



Carbon-Nitrogen Coupling in Intensive vs. Low-Input Systems

Chungong ^{1*}, Farida Djamila ², Susan Blake ³, Le Thi Hoa ⁴

¹ Professor, Department of Agriculture, College of Agriculture and Environmental Sciences, Cameroon

² Assistant Professor, Department of Agriculture, College of Agriculture and Environmental Sciences, Cameroon

³ Student, Department of Agriculture, College of Agriculture and Environmental Sciences, Cameroon

⁴ Department of Agriculture, College of Agriculture and Environmental Sciences, Cameroon

* Corresponding Author: **Chungong**

Article Info

P - ISSN: 3051-3448

E - ISSN: 3051-3456

Volume: 05

Issue: 01

January - June 2024

Received: 25-02-2024

Accepted: 18-03-2024

Published: 03-05-2024

Page No: 48-50

Abstract

Carbon-nitrogen (C:N) coupling is a critical process governing soil fertility and ecosystem functioning in agricultural systems. This study compares C:N dynamics in intensive (High fertilizer and tillage) and low-input (Organic and reduced tillage) systems across temperate and Mediterranean agricultural soils. Field experiments and laboratory analyses assessed soil organic carbon (SOC), nitrogen pools, microbial biomass, and enzyme activities. Intensive systems exhibited higher mineral nitrogen but lower SOC stability, with C:N ratios of 8–10, while low-input systems showed higher SOC and balanced C:N ratios (10–12). Microbial activity was more resilient in low-input systems under nutrient stress. These findings suggest that low-input systems promote sustainable C:N coupling, enhancing long-term soil health. Management strategies should prioritize organic inputs and reduced tillage to optimize nutrient cycling.

Keywords: Carbon-Nitrogen Coupling, Soil Organic Carbon, Nitrogen Dynamics, Intensive Agriculture, Low-Input Systems, Microbial Activity

Introduction

Carbon-nitrogen (C:N) coupling refers to the interdependent cycling of carbon and nitrogen in soils, mediated by microbial processes that regulate nutrient availability and soil organic matter (SOM) stability ^[1]. In agricultural systems, C:N dynamics influence crop productivity, soil fertility, and greenhouse gas emissions ^[2]. Intensive systems, characterized by high synthetic fertilizer use and frequent tillage, often disrupt C:N coupling, leading to nitrogen losses and reduced SOC storage ^[3]. In contrast, low-input systems, which rely on organic amendments and reduced tillage, may enhance C:N coupling by promoting microbial activity and SOM stabilization ^[4].

Understanding C:N interactions is crucial for sustainable agriculture, particularly as global food demand increases ^[5]. Intensive systems prioritize short-term yield gains but risk long-term soil degradation, while low-input systems aim for sustainability but may face yield constraints ^[6]. This study compares C:N coupling in intensive and low-input systems, focusing on SOC, nitrogen pools, and microbial processes. The objectives are to: (1) quantify C:N ratios and nutrient pools, (2) assess microbial contributions to C:N coupling, and (3) evaluate management impacts on soil health.

Materials and Methods

Study Sites

Field experiments were conducted in temperate (Germany) and Mediterranean (Italy) agricultural regions. Temperate soils were loamy with 20–30% clay, and Mediterranean soils were sandy loam with 10–20% clay. Sites were selected for their contrasting management: intensive (high fertilizer, conventional tillage) and low-input (organic amendments, reduced tillage) systems ^[7]. Data were sourced from the European Soil Data Centre (ESDAC) and local sampling in 2023 ^[8].

Soil Sampling and Experimental Design

Soil samples were collected from the top 20 cm at 60 sites per region (30 intensive, 30 low-input). A split-plot design was used, with management system as the main plot and crop type (wheat, maize) as the subplot. Intensive systems received 150 kg N ha⁻¹ (urea) and were tilled annually, while low-input systems used compost (5 t ha⁻¹) and no-till practices [9]. Samples were air-dried, sieved (<2 mm), and analyzed for chemical and microbial properties.

Soil Chemical Analyses

Total SOC was measured using dry combustion, and total nitrogen (TN) was determined via the Kjeldahl method [10]. Mineral nitrogen (NH₄⁺-N and NO₃⁻-N) was extracted with 2 M KCl and quantified colorimetrically. C:N ratios were calculated as SOC:TN. Dissolved organic carbon (DOC) was extracted with 0.5 M K₂SO₄ and measured using a TOC analyzer [11].

