



# Soil Microbial Population and Enzyme Activities as Influenced by Different Nutrient Management Practices in Arecanut and Black Pepper Cropping System of Uttara Kannada District of Karnataka, India

Vinayak K. Kumbar <sup>a</sup>, Shivakumar K. M. <sup>b\*</sup>,  
Manukumar H. R <sup>b</sup>, Rakesh M Satagond <sup>a</sup>, M.S. Nagaraja <sup>c</sup>,  
Yogeeshappa H <sup>d</sup> and Gurumurthy S.B. <sup>d</sup>

<sup>a</sup> Department of Soil Science, University of Horticultural Sciences, Bagalkot, Karnataka, India.

<sup>b</sup> College of Horticulture, Mysuru, UHS, Bagalkot, Karnataka, India.

<sup>c</sup> KSN UAHS, Shivamogga, Karnataka, India.

<sup>d</sup> University of Horticultural Sciences, Bagalkot, Karnataka, India.

## Authors' contributions

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

## Article Information

DOI: <https://doi.org/10.9734/ijpss/2025/v37i65516>

## Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://pr.sdiarticle5.com/review-history/136664>

**Original Research Article**

**Received: 25/03/2025**

**Accepted: 29/05/2025**

**Published: 12/06/2025**

\*Corresponding author: E-mail: [shivakumaruhs@gmail.com](mailto:shivakumaruhs@gmail.com);

**Cite as:** Kumbar, Vinayak K., Shivakumar K. M., Manukumar H. R, Rakesh M Satagond, M.S. Nagaraja, Yogeeshappa H, and Gurumurthy S.B. 2025. "Soil Microbial Population and Enzyme Activities As Influenced by Different Nutrient Management Practices in Arecanut and Black Pepper Cropping System of Uttara Kannada District of Karnataka, India". *International Journal of Plant & Soil Science* 37 (6):361-72. <https://doi.org/10.9734/ijpss/2025/v37i65516>.

## ABSTRACT

The diverse range of microorganisms live in soils and are responsible for the decomposition of organic matter and the mobilisation of nutrients. Thus, they play an important role in the cycling of nutrients in nature. Arecanut and black pepper, these commercial cropping systems are mainly grown in the Western Ghats of Karnataka, where microorganisms play an important role in nutrient cycling, as they are both sources and sinks for mineral nutrition and can carry out biochemical transformations. A survey was conducted to study the soil microbial population and enzyme activity in arecanut and black pepper gardens at Sirsi, Siddapur and Yellapur taluks of Uttara Kannada district during 2020-21. Geographically, the study area (Sirsi, Siddapur and Yellapur) lies between 14° 37' N - 74° 50' E, 14° 20' N - 74° 53' E, 14° 57' N - 74° 42' E, latitude and longitude respectively. The altitudes of the study area are at 611, 564, and 541 m above mean sea level, respectively. It lies under a tropical monsoon climate; therefore and the weather is hot and humid throughout the year. The mean rainfall of the tract is 2500 mm, with 103 rainy days in a year. These gardens were classified based on different nutrient management practices as INM, Organic and ZBNF gardens. The soil samples were collected from the rhizosphere of those selected groups of gardens at two depths, 0-15 cm and 15-30 cm. A study revealed that soil biological properties varied significantly among different nutrient management practices and soil depths. The organic areca-black pepper garden has recorded higher bacterial, fungal and actinomycetes populations, which were on par with ZBNF areca-black pepper gardens. The surface soil has exhibited higher bacterial and fungal populations, whereas the actinomycetes population was found to be highest in the subsurface soil. Urease activity among different nutrient management practices varied significantly in the order INM > Organic = ZBNF. Whereas dehydrogenase and acid phosphatase activities varied significantly in the order Organic = ZBNF > INM practices. The microbial biomass carbon (MBC) was recorded as highest in surface soil than in subsurface soil. Similarly, higher MBC was observed in organic areca-black pepper gardens than in other gardens at Sirsi, Siddapur and Yellapur taluks. It was observed from the current study that in organic areca-black pepper gardens due to higher application of organic nutrient sources resulted in higher organic carbon accumulation which resulted in higher microbial population.

