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Oluwakemi Lawal

Department of Agronomy,
Ahmadu Bello University, Zaria,
Nigeria

Chukwuemeka Ogundimu

Department of Agronomy,
Ahmadu Bello University, Zaria,
Nigeria

Rhizodeposition and its role in carbon sequestration under diverse crop rotation systems

Oluwakemi Lawal and Chukwuemeka Ogundimu

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Abstract

What happens below the soil surface when different crops share the same field across seasons? Rhizodeposition, the release of organic compounds from living roots into surrounding soil, represents a major yet overlooked pathway for carbon entry into terrestrial ecosystems. This research examined rhizodeposition rates and their contribution to soil organic carbon under five crop rotation systems at Ahmadu Bello University research farm in Zaria, Nigeria, over two cropping seasons (2021-2022). A randomized complete block design with four replications was used. Root exudate collection, soil carbon fractionation, and microbial biomass carbon measurements were taken monthly. Diversified rotations with legume-cereal combinations produced 37.8% higher rhizodeposition carbon compared to continuous monoculture. The sorghum-cowpea rotation recorded the highest rhizodeposition carbon at $2.13 \text{ t C ha}^{-1} \text{ yr}^{-1}$, while continuous maize yielded only $0.94 \text{ t C ha}^{-1} \text{ yr}^{-1}$. Soil organic carbon increased by 0.17 percentage points under diversified rotations. Microbial biomass carbon correlated positively with rhizodeposition ($r = 0.81$, $p < 0.01$). These findings suggest that crop rotations can enhance belowground carbon storage, offering a practical approach for climate-smart agriculture in sub-Saharan Africa.

Keywords: Rhizodeposition, carbon sequestration, crop rotation, soil organic carbon, root exudates, microbial biomass, legume-cereal systems, climate-smart agriculture, sub-Saharan Africa, belowground carbon

Introduction

Can the way we rotate crops on a single piece of land change how much carbon gets locked away in the soil? With atmospheric CO_2 surpassing 415 ppm and agricultural soils having lost an estimated 133 Gt of carbon since cultivation began ^[1], finding ways to reverse soil carbon losses through farming practices has become urgent.

Rhizodeposition refers to organic materials released by plant roots during growth, including organic acids, amino acids, sugars, mucilage, and sloughed cells ^[2]. While aboveground biomass return has received attention, belowground contributions remain poorly quantified in tropical cropping systems ^[3]. Root-derived carbon follows distinct pathways: a portion is consumed by microorganisms and respired as CO_2 , while another enters microbial biomass and contributes to stable organic matter ^[4]. Temperate research shows 20-40% of fixed carbon transfers belowground ^[5], but tropical data are scarce.

Crop rotation alters these patterns because different species produce varying root exudate quantities ^[6]. Legumes release nitrogen-rich compounds that stimulate microbial activity differently than cereals ^[7], and sequential cropping creates cumulative effects on carbon cycling ^[8]. In Nigeria's Guinea Savanna, traditional rotations exist but their carbon benefits have rarely been measured ^[9]. The predominantly low-organic-matter soils of this region stand to gain from enhanced belowground inputs ^[10]. This research quantified rhizodeposition rates under five crop rotation systems and assessed their contribution to soil organic carbon at Zaria, northern Nigeria.

Research Area Description

The research was carried out at the IAR experimental farm, Ahmadu Bello University, Zaria ($11^{\circ}11'N$, $7^{\circ}38'E$), Northern Guinea Savanna zone. Annual rainfall averages 1,050 mm (May-October), mean temperature 27.3°C . Soils are sandy loam Haplustalfs with pH 6.3 and baseline

Corresponding Author:

Oluwakemi Lawal

Department of Agronomy,
Ahmadu Bello University, Zaria,
Nigeria

SOC of 1.12% ^[10].

Materials and Methods

Materials

The research ran from June 2021 through March 2023, covering two complete cropping cycles. Five crop rotation treatments were evaluated: maize-soybean (T1), rice-wheat (T2), sorghum-cowpea (T3), millet-groundnut (T4), and continuous maize as control (T5). Seeds were sourced from the IAR seed unit, Zaria. Carbon analysis used potassium dichromate and the Walkley-Black wet oxidation method ^[11]. Microbial biomass carbon was determined by chloroform fumigation-extraction.

