancing resilience to climate change, and promoting environmental sustainability. By improving soil fertility, conserving water, enhancing biodiversity, and providing valuable income-generating products, it contributes significantly to building resilient agricultural systems in the face of a changing climate in northern Cameroon. Its integration into agroforestry systems offers a powerful tool for farmers to adapt to the challenges of climate change while simultaneously contributing to climate change mitigation. Thus, it is a nature-based solution for climate change effects. By limiting the use of urea, the amount of CO_2 emitted into the atmosphere, one of the main causes of climate change, is reduced. Indeed, the production and transportation of urea require energy, which relies on fossil fuels (Haskett et al., 2019). It is also highly appreciated for providing shade as the Sudano Sahelian area of Cameroon experiences a high rate of sunshine and drought in the dry season (Gautier and Van Santen, 2014; Akoni et al., 2025).

Conclusion

The main goal of this study was to investigate the impact of *F. albida* tree density and pruning on SOC, STN, crops (sorghum and cowpea) yields, and their contribution to people's livelihoods under dryland conditions. Results highlighted how the STN and SOC increase with tree density and pruning in parklands. Crop yields under this tree canopy were higher than those outside the tree crown and varied widely with the tree density class in the parkland. The 40 - 60 *F. albida* trees per hectare was the optimal density class to ensure high crop yields. Maintaining the trees in farms provides supplementary products (wood fuel, utility wood, and fodders for animals) which contribute to the household's livelihood. The contribution of these products was, on average, 58.7

Table 4. Annual household incomes generated by the parklands in far North Cameroon.

Site	Wood	Pods	Cultivated crops	Total
Kodek	5.840 ± 1.315	15.250 ± 1.000	718.780 ± 193.050	739.870 XAF
Mambang	5.625 ± 1.570	4.000 ± 3.270	356.610 ± 93.220	366.235 XAF

± 19.9% (Mambang) and 56.1 ± 18.5% (Kodek) to the total household income. The findings indicated that *F. albida* is a key agroforestry tree that plays a crucial role in people's livelihoods and should be extensively promoted in Northern Cameroon to mitigate the effects of climate change on agriculture and diversify household incomes.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

This work was supported by the French Development Agency (AFD) under the C2D/PAR program. The authors thank the farmers from the study area for their involvement in the trials and the survey. The support from IRAD in the implementation of field activities is highly appreciated.

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