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Microbial Diversity and Soil Quality of Coffee Plantation Soil under Organic and Chemical Farming Practicess

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Abstract
Organic farming is an agricultural production system that minimizes or completely excludes the use of synthetic fertilizers, pesticides, and other chemical inputs. Instead, it depends on ecological processes such as crop rotation, application of animal and green manures, and biological methods of pest management to maintain soil fertility, ensure adequate plant nutrition, and control insects, weeds, and other pests. Studies evaluating the long-term environmental impacts of organic and conventional farming systems have largely concentrated on indicators of soil quality and sustainability. In India, coffee is one of the most significant plantation crops and serves as a major source of foreign exchange, particularly in Kodagu District. In recent years, the production and consumption of organic coffee have gained considerable importance in international markets, with global organic coffee consumption accounting for approximately 4% of total coffee consumption. While conventional agriculture primarily relies on synthetic fertilizers, chemical pesticides, and other technological inputs to enhance crop production, organic agriculture seeks to optimize the use of naturally available resources and ecological processes for sustainable farming. Depending on the present farming trends, a comparative study of the soil properties and microbial diversity in the soil of coffee plantation of Kodagu District under organic and chemical farming practice was carried out.

Keywords: Sustainable Agriculture, Coffee, Microbial Diversity, Organic farming, Soil fertility, Nutrient content

Introduction

Before the 1960s, agriculture in most developing countries relied predominantly on organic nutrient sources such as compost, crop residues, animal manure, and green manure to maintain soil fertility and support crop production. However, with the introduction of inorganic chemical fertilizers, farming practices underwent a significant transformation. Chemical fertilizers became increasingly popular because they were readily available, less bulky, and easier to store, transport, and apply than organic manures. Moreover, they produced rapid and higher crop responses, particularly during the Green Revolution, when high-yielding crop varieties capable of utilizing large quantities of fertilizers were introduce. By the early 1970s, chemical fertilizers had become the primary source of crop nutrients in many developing countries. Although this shift contributed substantially to increased agricultural productivity, it also led to a decline in the use of organic manures and an excessive, imbalanced application of chemical fertilizers. Consequently, several soil-related problems emerged, including soil acidification and alkalization, deficiencies of secondary and micronutrients, deterioration of soil fertility, and an overall decline in soil health and sustainability (Bellaki and Badanur, 2024) [2]. In recent years, organic farming has gained increasing attention as a sustainable agricultural practice due to growing concerns over the adverse effects of intensive chemical-based farming on soil health. Continuous use of synthetic fertilizers and pesticides has contributed to the deterioration of soil quality and long-term agricultural sustainability. (Geethanjali, P.A. 2023) [6]. Organic fertilizer improves soil's physical and biological activities but has comparatively low nutrient content, therefore, usually, a larger quantity is required for plant growth (Bhatt *et al*., 2019) [13]. Organic farming systems are generally associated with higher concentrations of nitrogen and phosphorus in the soil, whereas conventionally managed farms often exhibit greater potassium levels.

Organic farming also enhances soil organic carbon and organic matter content, reflecting its beneficial effects on soil fertility and overall soil health. Although conventional farming systems frequently achieve higher crop yields during the initial stages due to the immediate availability of nutrients from synthetic fertilizers, a different trend is observed following the transition to organic farming. While crop productivity may decline temporarily during the conversion period, the sustained application of organic manures, along with effective pest and weed management practices, gradually restores soil fertility, leading to a significant recovery and stabilization of crop yields over time.

Materials and methods

Soil sample collection

Rhizosphere and non-rhizosphere soil samples were collected from coffee plantation of Kodagu (D), which are under organic farming and chemical farming. Soil samples were collected randomly in a polythene bag with a soil auger. Samples were brought to the laboratory and mixed thoroughly to make a composite sample for analysis and kept in a cool place prior to the determination of their physico-chemical and microbiological properties.