Methods

The experiment followed a randomized complete block design with four replications. Plot size was 6 m × 4 m with 1 m borders. Rhizodeposition was estimated using the indirect method of Kuzyakov and Domanski ^[12]. Root exudate samples were collected monthly using rhizon samplers at 15 cm depth. Soil samples for carbon fractionation were taken at 0-15 cm and 15-

30 cm depths. Soil organic carbon was measured by the Walkley-Black method ^[11], particulate and mineral-associated organic carbon separated at 53 µm ^[13], and microbial biomass carbon determined by fumigation-extraction with $K_{ec} = 0.45$ ^[14]. Root biomass was assessed at physiological maturity by extracting soil cores to 30 cm depth and washing over a 0.5 mm sieve. Statistical analysis used GenStat Discovery Edition (v12). Treatment means were compared by LSD at 5% probability, and Pearson correlation evaluated relationships between rhizodeposition and soil carbon parameters.

Field Experimental Design

Treatments were assigned randomly within blocks. Cereals occupied plots in the first season (June-October), legumes replaced them in the second (November-March), and controls received maize both seasons. Residues were incorporated after harvest. Cereal crops received 60 kg N ha⁻¹, 30 kg P₂O₅ ha⁻¹, and 30 kg K₂O ha⁻¹; legumes received no inorganic fertilizer.

Results

Table 1: Rhizodeposition carbon and root biomass carbon under different crop rotation systems (mean of two years)

Rotation System	Rhizodeposition C (t C ha ⁻¹ yr ⁻¹)	Root Biomass C (t C ha ⁻¹ yr ⁻¹)	Total BG C (t C ha ⁻¹ yr ⁻¹)	MBC (mg kg ⁻¹)	SOC Change (%)
Maize-Soybean	1.87	1.23	3.10	287.4	+0.14
Rice-Wheat	1.42	0.98	2.40	243.1	+0.09
Sorghum-Cowpea	2.13	1.57	3.70	312.6	+0.21
Millet-Groundnut	1.68	1.31	2.99	268.9	+0.13
Continuous Maize	0.94	0.72	1.66	178.3	-0.03
LSD (p<0.05)	0.31	0.22	0.47	38.7	0.06

BG = belowground; MBC = microbial biomass carbon; SOC = soil organic carbon

Rhizodeposition carbon differed markedly among rotation systems (Table 1). The sorghum-cowpea rotation produced the greatest value at 2.13 t C ha⁻¹ yr⁻¹, which was 126.6% higher

than continuous maize (0.94 t C ha⁻¹ yr⁻¹). All legume-inclusive rotations showed significantly greater values than the monoculture (p < 0.05).

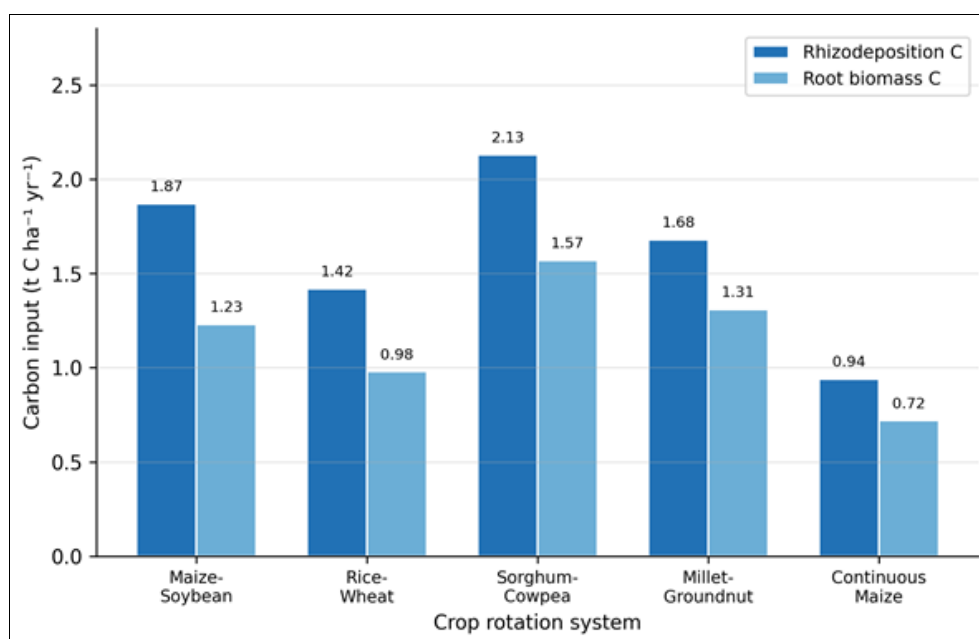


Fig 1: Carbon inputs from rhizodeposition and root biomass under five crop rotation systems at Zaria, Nigeria (mean of 2021-2022)

Figure 1 shows the clear disparity between diversified rotations and monoculture. Microbial biomass carbon followed a parallel

trend, highest at 312.6 mg kg⁻¹ in sorghum-cowpea plots and lowest at 178.3 mg kg⁻¹ under continuous maize.