**Keywords:** *Arecanut; black pepper; nutrient management; bacteria; fungi; actinomycetes.*

## 1. INTRODUCTION

Areca nut and black pepper are one of the most profitable commercial cropping systems followed in the Western Ghats of Karnataka. These gardens are mainly grown in Chikmagalur, Shimoga, Uttara Kannada, Dakshina Kannada and Udupi districts (Indiastat, 2019-20). These areas are characterised by heavy rainfall, altitude variations, temperature fluctuations and other factors. The predominantly acidic laterite soils (Ultisols).

A diverse range of microorganisms live in soils and are responsible for the decomposition of organic matter and the mobilisation of nutrients. Soil carbon cycling happens in three perspectives: metabolic pathways, microbial communities, and environmental influences. It elucidates the roles of different microbial species in carbon cycling and highlights the impact of microbial interactions and environmental factors on carbon cycling (Wu et al., 2024). Thus, they play an important role in the cycling of nutrients

in nature. Further, Soil microbial populations play an influential role in the biological management of soil fertility and productivity.

Microorganisms play an important role in nutrient cycling, as they are both source and a sink for mineral nutrition and can carry out biochemical transformations. (Jenkinson and Ladd, 1981; Nthebere et al., 2025). Microorganisms absorb a portion of nutrients and integrate them into their cells (biomass). Microorganisms control soil nutrient flow by absorbing nutrients, creating soil biomass (immobilisation), and converting carbon, nitrogen, phosphorus and sulphur to mineral forms (mineralisation) (Jenkinson and Ladd, 1981; Wani and Lee, 1995). To date, the responses of microorganisms, such as microbial activity, diversity, community structure and nutrient cycling processes, to biochar addition have been widely reported (Dai et al., 2021; Liu et al., 2024).

Variations in organic C concentration in the soil are also attributed to changes in microbial

biomass carbon and biological activity(Nthebere et al.,2025).

Furthermore, soil microbial biomass responds more quickly to nutrient management strategies and is frequently employed as a measure of soil quality and health (Ge et al., 2010). The addition of organic manure has a significant impact on microbial populations, which is expected to result in changes in soil organic matter content, which has a direct impact on soil microbial dynamics. (DeForest et al., 2012).

soil microorganisms and enzymes are focused on the upper horizons of the soil profile, even though they transform soil organic matter at every depth of the soil profile (Piotrowska-Długosz et al.,2022). Soil enzymatic activities can be used as an index of soil fertility and functional diversity of microbes (Nannipieri et al., 2002; Maurya et al., 2011;Nthebere et al.,2022)in catalysing several biochemical reactions which are necessary for their life processes of soil micro-organisms, organic waste decomposition, organic matter formation and nutrient cycling (Tabatabai, 1994). Urease and phosphatase are two key enzymes in the nitrogen and phosphorus cycles, respectively. (Badiane et al., 2001).

In this background, the purpose of this research was to see how different nutrient management strategies affected soil microorganisms and enzyme activity in the arecanut and black pepper cropping systems.

## 2. MATERIALS AND METHODS

### 2.1 Location of the Study Area

Uttara Kannada district is located between north latitudes 13° 55' to 15° 31' and east longitudes 74° 0' to 75° 10' with an altitude of 605 m, which falls under the hilly and coastal zone (9 and 10). The geographical area is about 10222 square feet. Km is dominated by red sandy loam soils with acidic pH. Geographically the study area (Sirsi, Siddapur and Yellapur) lies between 14° 37' N - 74° 50' E, 14° 20' N - 74° 53' E, 14° 57' N - 74° 42' E, latitude and longitude respectively. The altitudes of the study area are at 611, 564, 541 m above mean sea level, respectively. As the arecanut and black pepper growers were spread over large areas of Uttara Kannada, the study was restricted to only these three taluks of Uttara Kannada district.

