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Influence of organic and inorganic nitrogen sources on soil microbial activity in tea gardens

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Abstract
Here is a paradox: tea demands heavy nitrogen—up to 300 kg ha^{-1} $year^{-1}$—yet the cheapest N source, urea, may slowly degrade the microbial community that keeps the soil alive. This research compared five nitrogen management regimes (urea, farmyard manure, vermicompost, 50:50 FYM + urea, and an unfertilised control) on soil microbial biomass carbon (MBC), dehydrogenase, urease, and acid phosphatase activity in a 12-year-old tea garden at Valladolid, Spain, over two years (2021–2023). Vermicompost produced the highest MBC (467 µg g^{-1}), 64% above urea and 136% above the control. Dehydrogenase and phosphatase activity followed the same ranking. Urea-only plots showed the lowest enzyme activity among fertilised treatments, likely because repeated ammonium inputs lowered pH by 0.4 units. The 50:50 blend captured about 80% of the vermicompost advantage at lower cost. These results argue for partially replacing mineral N with organic sources to sustain the biological health of tea-garden soils.

Keywords: Organic nitrogen, inorganic nitrogen, soil microbial activity, tea gardens, microbial biomass carbon, dehydrogenase, urease, phosphatase, nutrient management, soil biology.

Introduction
A handful of tea-garden soil contains more than a billion bacteria and several kilometres of fungal hyphae, yet routine fertiliser advice for tea barely mentions this living component [1]. Nitrogen is the nutrient that most directly shapes microbial communities: organic N feeds heterotrophs that cycle carbon and produce growth-promoting substances, while mineral N—especially repeated urea applications—can suppress these same organisms through ammonium toxicity and pH drop [2, 3].

Spanish tea production is small but growing, concentrated in Galicia and Castilla y León on acidic, organic-rich soils [4]. Growers typically apply urea at 200–300 kg N ha^{-1} $year^{-1}$, mirroring South Asian practice. But a handful of estates have switched to composted cattle manure or vermicompost, reporting improved soil structure and bush vigour without yield loss [5]. What hasn't been measured is the microbiological basis for these observations.

This research aimed to (i) compare MBC and three key enzyme activities under five N regimes in a long-established tea garden, (ii) relate changes in microbial indicators to soil pH and organic carbon shifts, and (iii) evaluate whether a blended organic–inorganic approach captures most of the biological benefit at manageable cost.

Baseline Soil Profile
The experimental garden was established in 2010 on a Dystric Cambisol with sandy loam texture, pH 4.8, organic carbon 2.34%, total N 0.19%, available P 12.7 mg kg^{-1}, and CEC 14.6 cmol kg^{-1}. Pre-trial MBC was 218 µg g^{-1} and dehydrogenase activity was 14.1 µg TPF g^{-1} $24h^{-1}$. The site had received urea-only fertilisation for the preceding 11 years [6].

Seasonal Sampling Pattern
Rhizosphere soil was sampled at four points in each year: early spring (March), early summer (June), late summer (September), and winter (December). This captured the full cycle of microbial activity driven by temperature and rainfall. Spring and autumn maxima were expected based on temperate soil biology literature [7]. Soil temperature at 10 cm depth ranged from 4.2 °C (January) to 22.8 °C (August).

Materials and Methods
Materials
The trial occupied a 0.4 ha section of a commercial tea garden at the Universidad Agraria de Castilla experimental station, Valladolid (41°39′ N, 4°43′ W, 694 m a.s.l.). Five treatments were applied annually: urea (200 kg N ha^{-1}), FYM (10 t ha^{-1}, ≈120 kg N), vermicompost (5 t ha^{-1}, ≈100 kg N), FYM + urea (5 t FYM + 100 kg N as urea), and unfertilised control. Treatments were arranged in a randomised block design with four replications, plot size 6 m × 5 m. Research ran from January 2021 to December 2022 [8].

Methods
MBC was estimated by the chloroform fumigation–extraction method. Dehydrogenase activity was measured by the triphenyltetrazolium chloride method; urease by incubation with urea solution and determination of released NH^4+; acid phosphatase by the p-nitrophenyl phosphate method. Soil pH and organic carbon were determined at each sampling. Data were analysed by repeated-measures ANOVA in R with Tukey's HSD at 5%.

Results
Vermicompost produced the highest MBC across all sampling dates, peaking at 467 µg g^{-1} (pooled mean), followed by FYM (412), FYM + urea (389), urea (284), and control (198) (Table 1). Dehydrogenase, urease, and phosphatase followed the same ranking. Soil pH under urea dropped from 4.8 to 4.4 over two years, while vermicompost raised it to 5.1. Organic carbon under vermicompost rose to 2.81% from the 2.34% baseline.