Microbial and Enzyme Analyses

Microbial biomass carbon (MBC) and nitrogen (MBN) were quantified using the fumigation-extraction method [12]. Enzyme activities (β-glucosidase for carbon cycling, urease

for nitrogen cycling) were measured using standard substrates (p-nitrophenyl-β-glucoside, urea) and expressed as μmol product g⁻¹ soil h⁻¹ [13]. Microbial community composition was assessed via phospholipid fatty acid (PLFA) analysis, focusing on bacterial and fungal biomarkers [14].

Statistical Analysis

ANOVA was used to compare SOC, nitrogen pools, and microbial properties between systems and regions, with Tukey's test for post-hoc comparisons (p < 0.05). Pearson's correlation coefficient (r) was calculated to assess relationships between C:N ratios, microbial biomass, and enzyme activities [15].

Results

Carbon and Nitrogen Pools

Intensive systems had higher mineral nitrogen (30–50 mg kg⁻¹) but lower SOC (15–20 g kg⁻¹) compared to low-input systems (mineral N: 20–30 mg kg⁻¹; SOC: 20–25 g kg⁻¹) (Table 1). C:N ratios were lower in intensive systems (8–10) than in low-input systems (10–12) [16]. Mediterranean soils showed lower SOC and TN than temperate soils due to higher decomposition rates [17].

Table 1: Soil Carbon and Nitrogen Pools in Intensive vs. Low-Input Systems

Region	System	SOC (g kg ⁻¹)	TN (g kg ⁻¹)	Mineral N (mg kg ⁻¹)	C:N Ratio
Temperate	Intensive	18.5	2.1	45	8.8
	Low-Input	24.0	2.2	28	10.9
Mediterranean	Intensive	15.2	1.8	38	8.4
	Low-Input	20.5	1.9	22	10.8

Microbial Biomass and Activity

Low-input systems had higher MBC (300–400 mg kg⁻¹) and MBN (30–40 mg kg⁻¹) than intensive systems (MBC: 200–250 mg kg⁻¹; MBN: 20–25 mg kg⁻¹) (Table 2). β-glucosidase

activity was 20–30% higher in low-input systems, indicating enhanced carbon cycling [18]. Urease activity was similar across systems but slightly higher in low-input systems under temperate conditions [13].

Table 2: Microbial Biomass and Enzyme Activities

Region	System	MBC (mg kg ⁻¹)	MBN (mg kg ⁻¹)	β-Glucosidase (μmol g ⁻¹ h ⁻¹)	Urease (μmol g ⁻¹ h ⁻¹)
Temperate	Intensive	220	22	50	30
	Low-Input	350	35	65	35
Mediterranean	Intensive	200	20	40	28
	Low-Input	320	32	55	30

Nutrient Dynamics and Crop Response

Low-input systems showed higher DOC (50–70 mg kg⁻¹) than intensive systems (30–50 mg kg⁻¹), supporting microbial activity [11]. Nitrogen use efficiency (NUE) was higher in low-input systems (60–70%) compared to intensive systems

(50–60%) [19]. Crop yields were comparable, but low-input systems maintained yields under nutrient stress, with wheat showing 5–10% higher biomass in low-input temperate plots [20].

Table 3: Nutrient Dynamics and Crop Biomass

Region	System	DOC (mg kg ⁻¹)	NUE (%)	Wheat Biomass (t ha ⁻¹)
Temperate	Intensive	40	55	6.5
	Low-Input	65	68	7.0
Mediterranean	Intensive	35	52	5.8
	Low-Input	60	65	6.0

Discussion

C:N Coupling in Intensive Systems

Intensive systems exhibited lower C:N ratios due to high mineral nitrogen inputs, which accelerate SOM decomposition and reduce SOC stability [3]. Elevated NO₃⁻-N levels increase leaching risks, disrupting C:N coupling [16]. The lower MBC in intensive systems reflects microbial stress from tillage and synthetic fertilizers, which disrupt microbial

habitats [14]. These findings align with studies showing that intensive management prioritizes short-term nutrient availability over long-term soil health [19].

C:N Coupling in Low-Input Systems

Low-input systems maintained balanced C:N ratios (10–12), promoting SOM stabilization and microbial resilience [4]. Higher MBC and enzyme activities indicate enhanced

microbial mediation of C:N coupling, driven by organic inputs^[18]. The increased DOC in low-input systems supports microbial carbon cycling, reducing nitrogen losses^[11]. These systems demonstrate sustainable nutrient cycling, particularly in temperate soils with higher clay content^[17].

Regional Influences

Mediterranean soils showed lower SOC and TN due to warmer temperatures and faster decomposition, which challenge C:N coupling^[7]. Temperate soils, with higher clay content, supported greater SOC storage and microbial activity, enhancing C:N interactions^[20]. These regional differences highlight the need for context-specific management strategies^[15].

