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Silvicultural Management and Ecological Implications of Pruning Biomass in a Date Palm (*Phoenix dactylifera* L.) Plantation in Semi-Arid Northern Nigeria

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ABSTRACT

Pruning is a critical silvicultural practice in date palm (*Phoenix dactylifera* L.) plantations, helping maintain canopy structure, improve productivity, and support ecological functions. In semi-arid Northern Nigeria, pruning generates substantial biomass that is often underutilized, leading to nutrient loss and reduced ecosystem efficiency. This study quantified pruning biomass and examined its ecological implications in the Garkuwa Date Palm Plantation, Sokoto State. A total of 748 trees, planted in 2003, were assessed across four plantation sections (GDPP I, II, III, and W). Pruned materials were categorized into branches, fronds, and leaflets, with fresh weight measured in the field and subsamples oven-dried at 70°C for 48 h to estimate dry biomass. Results indicated that branches contributed the largest proportion of biomass, peaking in GDPP III (2.9 kg/tree), while GDPP W recorded the lowest values. ANOVA revealed significant differences among sections ($F = 5.62$, $p < 0.01$), highlighting spatial variability in pruning yield. Visually estimated crown diameter correlated strongly with total biomass ($r = 0.62$, $p < 0.01$), confirming its utility as a practical predictor for residue management, whereas uniform stand age showed no significant effect. The study demonstrates the ecological value of pruning residues in nutrient cycling, soil fertility enhancement, and carbon sequestration. It further supports the use of crown diameter for estimating biomass in mature plantations. Integrating biomass management into silvicultural planning can improve resource efficiency and sustainability in semi-arid date palm agroecosystems.

INTRODUCTION

Date palm (*Phoenix dactylifera* L.) is a perennial, drought-tolerant fruit crop widely cultivated in arid and semi-arid regions, where it contributes significantly to food security, rural livelihoods, and agro-ecosystem stability. Its physiological adaptation to high temperature, low rainfall, and marginal soils makes it particularly suitable for dryland environments where crop options are limited (Chao & Krueger, 2007). The integration of date palm into agroforestry systems supports sustainable land-use practices by combining ecological stability with productive agriculture, particularly in dryland regions where environmental constraints require optimized resource use strategies (Nair, 2011).

In semi-arid regions, pruning is a fundamental silvicultural practice used to regulate canopy structure, improve productivity, and maintain plantation hygiene. Date palm plantations are often managed under agroforestry-based systems that integrate ecological sustainability with productive land management. These systems promote spatial optimization of tree spacing, canopy structure, and resource use efficiency, enhancing both productivity and environmental resilience (Nair, 2011). However, pruning generates substantial quantities of biomass, including fronds and leaf residues, which are often underutilized or disposed of indiscriminately by burning or dumping. Such practices contribute to nutrient loss, reduced soil organic matter inputs, and potential environmental hazards, including increased fire risk and greenhouse gas emissions. From a soil ecological perspective, plant residues play a critical role in organic matter formation, nutrient cycling, and long-term soil fertility maintenance, particularly in nutrient-limited dryland ecosystems (Lehmann & Kleber, 2015). Therefore, the management of pruning biomass is not only a silvicultural concern but also a key component of ecosystem sustainability.

Biomass allocation and structural development in perennial crops significantly influence productivity, resource use efficiency, and ecological stability. Patterns of carbon distribution between roots, stems, and canopy components determine plant growth performance and resilience under environmental stress. Empirical evidence from global plant ecological studies shows that biomass partitioning follows predictable patterns across species and environments, with strong implications for canopy development and overall productivity (Poorter *et al.,* 2012). However, such relationships remain insufficiently quantified in many African plantation systems, including date palm agroecosystems, where management practices are often traditional and data-driven silvicultural optimization is limited.

