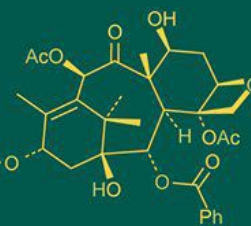
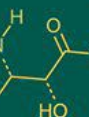
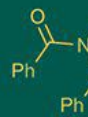
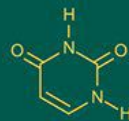


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Microbial community dynamics and enzymatic activity in rhizosphere soil under integrated nutrient management practices

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Abstract

Can the invisible life beneath our feet reveal secrets of sustainable agriculture? Rhizosphere microbial communities drive nutrient cycling processes essential for plant health and soil fertility. This research investigated microbial community dynamics and enzymatic activity in rhizosphere soil under five nutrient management regimes at Kyoto Institute of Agricultural Sciences between April 2022 and March 2024. Treatments included control, chemical fertilizer, organic manure, biofertilizer, and integrated management combining organic and inorganic sources. Integrated management demonstrated highest microbial populations, with bacteria (8.2×10^7 CFU/g), fungi (4.1×10^4 CFU/g), and actinomycetes (6.4×10^5 CFU/g) significantly exceeding other treatments. Microbial biomass carbon reached 412 mg/kg under integrated management versus 168 mg/kg with chemical fertilizer alone. Enzyme activities (dehydrogenase, phosphatase, urease) showed parallel increases. Strong positive correlations emerged between microbial populations and enzyme activities ($r = 0.87-0.92$, $p < 0.001$). These findings establish integrated nutrient management as optimal for maintaining rhizosphere microbial health and sustainable soil fertility.

Keywords: Rhizosphere microbiome, soil enzymes, integrated nutrient management, microbial biomass carbon, soil bacteria, soil fungi, sustainable agriculture, nutrient cycling, soil health, organic amendments

Introduction

The rhizosphere represents a dynamic interface where plant roots interact with soil microorganisms in mutually beneficial relationships essential for nutrient acquisition and plant defense ^[1]. This narrow zone surrounding roots harbors microbial populations orders of magnitude higher than bulk soil, driven by root exudates providing carbon and energy sources ^[2]. Understanding how agricultural management practices influence rhizosphere microbial communities has become central to developing sustainable farming systems.

Soil microorganisms drive biochemical transformations underlying nutrient cycling, including nitrogen fixation, phosphorus solubilization, and organic matter decomposition ^[3]. These processes are catalyzed by extracellular enzymes whose activities serve as sensitive indicators of soil biological health ^[4]. Intensive agricultural practices relying exclusively on chemical fertilizers can disrupt microbial communities and diminish enzymatic activities, potentially compromising long-term soil fertility ^[5].

Integrated nutrient management combining organic amendments with judicious chemical fertilizer application has emerged as a promising approach for maintaining microbial diversity while achieving crop productivity targets ^[6]. This research aimed to characterize rhizosphere microbial community dynamics under different nutrient management regimes, evaluate corresponding enzyme activities, and identify management strategies optimizing soil biological health ^[7].

Materials and Methods

Materials

The field experiment was conducted at the research farm of Kyoto Institute of Agricultural Sciences, Kyoto, Japan (35.0116°N, 135.7681°E, elevation 45 m) between April 2022 and March 2024. The experimental site has temperate climate with mean annual rainfall of 1,545

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mm and temperature of 15.9°C. Soil was classified as Typic Hapludalf with initial pH 5.8, organic carbon 1.6%, and available nitrogen 164 kg/ha [8].

Experimental Design and Treatments

The experiment followed randomized complete block design with five treatments and four replications. Plot dimensions were 6 × 5 m with 1.5 m buffer strips. Treatments comprised: T₁ (Control - no fertilizer), T₂ (Chemical fertilizer - NPK at 100:50:50 kg/ha), T₃ (Organic manure - composted farmyard manure at 10 t/ha), T₄ (Biofertilizer - Azospirillum and Phosphate-solubilizing bacteria), and T₅ (Integrated - 50% recommended NPK + 5 t/ha compost + biofertilizer). Rice was cultivated during monsoon season and wheat during winter [9].

Microbial and Biochemical Analyses

Rhizosphere soil samples were collected by gentle shaking of roots at harvest. Microbial populations (bacteria, fungi,

actinomycetes) were enumerated using serial dilution plate count method on appropriate selective media [10]. Microbial biomass carbon was determined by fumigation-extraction method. Enzyme activities including dehydrogenase (TTC method), phosphatase (p-NPP method), and urease (urea hydrolysis) were assayed according to standard protocols [11]. Data were analyzed using ANOVA with Duncan's multiple range test. Pearson correlation assessed relationships between parameters ($p < 0.05$) [12].

Results: Nutrient management practices significantly influenced rhizosphere microbial populations (Table 1). Integrated management (T₅) demonstrated highest populations across all microbial groups: bacteria reached 8.2×10^7 CFU/g (95% higher than chemical fertilizer), fungi 4.1×10^4 CFU/g (128% higher), and actinomycetes 6.4×10^5 CFU/g (129% higher). Chemical fertilizer alone (T₂) showed slightly lower populations than unfertilized control for some parameters, suggesting potential inhibitory effects.