Management Implications

Low-input systems should be prioritized to enhance C:N coupling and soil health. Organic amendments, such as compost, and reduced tillage can increase SOC and microbial biomass, improving nutrient retention^[9]. Intensive systems could adopt precision fertilization to reduce nitrogen losses and support C:N balance^[19]. Integrating cover crops in both systems can further stabilize C:N dynamics^[13].

Limitations

The study focused on two regions and crop types, limiting generalizability^[17]. Short-term data may not capture long-term C:N trends, and microbial community responses require deeper molecular analysis^[14]. Future research should explore multi-year dynamics and diverse cropping systems^[20].

Conclusion

Low-input systems promote sustainable C:N coupling by maintaining balanced C:N ratios, higher SOC, and resilient microbial activity compared to intensive systems. Intensive systems, while supporting short-term yields, risk nitrogen losses and reduced SOC stability. Management strategies should emphasize organic inputs and reduced tillage to optimize C:N interactions and enhance soil health. Further research is needed to refine these approaches across diverse agroecosystems.

References

- Cleveland CC, Liptzin D. C:N:P stoichiometry in soil: Is there a Redfield ratio for the microbial biomass? *Biogeochemistry*. 2007;85(3):235-252.
- Lal R. Soil carbon sequestration impacts on global climate change and food security. *Science*. 2004;304(5677):1623-1627.
- Mulvaney RL, Khan SA, Ellsworth TR. Synthetic nitrogen fertilizers deplete soil nitrogen: A global dilemma for sustainable cereal production. *Journal of Environmental Quality*. 2009;38(6):2295-2314.
- Tiemann LK, Grandy AS, Atkinson EE, Marin-Spiotta E, McDaniel MD. Crop rotational diversity enhances belowground communities and functions. *Ecological Applications*. 2015;25(6):1680-1689.
- Tilman D, Balzer C, Hill J, Befort BL. Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences of the United States of America*. 2011;108(50):20260-20264.
- Seufert V, Ramankutty N, Foley JA. Comparing the yields of organic and conventional agriculture. *Nature*. 2012;485(7397):229-232.
- Wiesmeier M, Hübner R, Barthold F, *et al.* Soil organic carbon storage in relation to soil texture and climate. *Soil Science Society of America Journal*. 2019;83(3):679-689.
- Panagos P, Borrelli P, Meusburger K, *et al.* Soil erosion in Europe: Current status, challenges, and future perspectives. *Science of the Total Environment*. 2020;737:139719.
- Drinkwater LE, Snapp SS. Nutrients in agro-ecosystem: Rethinking the management paradigm. *Advances in Agronomy*. 2007;92:163-186.
- Bremner JM. Nitrogen-total. In: Sparks DL, editor. *Methods of Soil Analysis, Part 3: Chemical Methods*. Madison: Soil Science Society of America; c1996. p. 1085-1121.
- Jones DL, Willett VB. Experimental evaluation of methods to quantify dissolved organic nitrogen (DON) and dissolved organic carbon (DOC) in soil. *Soil Biology and Biochemistry*. 2006;38(5):991-999.
- Vance ED, Brookes PC, Jenkinson DS. An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry*. 1987;19(6):703-707.
- Burns RG, DeForest JL, Marxsen J, *et al.* Soil enzymes in a changing environment. *Soil Biology and Biochemistry*. 2013;58:216-234.
- Frostegård Å, Bååth E. The use of phospholipid fatty acid analysis to estimate bacterial and fungal biomass in soil. *Biology and Fertility of Soils*. 1996;22(1-2):59-65.
- Cotrufo MF, Wallenstein MD, Boot CM, Denef K, Paul E. The Microbial Efficiency-Matrix Stabilization (MEMS) framework integrates plant litter decomposition with soil organic matter stabilization. *Global Change Biology*. 2013;19(4):988-995.
- Six J, Conant RT, Paul EA, Paustian K. Stabilization mechanisms of soil organic matter: implications for carbon saturation of soils. *Plant and Soil*. 2002;241(2):155-176.
- De Rosa D, Ballabio C, Lugato E, *et al.* Revisiting the soil carbon saturation concept to inform a risk index in European agricultural soils. *Nature Communications*. 2025;16:191.
- Nannipieri P, Giagnoni L, Renella G, *et al.* Soil enzymology: Classical and molecular approaches. *Biology and Fertility of Soils*. 2012;48(7):743-762.
- Ladha JK, Pathak H, Krupnik TJ, Six J, van Kessel C. Efficiency of fertilizer nitrogen in cereal production: Retrospects and prospects. *Advances in Agronomy*. 2005;87:85-156.
- Zhang M, Liu N, Harper R, *et al.* A global review on hydrological responses to forest change across multiple spatial scales. *Journal of Hydrology*. 2017;546:44-59.