Dryland ecosystems, including the Sudano–Sahelian zone of Nigeria, are characterized by low and highly variable rainfall, high evapotranspiration rates, and inherently low

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soil organic carbon levels. These conditions make them particularly sensitive to biomass removal and residue management practices, as organic inputs are essential for maintaining soil fertility and ecosystem functioning. Carbon cycling in such environments is strongly influenced by vegetation inputs and residue retention, making biomass recycling a key strategy for enhancing soil carbon storage and ecosystem resilience (Lal, 2020). Consequently, the management of pruning residues in date palm plantations has direct implications for both soil quality and long-term sustainability.

Despite the importance of date palm in semi-arid agroecosystems, there remains a significant knowledge gap regarding the quantity, distribution, and ecological implications of pruning biomass in Nigerian plantations. Limited empirical studies have quantified pruning outputs or evaluated their potential reuse pathways within local management systems. This gap restricts the development of evidence-based silvicultural recommendations and limits the integration of biomass recycling into plantation management strategies.

The present study therefore addresses this gap by quantifying pruning biomass across distinct plantation sections, assessing the distribution of biomass components, and examining relationships between tree morphological characteristics and biomass allocation patterns. By generating empirical data on pruning biomass dynamics, the study aims to inform sustainable silvicultural practices that enhance nutrient retention, improve ecosystem resilience, and promote efficient utilization of pruning residues. Ultimately, this research contributes to advancing sustainable date palm plantation management in semi-arid environments where ecological constraints and livelihood dependence necessitate optimized resource use.

MATERIALS AND METHODS

Study Area

The study area is characterized by semi-arid conditions typical of global dryland ecosystems, where water scarcity, high evapotranspiration, and soil nutrient limitations strongly influence vegetation performance and management outcomes (Lal, 2020). These environments are characterized by low and highly variable rainfall, high temperatures, and inherently low soil organic carbon levels, which significantly affect plant growth, biomass accumulation, and ecosystem productivity.

Such conditions make vegetation and residue management essential for maintaining soil fertility and ecological stability (Lal, 2020). The plantation was established in 2003 and managed under standard silvicultural practices, including regular pruning and a uniform spacing arrangement of 5 × 5 m, which supports canopy development, light penetration, and operational accessibility (Chikamai *et al.,* 2004).

Sampling and Plantation Layout

A total of 748 date palms were assessed across four sections: GDPP I, GDPP II, GDPP III, and GDPP W. All trees were approximately 21 years old, ensuring uniform stand conditions. Each tree was included in the assessment to provide full replication. Crown diameter was visually estimated and cross-checked with plantation records and used as a proxy for above-ground biomass due to its strong relationship with canopy development

Pruning Biomass Collection

Pruned materials were categorized into branches, fronds, and leaflets. Fresh weight was measured using a hanging scale. A 10% subsample of each component was oven-dried at 70°C for 48 hours to determine dry matter content. Total dry biomass per tree was estimated using moisture correction factors. This approach aligns with biomass utilization frameworks that emphasize efficient conversion of plant residues into usable ecological or energy resources (Kim & Lee, 2022)

Data Analysis

Descriptive statistics summarized biomass variation across sections. Pearson correlation was used to assess relationships between crown diameter, age, and biomass. One-way ANOVA with Tukey's test was applied for sectional comparison. Analyses were conducted using SPSS v26 and R v4.3.1

Ecological Implications

The ecological functions of pruning biomass were evaluated in terms of decomposition, nutrient cycling, and habitat provision, drawing on the dryland agroforestry literature (Hassani *et al.,* 2021; Zhao *et al.,* 2023).

RESULTS AND DISCUSSION

Pruning Biomass Distribution Across Plantation Sections

Pruning biomass varied significantly across plantation sections, with branches consistently contributing

Table 1: Pruning Biomass Distribution by Plantation Section

Section	Tree No.	Row No.	Component	Weight (kg)
GDPP W	–	–	Leaves	0.9
	–	–	Branches	1.6
GDPP I	7	6	Leaves	0.7
	7	6	Branches	2.1
	8	5	Leaves	0.9
	8	5	Branches	1.5
	10	3	Leaves	1.2

	10	3	Branches	1.9
GDPP II	2	3	Leaves	0.9
	2	3	Branches	2.2
	3	2	Leaves	0.7
	3	2	Branches	1.6
GDPP III	6	1	Leaves	0.9
	6	1	Branches	2.4
	7	1	Leaves	0.6
	7	1	Branches	2.0
	8	2	Leaves	1.9
	8	2	Branches	2.9

the largest proportion. Spatial variation reflects environmental heterogeneity commonly observed in dryland agroecosystems (García *et al.,* 2023; Hassani *et al.,* 2021). GDPP III recorded the highest biomass, while GDPP W showed reduced productivity, likely due to site-specific environmental constraints such as soil fertility and moisture availability.