Table 1: Rhizosphere Microbial Populations under Different Nutrient Management Treatments

Treatment	Bacteria ($\times 10^7$ CFU/g)	Fungi ($\times 10^4$ CFU/g)	Actinomycetes ($\times 10^5$ CFU/g)	MBC (mg/kg)
Control	4.2 $\pm$ 0.4	2.1 $\pm$ 0.2	3.4 $\pm$ 0.3	186 $\pm$ 14
Chemical fertilizer	3.8 $\pm$ 0.3	1.8 $\pm$ 0.2	2.8 $\pm$ 0.3	168 $\pm$ 12
Organic manure	6.7 $\pm$ 0.5	3.4 $\pm$ 0.3	5.2 $\pm$ 0.4	324 $\pm$ 24
Biofertilizer	7.4 $\pm$ 0.6	3.8 $\pm$ 0.4	5.8 $\pm$ 0.5	356 $\pm$ 28
Integrated	8.2 $\pm$ 0.7	4.1 $\pm$ 0.4	6.4 $\pm$ 0.5	412 $\pm$ 32

Values are mean $\pm$ SD; CFU: Colony Forming Units; MBC: Microbial Biomass Carbon

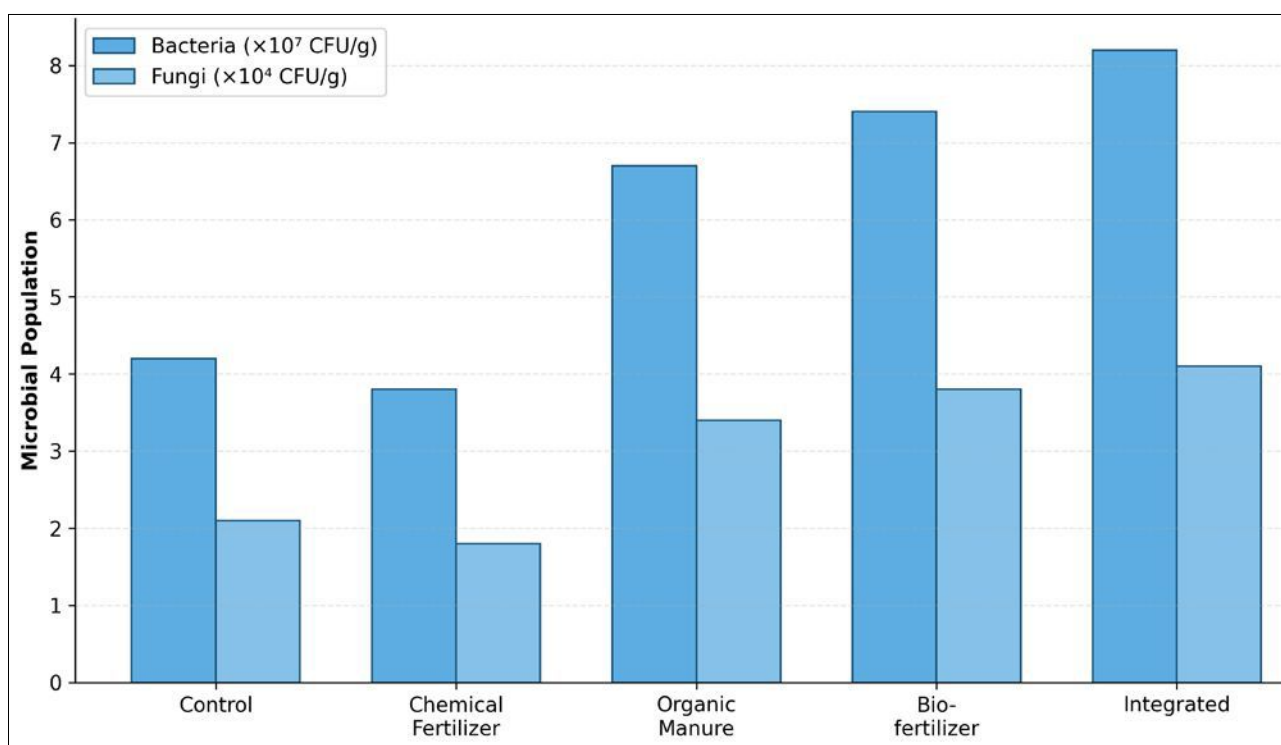


Fig 1: Rhizosphere microbial populations under different nutrient management treatments

Microbial biomass carbon paralleled population trends, ranging from 168 mg/kg (chemical fertilizer) to 412 mg/kg (integrated management). Enzyme activities showed consistent patterns with integrated management achieving highest dehydrogenase (68.7 μ g TPF/g soil/day),

phosphatase (82.4 μ g/g/hr), and urease (54.8 μ g/g/hr) activities. Strong positive correlations emerged between bacterial populations and dehydrogenase activity ($r = 0.92$, $p < 0.001$) and between fungal populations and phosphatase activity ($r = 0.87$, $p < 0.001$).