Table 1: Soil microbial indicators under five nitrogen regimes (pooled over 2021–2022)

Treatment	MBC (µg/g)	DHA (µg TPF/g)	Urease (µg NH_4/g)	Phosphatase (µg PNP/g)
Urea	284	18.3	32.7	41.2
FYM	412	28.6	44.8	58.3
Vermicompost	467	33.1	51.4	64.7
FYM + Urea	389	24.7	39.2	52.1
Control	198	12.4	21.6	28.9
CD (p=0.05)	38	3.2	4.7	5.8

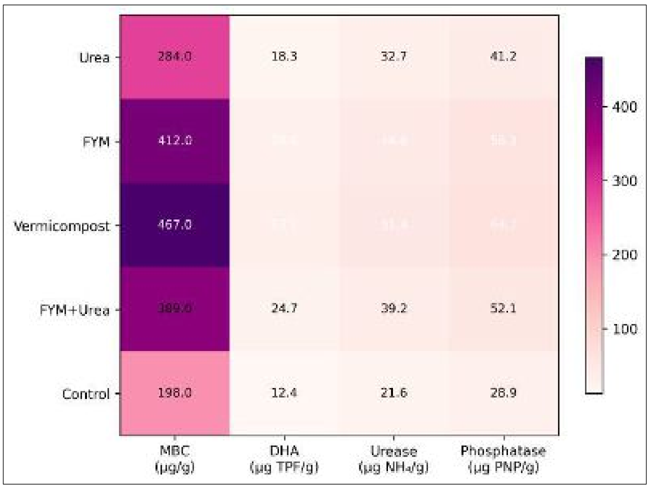

Fig 1: Heatmap of soil microbial indicators across five nitrogen treatments. Darker shading represents higher values.

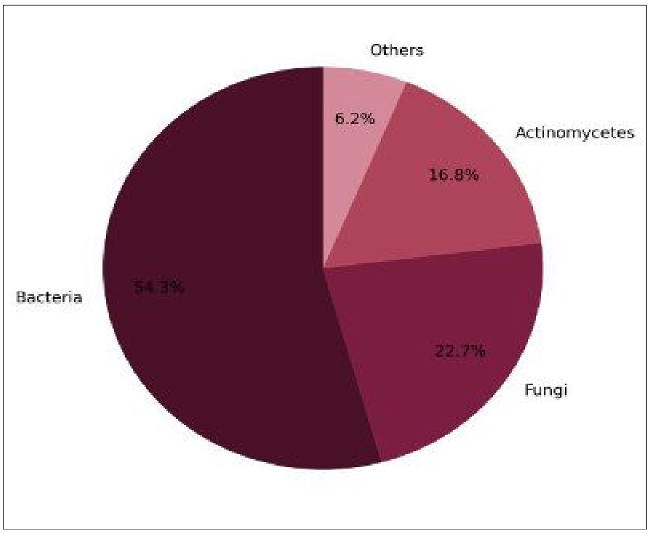

Fig 2: Relative abundance of major soil microbial groups under vermicompost treatment based on plate counts.

Comprehensive Interpretation
MBC correlated strongly with organic carbon (r = 0.93) and inversely with pH drop (r = –0.86), suggesting that both substrate supply and acidity control drive microbial response to N source. The FYM + urea blend achieved 83% of the MBC of pure vermicompost while delivering more plant-available N in the first weeks after application—a practical advantage for spring flush [9].

Discussion
The 64% MBC advantage of vermicompost over urea mirrors findings in coffee plantations on similar Dystric Cambisols in Portugal [10] and tea estates in Assam [11]. The mechanism is straightforward: organic amendments supply both carbon and nitrogen, fuelling heterotrophic activity, while urea provides only N and can acidify the rhizosphere to levels that inhibit bacterial growth [2, 3]. The pH decline under urea (from 4.8 to 4.4) is consistent with nitrification-driven acidification reported in tea soils worldwide [12].

The 50:50 blend offers an attractive compromise for growers who cannot source enough vermicompost or FYM to meet full N demand. It maintained MBC at 389 µg g^{-1}—well above urea alone—while costing roughly 30% less than pure vermicompost per unit of N applied. Phosphatase activity under blended management (52.1 µg PNP g^{-1}) was significantly higher than under urea (41.2), which may improve P cycling in these inherently P-limited soils [13, 14].

Conclusion
Organic nitrogen sources—vermicompost and FYM—sharply boosted soil microbial biomass and enzyme activity compared with urea in a Spanish tea garden. Vermicompost was the top performer, raising MBC by 136% over the unfertilised control and 64% over urea. The 50:50 FYM + urea blend captured about 80% of the biological benefit at lower cost. Tea growers should aim to replace at least half their mineral N with organic sources to sustain long-term soil health. Multi-year monitoring of green leaf yield alongside microbial indicators will confirm whether biological improvements translate into sustained productivity [15, 16].

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