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Assessment of soil aggregate stability and root biomass distribution in agroforestry-based cropping systems

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Abstract

According to leading soil scientists, aggregate stability is the single best physical indicator of soil health—and it is one of the first properties to collapse under continuous monoculture in the tropics. This research assessed soil aggregate stability and root biomass distribution across three agroforestry-based cropping systems, two sole crop monocultures, and a natural forest reference in the sub-humid zone of southwestern Nigeria. Field measurements were taken at the University of Ibadan Teaching and Research Farm between June 2022 and May 2023 on plots established eight years earlier. Mean weight diameter (MWD) of soil aggregates in agroforestry systems ranged from 2.71 to 2.94 mm, significantly higher than monoculture plots (1.72-1.83 mm) and approaching natural forest values (3.24 mm). Root biomass in the top 10 cm was 2.1-2.4 times greater under agroforestry than monoculture, and a strong positive correlation ($r = 0.89$, $p < 0.001$) was found between root biomass and MWD. Agroforestry systems also showed higher soil organic carbon, porosity, and infiltration rates. These results confirm that tree-crop combinations can rebuild aggregate structure on degraded tropical soils within a decade.

Keywords: Soil aggregate stability, root biomass, agroforestry, mean weight diameter, water-stable aggregates, organic carbon, infiltration, tropical soils, monoculture, land-use systems

Introduction

The eminent soil physicist Rattan Lal once described soil structure as “the architecture that holds the soil together,” and nowhere is that architecture more threatened than in the humid and sub-humid tropics, where intensive cropping without tree cover can destroy aggregate stability within a few years ^[1]. When aggregates break down, the consequences cascade: pore space collapses, infiltration drops, runoff increases, and the soil’s capacity to store water and nutrients for crops declines sharply ^[2].

Agroforestry—the deliberate integration of trees with crops or livestock—has long been promoted as a way to reverse this degradation. Trees contribute to aggregate formation through multiple pathways: their roots physically enmesh soil particles, their litter adds organic binding agents, and the mycorrhizal networks associated with tree roots produce glomalin, a glycoprotein that cements microaggregates into macroaggregates ^[3, 4]. But most evidence for these effects comes from temperate systems or from short-term measurements that may not reflect the equilibrium state ^[5].

Root biomass distribution is a key but under-studied driver of aggregate stability in agroforestry. While aboveground biomass is routinely measured, the below-ground contribution—which may represent 20-40% of total tree biomass—is far harder to quantify and is often ignored ^[6]. This research assessed both aggregate stability and root biomass at five depth intervals across six land-use systems, including three agroforestry combinations, two monocultures, and a natural forest reference, in southwestern Nigeria.

Research Area Description

The research was conducted at the University of Ibadan Teaching and Research Farm (7.4437° N, 3.8997° E, elevation 227 m) in Oyo State, southwestern Nigeria. The site has a sub-humid tropical climate with bimodal rainfall (April-July and September-November), a mean annual total of 1,218 mm, and mean temperature of 26.4°C. Soils are Ferric Luvisols (Alfisols) with a

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sandy clay loam texture. The agroforestry plots were established in 2015 on land that had been under continuous maize for seven years prior. The natural forest reference was a secondary forest at least 30 years old located 800 m from the experimental plots.

Materials and Methods

Materials

Six land-use systems were compared: (1) *Parkia biglobosa* + maize (alley cropping), (2) *Leucaena leucocephala* + cassava (alley cropping), (3) *Gliricidia sepium* + yam (relay cropping), (4) sole maize, (5) sole cassava, and (6) natural secondary forest. Tree spacing was 4 m between rows with crop alleys of 4 m. All cropped plots received 60-30-30 kg NPK/ha per season. Soil samples were collected using a stratified random approach at five depth intervals (0-10, 10-20, 20-30, 30-40, and 40-50 cm) with four replications per land-use system.