Sectional Variation in Total Biomass (ANOVA)

Significant differences in biomass production were observed among plantation sections (Table 2). The significant variation in biomass among sections ($p < 0.05$) indicates that plantation productivity is not uniform. GDPP II exhibited the highest mean biomass, likely due to relatively larger crown development and favorable micro-site conditions. This finding aligns with recent studies emphasizing that biomass production in semi-arid plantations is strongly influenced by localized environmental factors such as soil organic matter, nutrient availability, and water retention capacity (Ayele *et al.,* 2022; García *et al.,* 2023). It also reinforces the importance of precision silviculture, where management practices are tailored to site-specific conditions to enhance productivity.

Table 2: Sectional Variation in Total Biomass (ANOVA)

Source	df	F-value	p-value	Significant Difference (Tukey)
Between Sections	2	5.62	0.004	GDPP II > GDPP I, GDPP III ($p < 0.05$)
Within Sections	745			
Total	747			

Relationship Between Tree Characteristics and Biomass

Crown diameter showed a strong positive correlation with biomass, confirming canopy size as a reliable predictor of pruning biomass. Biomass allocation patterns in perennial systems are strongly influenced by canopy structure and follow predictable ecological scaling relationships (Poorter *et al.,* 2012; Singh *et al.,* 2023).

Table 3: Pearson Correlation Between Tree Characteristics and Pruning Biomass

Variable	Total Biomass (kg/tree)
Stand Age (~21)	0.05 (ns)
Crown Diameter (m)	0.62**

*** = Significant at p < 0.01 ns = Not significant Stand age is uniform (~21 years), limiting variability*

Ecological Implications of Pruning Biomass Components

Retention of pruning residues enhances soil organic matter, nutrient cycling, and carbon storage in dryland ecosystems (Lal, 2020; Zhao *et al.,* 2023). Improper disposal reduces soil fertility, while integrated biomass management improves ecosystem resilience. Biomass utilization also supports circular economy approaches in agroforestry systems (Kim & Lee, 2022).

Table 4: Ecological Roles and Management Implications of Pruning Biomass

Component	Ecological Function	Management Use
Fronds	Soil cover, moisture retention, nutrient recycling	Mulching, composting
Leaflets	Rapid decomposition, nutrient release	Green manure, organic fertilizer
Branches	Slow decomposition, carbon storage, habitat provision	Firewood, carbon sequestration, habitat enrichment

CONCLUSION

Pruning biomass in mature date palm plantations represents a significant but underutilized ecological resource. Spatial variation in biomass production reflects environmental heterogeneity typical of dryland ecosystems, while crown diameter serves as a reliable predictor of biomass yield. These findings support climate-smart silvicultural practices that enhance carbon sequestration and soil fertility in semi-arid landscapes (Lal, 2020; Zhao *et al.,* 2023).

Recommendations

Based on the findings of this study, the following recommendations are proposed to enhance sustainable silvicultural management and ecological efficiency in date palm plantations:

1. Retain and utilize pruning residues for mulching and composting to improve soil fertility.
2. Explore value-added uses of branch biomass such as bioenergy and carbon storage.
3. Use crown diameter as a practical tool for biomass estimation and management planning.
4. Implement site-specific management practices to address productivity variations.
5. Promote sustainable biomass utilization to reduce fire risk and environmental degradation.
6. Support training and extension services on silvicultural best practices.
7. Encourage further research on biomass decomposition and nutrient cycling.

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