### Climate:

$$\text{Biomass C g}^{-1} \text{ soil} = \frac{\text{Ninhydrin reactive-N in fumigated soil} - \text{Ninhydrin reactive-N in unfumigated soil}}{\text{Weight of the sample}} \times 24$$

The Uttara Kannada district experiences a tropical monsoon climate, and the weather is hot and humid throughout the year. It receives both the South West and North West monsoons. The mean rainfall of the tract is 2500 mm, with 103 rainy days in a year. Annually, the day temperature averages about 25 hot days with temperatures more than 35° °C and 124 warm days ranging 30-35° °C and remains below 35° °C during the rest of the year for about 214 days (Agriculture Contingency Plan).

### Selection and grouping gardens:

An initial survey was conducted to identify arecanut and black pepper growing farmers who adopted different nutrient management practices. Based on the nutrient management practices, the arecanut gardens were grouped into **INM**: Integrated nutrient management practices (INM areca gardens), **Organic**: Organic farming nutrient management practices (organic areca gardens), **ZBNF**: ZBNF nutrient management practices (ZBNF areca gardens)(Table 1).

### 2.2 Collection and Analysis of Samples

The soil samples were collected from three selected groups of arecanut and black pepper gardens at two depths, 0-15 cm and 15-30 cm, in three taluks. All 180 soil samples (90 from 0-15 cm and 90 from 15-30 cm) were analysed for soil microbial activities. The fresh soil was analysed for microbial population and enzyme activity by standard methods.

The serial dilution plating method was followed to enumerate the microbial population. The enumeration of culturable bacteria, fungi and actinomycetes was done using soil extract agar, Martin' rose Bengal agar and Kuster's agar, respectively (Allen, 1957), and the results were expressed as colony-forming units (CFU) per gram dry soil.

Dehydrogenase activity in the soil samples was determined using the procedure as described by Casida et al. (1964). The phosphatase activity of soil samples was determined by measuring p-nitrophenol content (Tabatabai and Berner, 1969). The urease activity was estimated by following the method of Tabatabai (1984). Soil microbial biomass (SMB) was estimated by the fumigation-extraction method given by Carter (1991).

**Table 1. Grouping of arecanut-black pepper cropping system based on nutrient inputs**

<b>Group of areca - black pepper gardens</b>	<b>Types of organic nutrient sources applied</b>	<b>Types of fertilizers applied</b>	<b>Group of areca - black pepper gardens based on nutrients inputs</b>
<b><i>INM - areca + black pepper gardens</i></b>	FYM-10-12 t/ha Vermicompost- 5-6 t/ha	Urea- 300 kg/ha Rock phosphate- 200 kg/ha DAP- 150 kg/ha SSP- 350 kg/ha MOP- 300 kg/ha	Integrated nutrient management practice
<b><i>Organic - areca + black pepper gardens</i></b>	FYM- 20-25 t ha <sup>-1</sup> Vermicompost-10 t ha <sup>-1</sup> Green gold OM-2.5 t ha <sup>-1</sup> Gold gromin OM-3 t ha <sup>-1</sup> Sanjeevini-500 kg ha <sup>-1</sup> Sheep manure- 3-3.5 t ha <sup>-1</sup> Poultry manure- 2-2.5 t ha <sup>-1</sup> Cow dung Slurry- 500 L ha <sup>-1</sup> month <sup>-1</sup>	-----	Organic nutrient management practice
<b><i>ZBNF - areca + black pepper gardens</i></b>	Jeevamrutha- 1000 L/ ha/ month Ghanajeevamrutha- 1000kg/ha/yr Mulching	-----	Zero budget natural farming - nutrient management practice

## 2.3 Statistical analysis

Data obtained during the investigation was subjected for two two-factor RCBD. By taking nutrient management practices and soil depth as factors. Statistical analysis was performed at a 5% level of significance using OPSTAT software.