Determination of Physico-Chemical Properties

Physical parameters like temperature, pH and moisture content of the soil were determined using standard protocols as given by Aneja, (2003) [1] and Sharma, *et al*., (2018) [16]. Chemical parameters of soil like Organic carbon, Nitrogen, Phosphorus and Potassium were determined using standard protocols as given by Black, C. A. (1993) [3], Egeta, (2023) [4] and Fatehi, S. (2013) [5].

Determination of Microbiological Properties

Microbiological parameters of soil were determined by screening for bacteria, fungi, nitrogen fixing, phosphate solubilizing and potassium solubilizing bacteria by serial dilution and the pour plate method. One gram of soil was serially diluted up to 10^{-6} using sterile distilled water, and 0.1 ml aliquots were plated on nutrient agar media for the isolation of bacteria, Potato Dextrose Agar media for media for the isolation of fungi (Aneja, 2003) [1] and selective media such as Jensen's medium for Azotobacter, Pikovskaya's medium for phosphate solubilizing bacteria, and Aleksandrow's medium for potassium solubilizing bacteria. Plates were incubated at 28 30 °C for 7 days, and distinct colonies were purified by streak plate method and the cultures were maintained at 4^0 C (Katkar *et al*., 2025) [8]. The isolates were characterized based on colony morphology, pigmentation, Gram reaction and cell shape. The nitrogen fixing, phosphate solubilizing and potassium solubilizing bacteria isolated from soil samples soil under organic farming and chemical farming were assessed for the production of IAA, HCN and Ammonia.

Results and Discussion

The study on the soil properties and microbial diversity in rhizosphere and non-rhizosphere soil samples under organic and chemical farming of coffee plantation showed the following results. The Physico-Chemical Parameters of rhizosphere and non-rhizosphere soil sample under organic and chemical farming is summarized in Table 1. Under organic farming, the non-rhizosphere region has high temperature, pH and moisture content than rhizosphere region; The concentration of carbon and potassium was found to remain same in both rhizosphere and non-rhizosphere region and the concentration of nitrogen and phosphate was higher in rhizosphere region and lower in non-rhizosphere region. Under chemical farming, the temperature was same in rhizosphere and non-rhizosphere region; The pH was higher in non-rhizosphere region than rhizosphere region; The moisture content was higher in rhizosphere region than non-rhizosphere region; The concentration of carbon was high in non-rhizosphere region than rhizosphere region; The concentration of nitrogen remained same both in rhizosphere and non-rhizosphere region; The concentration of phosphate was high in rhizosphere region than non-rhizosphere region; The concentration of potassium was high in rhizosphere region than non-rhizosphere region.

Table 1: Physico-Chemical Parameters of Rhizosphere and Non-Rhizosphere Soil Samples under Organic and Chemical Farming

Farming System	Soil Sample	Temperature (°C)	pH	Moisture Content (%)	Carbon (%)	Nitrogen (kg/acre)	Phosphorus (kg/acre)	Potassium (kg/acre)
Organic Farming	R	30	6.56	21.3	0.5–0.75	0.73	0.22	0.122
	S	29	6.95	19.9	0.5–0.75	0.15	Nil	0.112
Chemical Farming	R	29	6.71	20.5	0.3–0.5	0.15	0.122	0.112
	S	29	7.10	16.4	0.5–0.75	0.15	0.22	0.122

Note: R = Rhizosphere soil; S = non-rhizosphere soil; Nil = Not detected

The bacteria, Nitrogen fixing bacteria, Phosphate and Potassium solubilising bacteria and fungi isolated from various soil samples is shown in Table 2 and 3. Under organic farming, bacterial colonies were more in rhizosphere region than in non-rhizosphere region; The nitrogen fixing bacterial colonies were found to be more in Non rhizosphere region than rhizosphere region; The phosphate solubilizing bacterial colonies were more in rhizosphere region than in non-rhizosphere region; and fungal colonies were more in non-rhizosphere region than in rhizosphere region. Under chemical farming, bacterial colonies, fungal colonies and nitrogen fixing bacterial colonies were more in non-rhizosphere region than in rhizosphere region; the phosphate solubilizing bacterial colonies were more in rhizosphere region than in non-rhizosphere region.

