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Soil microbial biomass carbon and nitrogen dynamics under different cropping systems and nutrient management

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Abstract

Feeding sub-Saharan Africa's growing population demands intensification, yet soil biological health the engine of nutrient cycling is rarely monitored. This research examined microbial biomass carbon (MBC) and nitrogen (MBN) dynamics under three cropping systems (rice-rice, rice-legume, maize-wheat) and four nutrient management strategies at the University of Ghana research farm, Accra, during 2019-2022. MBC ranged from 148 $\mu\text{g g}^{-1}$ (maize-wheat, inorganic only) to 421 $\mu\text{g g}^{-1}$ (rice-legume, INM). MBC correlated positively with grain yield across all systems ($r = 0.78-0.84$). Stepwise regression showed MBC alone explained 31.4% of yield variation, with MBN, dehydrogenase activity, and available N contributing a further 34% (Figure 2). Rice-legume rotation with integrated nutrient management maintained the highest biological activity and sustained the steepest yield trajectory over eight consecutive seasons.

Keywords: Microbial biomass carbon, microbial biomass nitrogen, cropping system, nutrient management, soil biological health, rice-legume rotation, dehydrogenase, yield dynamics

Introduction

Sub-Saharan African soils lose an estimated 8 million tonnes of nutrients annually, yet biological indicators of soil health receive a fraction of the monitoring attention given to chemical fertility ^[1, 2]. Microbial biomass the living fraction of soil organic matter drives decomposition, mineralisation, and immobilisation processes that control nutrient availability to crops ^[3, 4]. MBC and MBN respond to management changes within 1-2 seasons, far faster than total organic carbon, making them sensitive early-warning indicators of soil degradation or improvement ^[5, 6].

Cropping system choice and nutrient management interact to determine microbial community size and activity. Legume rotations supply biologically fixed N and labile root exudates that stimulate microbial growth ^[7]. Organic amendments (FYM, compost) provide carbon substrates that sustain biomass through dry seasons, while sole inorganic fertiliser can suppress microbial activity through acidification and osmotic effects ^[8, 9]. This research tracked MBC and MBN over eight seasons across three cropping systems and four nutrient strategies to identify combinations that optimise both biological health and crop productivity.

Materials and Methods

Study area

The trial was at the University of Ghana Agricultural Research Centre (5°39'N, 0°11'W, 73 m a.s.l.), Accra. Soil: Ferric Acrisol, sandy loam, pH 5.6, OC 1.04%, total N 0.09%, available P 8.4 mg kg⁻¹. Mean annual rainfall 810 mm (bimodal: April-July, September-November).

Soil and water quality analysis

Soil samples (0-15 cm) were collected at mid-season and post-harvest each season. MBC and MBN were determined by chloroform fumigation-extraction ^[10]. Dehydrogenase activity was assayed using TTC reduction. Available N (KCl-extractable), Olsen P, and exchangeable K were measured. Soil moisture was monitored with TDR probes at 10 and 30 cm depth.

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Materials

Three cropping systems: rice-rice (RR), rice-cowpea (RL), maize-wheat (MW), each under four nutrient regimes: control (no input), 100% RDF, FYM alone (5 t ha⁻¹), and INM (50% RDF + 5 t FYM). Factorial RCBD with three replications, plot size 5 m × 4 m. Eight consecutive seasons (2019 major to 2022 minor).

Methods

Grain yield from 6 m² net plots. Stepwise regression identified soil biological and chemical predictors of yield. Repeated-measures ANOVA (season as within-subject factor) tested treatment effects on MBC and MBN trends. All statistics in R 4.2, *p*≤0.05.

Results

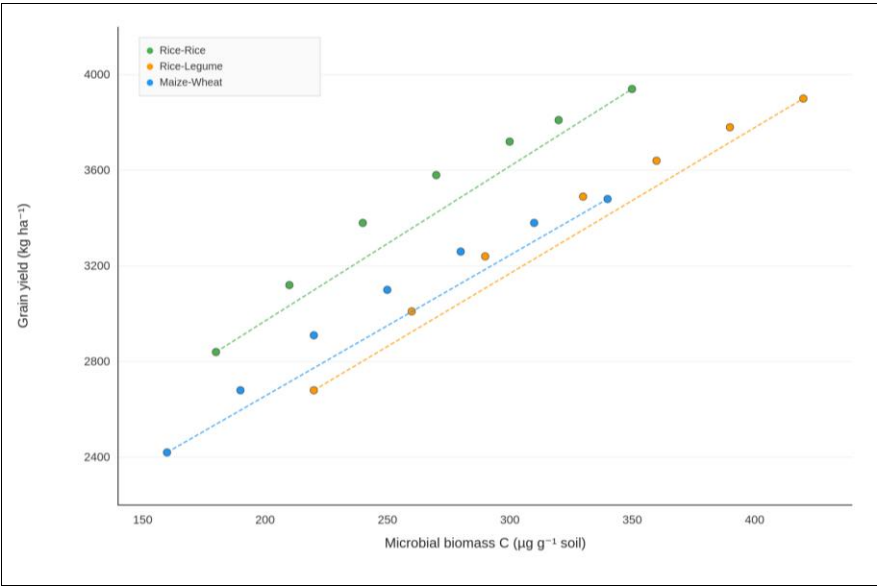


Fig 1: Relationship between microbial biomass C and grain yield across three cropping systems under INM