## 3. RESULTS AND DISCUSSION

### 3.1 Microbial Population of Bacteria, Fungi and Actinomycetes

Among the three groups of areca - black pepper gardens, organic areca- black pepper garden was recorded significantly higher bacterial population ( $80.61 \times 10^6$  and  $79.71 \times 10^6$ ) followed by ZBNF ( $79.34 \times 10^6$  and  $79.07 \times 10^6$ ) and INM areca - black pepper garden ( $68.98 \times 10^6$  and  $73.86 \times 10^6$ ) at Sirsi and Siddapur taluks respectively. Whereas, in the Yellapur location, ZBNF areca - black pepper gardens observed higher bacterial population ( $80.51 \times 10^6$ ) and it was on par with organic areca - black pepper gardens. However, a Lower bacterial population was recorded in INM areca- black pepper gardens ( $68.98 \times 10^6$ ,  $73.86 \times 10^6$ ,  $73.47 \times 10^6$ ) at Sirsi, Siddapur and Yellapur, respectively. (Table 2).

Significantly higher fungal population ( $8.67 \times 10^4$ ) was noticed under ZBNF areca- black pepper gardens at Sirsi location. A similar trend was observed in Yellapur ( $8.21 \times 10^4$ ) and which was on par with organic areca - black pepper gardens. Whereas, in Siddapur higher fungal population ( $8.58 \times 10^4$ ) was recorded under organic areca - black pepper gardens, and it was on par with ZBNF areca - black pepper gardens. However, the fungal population was lower in INM areca - black pepper gardens ( $5.94 \times 10^4$ ,  $6.66 \times 10^4$  and  $6.46 \times 10^4$ , respectively) at all three taluks.

The actinomycetes population differed significantly among different nutrient management practices. Significantly higher actinomycetes population ( $29.78 \times 10^5$ ) was recorded in ZBNF areca- black pepper gardens soils compared to other areca - black pepper gardens soils. However, the least population was found in INM areca- black pepper gardens ( $24.68 \times 10^5$ ) at Sirsi location. Similarly, Siddapur and Yellapur soils were recorded higher ( $30.22 \times 10^5$  and  $32.05 \times 10^5$ ) actinomycetes population in organic areca - black pepper gardens.

The surface soil recorded significantly higher population of bacterial, fungal and actinomycetes activity compared to subsurface soils at all three taluks of the entire study area.

The treatment which received exclusively organic manures had significantly more influence on the population of bacteria, fungi and actinomycetes than the combined application of organic and inorganic application (Karikatti et al., 2020). The reason behind this could be due to the enhanced organic carbon content of the soil as a result of organic manure application as compared to inorganic fertilisers. Besides this, the application of organic manure would have resulted in increased secondary and micronutrients in the soil, which might have helped to increase the microbial population. The carbon acts as a source of energy for microbes and ferments organics that resulting in a quick build-up of microflora and fauna. This leads to activation of soil microflora, viz. bacteria, actinomycetes and fungi that are present in soil. The organic manure addition would have resulted in increased secondary and micronutrients in the soil, which might have helped to increase the microbial population. The results are analogous to the findings of Reddy et al. (2000).

### 3.2 Soil Enzyme Activity

Soil enzyme activity is an indirect indication of the activities of microbes, which is directly correlated with the soil microbial population. In the present investigation, significantly increased enzyme activity of urease, dehydrogenase, and alkaline phosphatase was noticed (Table 3).

### 3.3 Dehydrogenase Activity

The metabolic status of soil microorganisms is measured by the activity of dehydrogenase enzymes. Dehydrogenase can thus be employed as a reliable indicator of microbial activity in soil and a measure of microbial respiration. (Tejada et al., 2011). The dehydrogenase activity was found significantly higher in soils of organic areca - black pepper gardens ( $20.53$  and  $18.82 \mu\text{g of TPF g}^{-1} 24 \text{ h}^{-1}$ ) at Sirsi and Yellapur, respectively, compared to ZBNF and INM areca- black pepper gardens. But concerning Siddapur, ZBNF gardens soils recorded higher ( $20.83 \mu\text{g of TPF g}^{-1} 24 \text{ h}^{-1}$ ) enzyme activity.