Methods

Aggregate stability was measured by the wet-sieving method of Yoder ^[7], passing air-dried aggregates (4-8 mm) through a nest of sieves (4, 2, 1, 0.5, 0.25 mm) for 10 minutes. Mean weight diameter (MWD) was calculated as the sum of (mean diameter of each fraction × proportion of total weight in that fraction). Water-stable aggregates (WSA) >0.25 mm were expressed as a percentage of total soil. Root biomass was determined by extracting roots from soil cores (8 cm diameter) over a 0.5 mm sieve, washing with water, oven-drying at 65°C, and weighing ^[8]. Organic carbon was measured by Walkley-Black, porosity by core method, and infiltration rate using a double-ring infiltrometer ^[9]. Pearson correlation analysis was used to assess

the relationships between root biomass, organic carbon, and MWD. All data were analysed by one-way ANOVA in GenStat 20 with LSD at $p \leq 0.05$.

Soil Chemical Analysis

Soil chemical properties were analysed at 0-20 cm depth to complement the physical measurements. Agroforestry plots had 56-68% more organic carbon than sole crop plots. Available nitrogen (alkaline KMnO_4 method) ranged from 147 to 168 kg/ha under agroforestry compared to 89-97 kg/ha under monoculture. Soil pH was slightly higher under agroforestry (6.12-6.28) than monoculture (5.78-5.84), likely due to the base-cycling effect of deep-rooted trees returning calcium and magnesium from lower soil layers through litter decomposition.

Limitations

This research compared systems established only eight years earlier, which may not reflect the full equilibrium state of agroforestry effects on soil structure. The natural forest reference, while valuable, differed from the experimental plots in management history and age, making direct comparisons approximate. Root biomass sampling by coring underestimates large structural roots (>5 mm), so the actual below-ground biomass of tree-based systems is likely higher than reported here. Future research should incorporate trenching or ground-penetrating radar approaches for more complete root architecture mapping.

Results

Table 1: Soil physical properties and root biomass across land-use systems (0-10 cm depth)

Land-Use System	MWD (mm)	WSA >0.25mm (%)	Org. C (%)	Root Biomass (g/m ²)	Porosity (%)	Infiltration (mm/h)
Parkia+Maize	2.87	64.3	1.84	487	48.7	42.3
Leucaena+Cassava	2.94	67.8	1.92	524	49.4	44.8
Gliricidia+Yam	2.71	61.4	1.78	463	47.2	39.7
Sole Maize	1.83	42.1	1.14	218	38.6	24.1
Sole Cassava	1.72	39.8	1.08	196	37.1	21.8
Natural Forest	3.24	74.6	2.38	612	54.3	58.7

Agroforestry systems had MWD values 48-71% higher than monocultures (Table 1). *Leucaena*+cassava recorded the highest MWD (2.94 mm) and root biomass (524 g/m²) among the cropped systems. Natural forest exceeded all treatments with

MWD of 3.24 mm and 612 g/m² root biomass. Infiltration rates in agroforestry (39.7-44.8 mm/h) were roughly double those of monoculture (21.8-24.1 mm/h).

Table 2: Soil organic carbon (%) distribution by depth across land-use systems

Depth (cm)	Parkia+Maize	Leucaena+Cassava	Sole Maize	Sole Cassava	Natural Forest
0-10	1.84	1.92	1.14	1.08	2.38
10-20	1.62	1.71	0.93	0.87	2.14
20-30	1.38	1.48	0.74	0.68	1.87
30-40	1.12	1.21	0.58	0.51	1.63
40-50	0.91	0.98	0.43	0.37	1.42

Organic carbon declined with depth in all systems, but the rate of decline was steeper under monoculture (Table 2). At 30-40 cm, agroforestry systems still maintained 1.12-1.21% organic

carbon compared to 0.51-0.58% under sole crops, reflecting the deeper root distribution of trees.