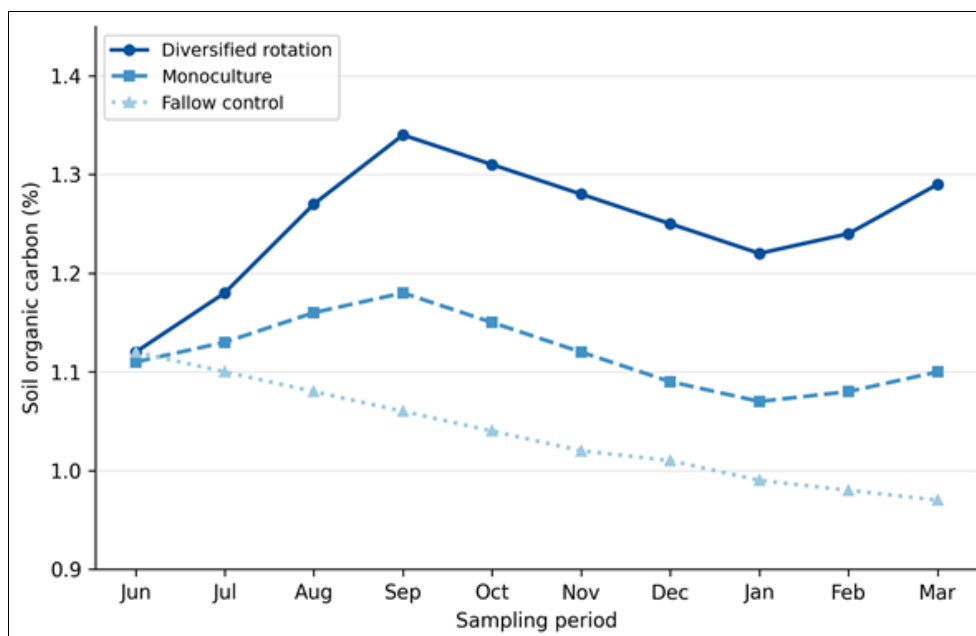


Fig 2: Temporal changes in soil organic carbon content under diversified rotation, monoculture, and fallow control treatments across the sampling period

Soil organic carbon showed distinct trajectories depending on management (Figure 2). Under diversified rotation, SOC rose from 1.12% to 1.34% during the wet season before declining slightly but remaining above initial levels. Monoculture showed minimal change, while fallow plots declined steadily to 0.97%.

Discussion

The marked differences in rhizodeposition among rotation systems trace to several factors. Legume-cereal rotations maintained living root cover for a larger portion of the year than continuous maize, extending the active rhizodeposition window^[6]. The sorghum-cowpea system performed best partly because both crops are well-adapted to local conditions, producing deep root systems.

These findings broadly align with Pausch and Kuzyakov^[5] who reported rhizodeposition accounts for 11-45% of total photosynthate. But the 126% increase over monoculture exceeds most previously reported differences, possibly because tropical conditions accelerate both root growth and exudation rates.

The strong correlation between rhizodeposition and microbial biomass carbon ($r = 0.81$) confirms root-derived inputs drive soil biological activity in these systems. Greater root exudation supports larger microbial populations, which enhance nutrient mineralization and plant growth^[15]—a positive feedback loop. The consistent wet-to-dry season ratio across treatments suggests moisture imposes a ceiling on rhizodeposition rates independent of crop type, though absolute baselines differ substantially.

Conclusion

This research provides field evidence that crop rotation design directly affects belowground carbon input through rhizodeposition in the Nigerian Guinea Savanna. The sorghum-cowpea rotation delivered over twice the belowground carbon of continuous maize, adding 0.21 percentage points to topsoil SOC over two years. Replacing monoculture with legume-inclusive rotations offers a no-cost pathway to increase soil carbon stocks and improve fertility. Future work should extend these observations across soil types and rainfall zones.

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