While least activity was found in INM areca- black pepper gardens ( $16.46$ ,  $18.13$  and  $16.25 \mu\text{g of TPF g}^{-1} 24 \text{ h}^{-1}$ ) at all three taluks

respectively. The dehydrogenase activity was significantly higher at surface soil (20.66  $\mu\text{g}$  of TPF  $\text{g}^{-1} 24 \text{ h}^{-1}$ ) compared to subsurface soils (17.57  $\mu\text{g}$  of TPF  $\text{g}^{-1} 24 \text{ h}^{-1}$ ) at Sirsi. Similarly, the same trend was noticed at Siddapur (21.01  $\mu\text{g}$  of TPF  $\text{g}^{-1} 24 \text{ h}^{-1}$ ) and Yellapur (19.34  $\mu\text{g}$  of TPF  $\text{g}^{-1} 24 \text{ h}^{-1}$ ) taluks. The higher dehydrogenase activity after the addition of organic manures could be due to increased microbial activity, which is known to stimulate the dehydrogenase activity (Watts et al., 2010).

### 3.4 Acid Phosphatase Activity

Acid phosphatase is a highly useful enzyme in agriculture because it hydrolyses organic phosphorus molecules and converts them to inorganic phosphorus that plants can use. (Maestre et al., 2011). Among different areca-black pepper gardens practicing different nutrient management, the organic areca - black pepper gardens recorded higher (23.72 and 20.72  $\mu\text{g}$  PNP  $\text{g}^{-1} \text{ h}^{-1}$  respectively) phosphatase activity at Siddapur and Yellapur taluks, whereas, ZBNF areca- black pepper gardens recorded higher (18.82  $\mu\text{g}$  PNP  $\text{g}^{-1} \text{ h}^{-1}$ ) acid phosphatase activity at Sirsi. However, in all three locations, INM areca- black pepper gardens showed the lowest activity of acid phosphatase (16.25, 19.66, 18.20  $\mu\text{g}$  PNP  $\text{g}^{-1} \text{ h}^{-1}$ ) respectively. The surface soil of Sirsi, Siddapur and Yellapur taluk recorded the highest acid phosphatase activity (19.36, 23.28 and 20.24  $\mu\text{g}$  PNP  $\text{g}^{-1} \text{ h}^{-1}$ , respectively) than the subsurface soil (16.42, 21.40 and 19.18  $\mu\text{g}$  PNP  $\text{g}^{-1} \text{ h}^{-1}$ , respectively).

This might be due to higher organic manure application, which would have favoured more microbial populations, ultimately more enzyme activity. The results of the present study were very close to the observations made by Krishnakumar et al. (2005). Sriramachandrasekharan and Ravichandran (2011) also reported that organic matter added to the soil provided a carbon supply that increased microbial biomass and phosphatase activity.

### 3.5 Urease Activity

Urease is a key enzyme that converts urea fertiliser into  $\text{NH}_3$  and  $\text{CO}_2$ , resulting in a rise in soil pH (Byrnes and Amberger, 1989). INM areca- black pepper garden soils recorded significantly higher urease activity (115.47, 121.29, 117.64  $\mu\text{g}$   $\text{NH}_4^+$  released  $\text{g}^{-1} \text{ soil hr}^{-1}$ ) compared to other areca - black pepper garden

soils at all three taluks, respectively. While least urease activity was found in ZBNF areca- black pepper gardens (111.19, 115.37, 114.37  $\mu\text{g}$   $\text{NH}_4^+$  released  $\text{g}^{-1} \text{ soil hr}^{-1}$ ) at Sirsi, Siddapur and Yellapur taluks, respectively. The urease enzyme activity was found significantly higher in surface soil (115.76, 120.34, 118.17  $\mu\text{g}$   $\text{NH}_4^+$  released  $\text{g}^{-1} \text{ soil hr}^{-1}$ ) of Sirsi, Siddapur and Yellapur taluks, respectively, than in subsurface soils. Higher urease activity in INM areca gardens may be due to high use of fertiliser inputs, including urea. Thus, the present study results indicated that the higher availability of substrate nitrogen (Urea) and other nutrients promoted the urease activity (Shen et al., 2010). The fact that organic manures and fertilisers are only applied to the surface layer may explain the lower urease activity in subsurface layers (Rao and Ghai, 1989).