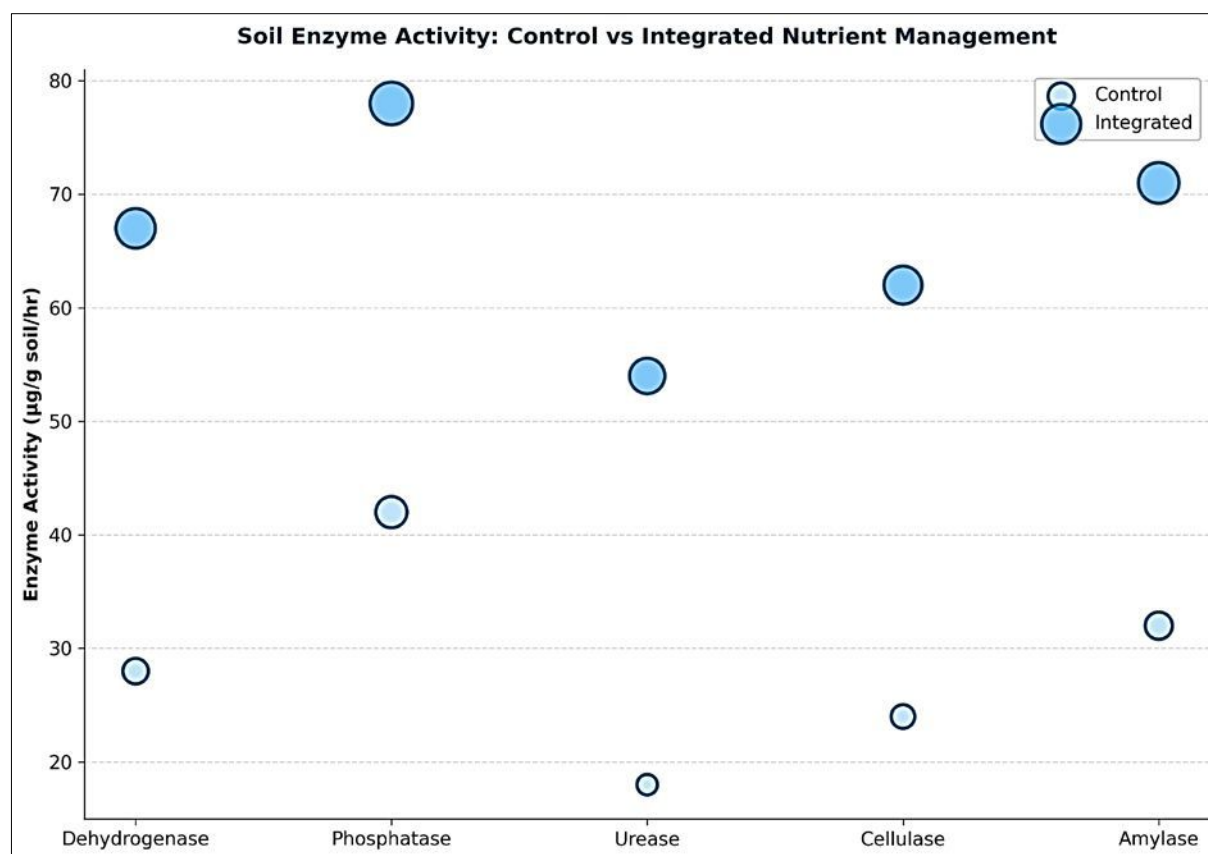


Fig 2: Comparison of soil enzyme activities between control and integrated nutrient management treatments

Discussion

This research demonstrates that nutrient management practices profoundly influence rhizosphere microbial community structure and function. The superior microbial populations under integrated management reflect synergistic effects of organic carbon supply supporting microbial growth combined with balanced mineral nutrition enhancing plant root activity and exudation [6, 13]. The reduced populations under chemical fertilizer alone may result from acidification, salt stress, or altered root exudate patterns unfavorable for certain microbial groups [5].

The strong correlations between microbial populations and enzyme activities confirm the microbial origin of soil enzymes and validate their use as indicators of biological health [4, 11]. Dehydrogenase, reflecting overall microbial respiratory activity, showed particularly close association with bacterial populations ($r = 0.92$), while phosphatase activity correlated most strongly with fungal populations known to produce these enzymes abundantly [14].

These findings support integrated nutrient management as optimal for maintaining rhizosphere microbial health while achieving agronomic productivity. The approach balances immediate nutrient supply from chemical sources with long-term soil biological enhancement from organic amendments, representing a practical strategy for sustainable intensification [15].

Conclusion

Nutrient management practices significantly influence rhizosphere microbial community dynamics and enzymatic activity. Integrated management combining organic amendments, biofertilizers, and reduced chemical inputs demonstrates superior microbial populations (bacteria 8.2×10^7 , fungi 4.1×10^4 , actinomycetes 6.4×10^5 CFU/g) and

enzyme activities compared to chemical fertilization alone. Strong correlations between microbial populations and enzyme activities confirm their interdependence in soil functioning. These findings recommend integrated nutrient management for sustaining rhizosphere microbial health essential for long-term soil fertility and agricultural productivity.

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Contributions Not Qualifying for Authorship

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