Table 2: Microbial Isolates from Rhizosphere and Non-Rhizosphere Soil Samples under Organic Farming

Soil Sample	Dilution	Bacteria CFU/ml	Nitrogen-Fixing Bacteria CFU/ml	Phosphate-Solubilizing Bacteria CFU/ml	Potassium solubilizing bacteria	Fungi CFU/ml
R	10^{-2}	TNTC	TNTC	156	128	93
	10^{-3}	18	27	TNTC	67	100
	10^{-4}	9	11	14	43	36
S	10^{-2}	TNTC	20	17	16	40
	10^{-3}	6	40	21	24	85
	10^{-4}	8	5	25	20	200

Table 3: Microbial Isolates from Rhizosphere and Non-Rhizosphere Soil Samples under Chemical Farming

Soil Sample	Dilution	Bacteria CFU/ml	Nitrogen-Fixing Bacteria CFU/ml	Phosphate-Solubilizing Bacteria CFU/ml	Potassium solubilizing bacteria	Fungi CFU/ml
R	10^{-2}	6	9	33	12	80
	10^{-3}	5	1	6	7	38
	10^{-4}	11	4	5	4	13
S	10^{-2}	17	15	11	6	210
	10^{-3}	20	3	13	4	24
	10^{-4}	4	6	2	0	95

Notes: R = Rhizosphere soil; S = non-rhizosphere soil; CFU/ml = Colony Forming Units per millilitre; TNTC = Too Numerous to Count

Continuous application of organic manure is also reported to increase soil enzyme and microbial activities. Higher soil nutrient status in coffee under organic cultivation was also reported (Ramesh P. 2005) [15]. Higher levels of available phosphorus (P) were observed in the conventional (chemical) farming system than in the organic farming system. This increase in available P may be attributed to the greater application of phosphorus-containing chemical fertilizers in conventional farming. In contrast, the total culturable microbial population was significantly higher in soils managed under organic farming, indicating enhanced microbial activity and improved soil biological health. Among the microbial groups, bacterial populations were markedly greater in the organic farming system than in the chemical farming system. However, no significant differences were observed in the populations of fungi and actinomycetes between the two farming systems at either soil depth. Long-term evaluation after 12 years of management further revealed that organic farming supported a higher abundance of culturable microorganisms. Compared with the chemical farming system, populations of bacteria increased by 24% and 6.7% at soil depths of 0–15 cm and 15–30 cm, respectively. Similarly, fungal populations increased by 12% and 48%, while yeast populations were higher by 59% and 32% at the corresponding soil depths, demonstrating the positive influence of organic farming on soil microbial diversity and biological fertility (K. Velmourougane, 2016) [11].

The isolates were characterized based on colony morphology, pigmentation, Gram reaction and cell shape. The fast-growing dominant species of bacteria (nitrogen fixing, phosphate solubilizing and potassium solubilizing bacteria) isolated from soil samples soil under organic farming and chemical farming were assessed for the production of IAA, HCN and Ammonia. The results are tabulated in Table 5.

Table 4: Production of Growth Promoters by isolates from Rhizosphere and Non-Rhizosphere Soil Samples under organic and chemical farming

Bacterial Colonies	Ammonia Production			HCN Production			IAA Production		
	24 hrs	48 hrs	72 hrs	24 hrs	48 hrs	72 hrs	24 hrs	48 hrs	72 hrs
OR1	+	++	+++	-	+	+	-	+	+
OR2	+	+++	+++	-	++	++	-	+	+
ONR1	+	++	++	-	+	+	-	+	+
ONR2	+	++	++	-	+	+	-	+	+
CR1*	+	++	+++	-	+	+	-	+	+
CR2	+	++	++	-	+	+	-	+	+
CNR1	+	+++	++	-	+	+	-	+	+
CNR2	+	++	++	-	+	+	-	+	+
CNR3	+	++	+	-	–	–	-	-	–
CNR4	+	++	++	-	+	+	-	-	–

Note: + = Low production; ++ = Moderate production; +++ = High production; – = No production