### 3.6 Soil Organic Carbon and Microbial Biomass Carbon

Soil organic carbon content has significantly differed between different nutrient management practices, as presented in Fig. 1. The organic areca - black pepper gardens recorded significantly higher soil organic carbon content (1.16 %, 1.20 % and 1.19 %) compared to other nutrient management practices at Sirsi, Siddapur and Yellapur, respectively. This was mainly attributed to a higher amount of organic input application. Such an increase in SOC due to fertiliser and FYM application was reported by Nagaraja (1997). Whereas, lower soil organic carbon content was noticed in INM areca- black pepper gardens (0.90, 1.07 and 1.08 %) respectively at all three taluks of Uttara Kannada district.

Soil microbial biomass carbon (MBC) is the most active and dynamic pool of the soil organic matter, acts as a transient nutrient sink and is responsible for releasing nutrients from organic matter for use by plants. Significantly higher MBC was observed in organic areca - black pepper gardens (276.93, 285.83 and 283.51  $\text{mg kg}^{-1}$ , respectively) at Sirsi, Siddapur and Yellapur taluks. Lower MBC (263.86, 263.81 and 263.87  $\text{mg kg}^{-1}$ , respectively) was observed in INM areca- black pepper gardens at all three taluks. Similarly, the content of MBC was significantly higher in surface soil (279.95, 283.70 and 282.36  $\text{mg kg}^{-1}$ , respectively) as compared to subsurface soil (263.19, 265.75 and 264.33  $\text{mg kg}^{-1}$ , respectively) at all three taluks.

**Table 2. Effect of different nutrient management practices on microbial population of bacteria, fungi and actinomycetes in soils of arecanut and black pepper cropping system**