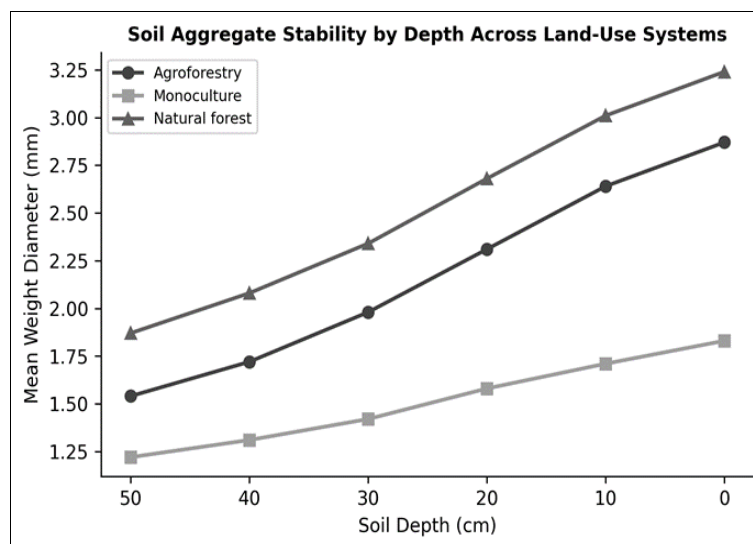


Fig 1: Soil aggregate stability (MWD) by depth across land-use systems

MWD declined with depth in all systems, but the gap between agroforestry and monoculture widened at greater depths (Figure 1). At 40-50 cm, agroforestry MWD was still above 1.5 mm

while monoculture had dropped to around 1.2 mm, close to the structureless threshold.

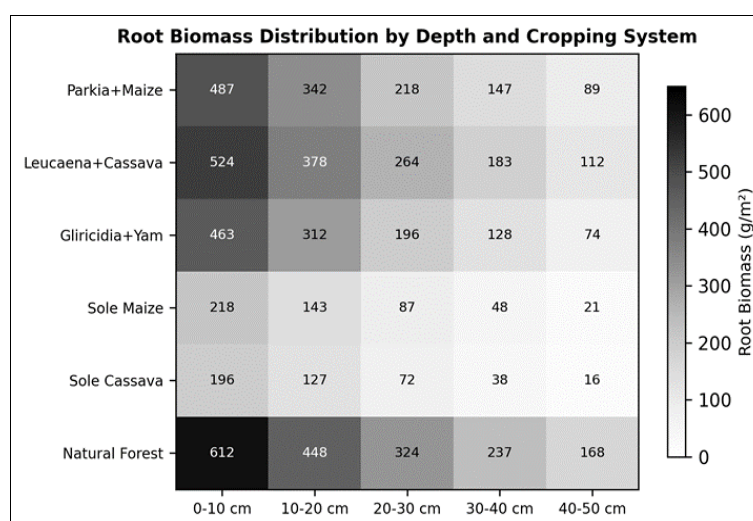


Fig 2: Root biomass distribution (g/m²) by depth and cropping system

Root biomass was concentrated in the top 10 cm for all systems but declined more gradually under agroforestry and forest (Figure 2). At 40-50 cm, agroforestry plots still had 74-112 g/m² root biomass compared to just 16-21 g/m² for sole crops, indicating the deeper rooting pattern of tree components.

Discussion

The strong correlation between root biomass and MWD ($r = 0.89$) supports the mechanical binding theory of aggregate formation, where fine roots and their associated fungal hyphae physically hold soil particles together [3, 10]. The eight-year-old agroforestry systems had already recovered aggregate stability to 84-91% of natural forest levels, which is encouraging for tropical soil restoration efforts. Similar recovery rates have been reported for agroforestry in Kenya and Indonesia [11, 12].

The deeper distribution of both roots and organic carbon under agroforestry has important implications beyond aggregate stability. Deeper carbon storage is more resistant to oxidation and contributes to long-term carbon sequestration [13]. The doubled infiltration rates in agroforestry compared to monoculture translate directly into reduced runoff and erosion—

critical benefits on the sloping, erosion-prone landscapes typical of southwestern Nigeria [14].

Conclusion

Agroforestry-based cropping systems rebuilt soil aggregate stability to near-natural forest levels within eight years on previously degraded tropical farmland. Root biomass was the strongest predictor of aggregate stability, and its deeper distribution under tree-crop combinations improved soil physical properties throughout the measured profile. Leucaena+cassava showed the best overall performance among the agroforestry combinations. These results make a clear case for integrating trees into tropical cropping systems, not just for their above-ground products but for the below-ground structural benefits they provide to the soil. Scaling up agroforestry adoption could help reverse the widespread soil degradation affecting food production across the West African sub-humid zone.

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