Eight out of ten bacterial isolates were able to produce IAA with the development of pink color in the presence of IAA precursor tryptophan. All the bacterial isolates were able to produce HCN. This was shown by the development of orange-brown color in the Petri plate. Bacterial strain 2 from Rhizosphere region of organic soil produced maximum HCN. In the present study, the ammonia production by all the isolates was observed. Bacterial strain 1 and 2 from Rhizosphere region of organic soil produced maximum ammonia**.** Plant growth-promoting rhizobacteria often produce indole acetic acid (IAA) and thereby assist plant growth. The biosynthesis of bacterial IAA takes place either by tryptophan-dependent or independent manners. The potential of bacterial isolates to produce IAA indicates their ability to use it as growth hormones or growth regulators. (Poonguzhali *et al*., 2008) [14]. Hydrogen cyanide (HCN) is a volatile secondary metabolite that is synthesized by many rhizobacteria and has a powerful effect on many organisms.

HCN inhibits the electron transport chain and leads to death of pathogens. Many bacterial genera have the ability to produce HCN including species of *Alcaligenes*, *Aeromonas*, *Bacillus*, *Pseudomonas*, *and Rhizobium*. In general, ammonia produced by PGPR has been shown to supply nitrogen to their host plants and thereby promote root and shoot elongation and their biomass (Marques *et al*., 2010) [12].

Summary and Conclusion

The objective of the present study was to study the soil properties and microbial diversity in the soil of coffee plantation under organic and chemical farming practice was carried out in of Kodagu (D). This is a basic study that has provided an insight into the bacterial community present in the soil samples from rhizosphere and non-rhizosphere region of coffee plantation of Kodagu District which are under organic farming and chemical farming for more than 3 years. The moisture, C, N content, bacteria, nitrogen fixing bacteria and phosphate solubilizing bacteria was found to be high in rhizosphere soil under organic farming. Phosphorous and potassium were more in rhizosphere soil under chemical farming. Under organic farming, bacterial colonies were more in rhizosphere region than in non-rhizosphere region. Under chemical farming, bacterial colonies were more in non-rhizosphere region than in rhizosphere region. The Nitrogen fixing bacteria, Phosphate and Potassium solubilizing bacteria isolated from rhizosphere and non-rhizosphere soil of Coffee plantation under Organic and chemical farming were studied for the production of IAA, HCN and Ammonia which enhances the soil fertility. About 300 colonies were isolated from rhizosphere region and 63 colonies from non-rhizosphere region of soil under organic farming. Comparatively lesser number of colonies were isolated from soil under chemical farming. It was found out that the inoculated PGPR produced IAA, HCN and Ammonia in adequate quantities, thus promising a sustainable use in agriculture when produced in mass using cheap solid substrate.

The findings of the present study demonstrate that the adoption of organic farming practices significantly enhances soil fertility and quality in coffee plantations compared with conventional chemical-based farming systems. Organic cultivation improved the physical, chemical, biological, and microbiological properties of the soil, thereby contributing to greater soil health and sustainability. The higher microbial population and diversity observed in the surface soil can be attributed to the increased availability of organic carbon, nutrients, moisture, and improved soil aeration. In contrast, the lower microbial abundance in subsurface layers may be associated with reduced organic matter availability, limited root penetration, and nutrient depletion at greater soil depths. Furthermore, continuous application of organic manures and plant residues was found to rapidly enhance soil microbial activity while gradually increasing soil organic carbon, exerting a more pronounced effect on soil biological properties than conventional fertilization practices. The study also revealed the presence of efficient plant growth-promoting rhizobacteria (PGPR) capable of phosphate solubilization and the production of indole-3-acetic acid (IAA), hydrogen cyanide (HCN), and ammonia in coffee-growing soils. These traits are recognized as important mechanisms through which PGPR enhance plant growth, nutrient uptake, and overall crop productivity. The identified bacterial isolates therefore possess considerable potential for development as bioinoculants to promote sustainable coffee cultivation and reduce dependence on chemical fertilizers. Further investigations involving molecular identification, genomic characterization, and field-scale evaluation of these isolates are recommended to validate their efficacy and facilitate their practical application in sustainable agricultural systems.

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