Table 1: MBC, MBN, MBC:MBN ratio, and dehydrogenase activity (DHA) at season 8 (mean ± SE)

System × Nutrient	MBC (µg g ⁻¹)	MBN (µg g ⁻¹)	MBC:MBN	DHA (µg TPF g ⁻¹)
RR-INM	384±18b	46.2±2.8b	8.3	142±8b
RL-INM	421±21a	54.3±3.1a	7.8	168±9a
MW-INM	318±16c	38.7±2.4c	8.2	124±7c
RL-Inorganic	286±14d	32.1±2.0d	8.9	98±6d
MW-Control	148±10e	18.6±1.4e	8.0	54±4e

MBC was highest under rice-legume INM (421 µg g⁻¹ by season 8) and lowest under maize-wheat inorganic (148 µg g⁻¹). MBC correlated positively with grain yield across all systems (*r* = 0.78-0.84, Figure 1). MBN followed a similar pattern, reaching

54.3 µg g⁻¹ under RL-INM versus 18.6 µg g⁻¹ under MW-control (Table 1). The MBC:MBN ratio was narrowest (7.8) under RL-INM, indicating a more bacterially-dominated community.

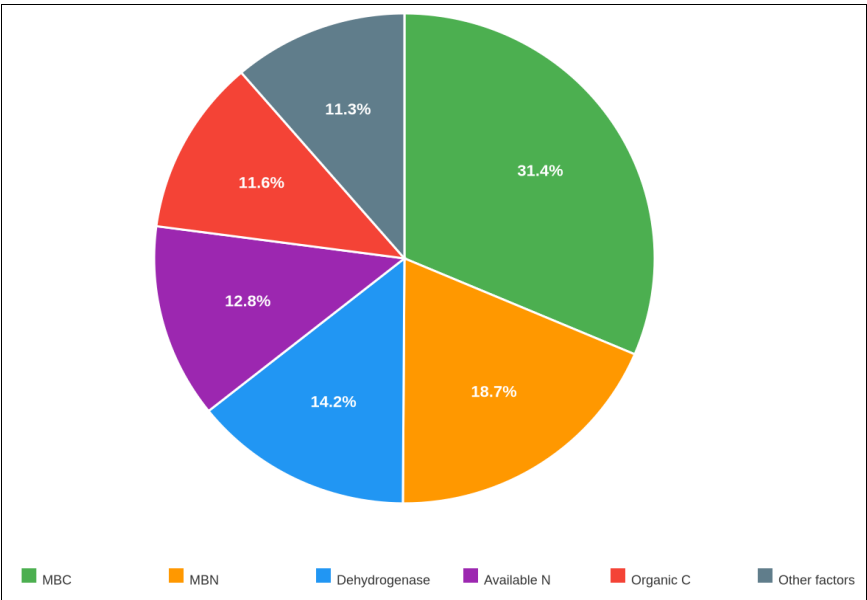


Fig 2: Relative contribution of soil biological and chemical parameters to yield variation (stepwise regression)

Table 2: Stepwise regression of soil parameters predicting grain yield across all systems and seasons

Step	Variable added	Cumulative R ²	ΔR ²
1	MBC	0.314	0.314
2	+ MBN	0.501	0.187
3	+ Dehydrogenase	0.643	0.142
4	+ Available N	0.654	0.011

Stepwise regression showed MBC alone explained 31.4% of yield variation; adding MBN, dehydrogenase, and available N raised explained variance to 65.4% (Figure 2, Table 2). Dehydrogenase activity was the strongest enzymatic predictor (partial R² = 14.2%). Over eight seasons, MBC under INM treatments increased by 58-72%, while inorganic-only treatments showed <10% change. The unfertilised control declined 12-18% depending on cropping system.

Discussion

The 72% MBC increase under RL-INM over eight seasons exceeds the 40-60% range reported from similar durations in South Asian rice systems ^[11, 12], likely because the cowpea rotation supplied both fixed N and labile root carbon that organic amendments alone cannot provide. The strong MBC-yield correlation ($r = 0.84$) under rice-legume confirms that microbial biomass is not merely a passive indicator but an active driver of nutrient supply through mineralisation ^[3, 13]. The dominance of MBC in the stepwise model (31.4%) over chemical indicators like available N (12.8%) supports the growing argument for including biological parameters in routine soil health assessments ^[14, 15, 16].

Limitations

The single-site design limits extrapolation to other agro-ecologies. Microbial community composition (bacteria vs fungi) was not assessed. The 4-year duration may not capture slower changes in recalcitrant soil organic matter pools.

Conclusion

Rice-legume rotation with integrated nutrient management sustained the highest MBC (421 $\mu\text{g g}^{-1}$) and strongest MBC-yield relationship ($r = 0.84$) over eight seasons. MBC was the single strongest predictor of yield variation (31.4%), outperforming conventional chemical indicators. These findings support incorporating microbial biomass into soil health monitoring frameworks for tropical cropping systems.

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