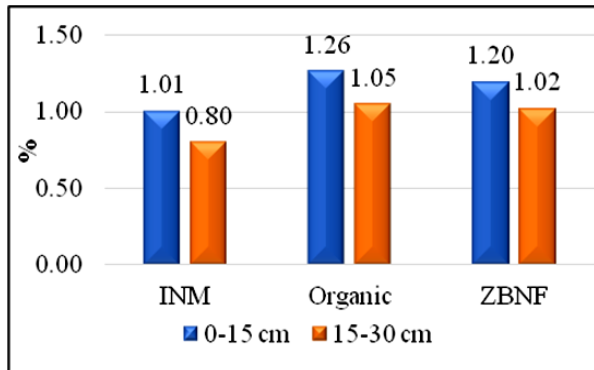
Group of areca - black pepper gardens	Bacterial count (10 <sup>6</sup> )								
	Sirsi			Siddapur			Yellapur		
	0-15 cm	15-30 cm	Mean	0-15 cm	15-30 cm	Mean	0-15 cm	15-30 cm	Mean
INM - areca + black pepper gardens	71.46	66.50	68.98	76.12	71.60	73.86	75.74	71.21	73.47
Organic areca + black pepper gardens	82.43	78.80	80.61	81.12	78.30	79.71	81.65	77.44	79.55
ZBNF areca + black pepper gardens	80.94	77.73	79.34	81.50	76.64	79.07	83.29	77.74	80.51
Mean	78.28	74.34		79.58	75.51		80.26	75.49	
Interaction	<b>M</b>	<b>D</b>	<b>M x D</b>	<b>M</b>	<b>D</b>	<b>M x D</b>	<b>M</b>	<b>D</b>	<b>M x D</b>
S. Em. ±	0.71	0.58	1.00	1.22	1.00	1.73	0.70	0.57	0.99
CD at 5%	2.02	1.65	NS	3.50	2.85	NS	2.00	1.63	NS
	Fungi count (10 <sup>4</sup> )								
INM - areca + black pepper gardens	6.56	5.32	5.94	6.91	6.41	6.66	6.71	6.21	6.46
Organic areca + black pepper gardens	8.60	7.54	8.07	8.90	8.26	8.58	8.41	7.96	8.19
ZBNF areca + black pepper gardens	9.31	8.03	8.67	8.78	8.03	8.41	8.58	7.83	8.21
Mean	8.16	6.96		8.20	7.57		7.90	7.33	
Interaction	<b>M</b>	<b>D</b>	<b>M x D</b>	<b>M</b>	<b>D</b>	<b>M x D</b>	<b>M</b>	<b>D</b>	<b>M x D</b>
S. Em. ±	0.12	0.10	0.17	0.09	0.08	0.13	0.08	0.06	0.11
CD at 5%	0.35	0.29	NS	0.26	0.22	NS	0.22	0.18	NS
	Actinomycetes count (10 <sup>5</sup> )								
INM - areca + black pepper gardens	23.68	25.68	24.68	24.03	26.10	25.07	24.12	29.56	26.84
Organic areca + black pepper gardens	27.80	29.31	28.55	28.18	32.26	30.22	29.251	34.84	32.05
ZBNF areca + black pepper gardens	28.94	30.61	29.78	29.16	30.22	29.69	28.396	32.84	30.62
Mean	26.81	28.53		27.12	29.53		27.26	32.41	
Interaction	<b>M</b>	<b>D</b>	<b>M x D</b>	<b>M</b>	<b>D</b>	<b>M x D</b>	<b>M</b>	<b>D</b>	<b>M x D</b>
S. Em. ±	0.33	0.27	0.47	0.35	0.28	0.49	0.65	0.53	0.91
CD at 5%	0.95	0.78	NS	0.99	0.81	1.41	1.85	1.51	NS

M- Nutrient management practice; D- Soildepth

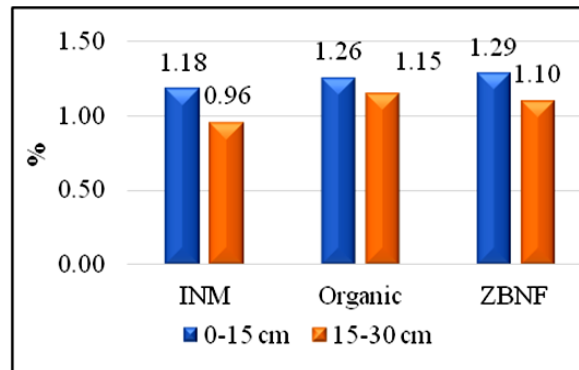
Table 3. Effect of different nutrient management practices on enzyme activities in arecanut and black pepper cropping system

Group of areca - black pepper gardens	Dehydrogenase ( $\mu\text{g TPF d}^{-1} \text{g}^{-1}$ )								
	Sirsi			Siddapur			Yellapur		
	0-15 cm	15-30 cm	Mean	0-15 cm	15-30 cm	Mean	0-15 cm	15-30 cm	Mean
INM -areca + black pepper gardens	17.26	15.66	16.46	19.74	16.53	18.13	17.23	15.27	16.25
Organic areca + black pepper gardens	22.98	18.09	20.53	21.92	17.88	19.90	20.70	16.93	18.82
ZBNF areca + black pepper gardens	21.74	18.97	20.35	21.35	20.30	20.83	20.09	17.06	18.58
Mean	20.66	17.57		21.01	18.24		19.34	16.42	
Interaction	<b>M</b>	<b>D</b>	<b>M x D</b>	<b>M</b>	<b>D</b>	<b>M x D</b>	<b>M</b>	<b>D</b>	<b>M x D</b>
S. Em. $\pm$	0.43	0.35	0.61	0.51	0.42	0.72	0.55	0.45	0.78
CD at 5%	1.23	1.00	1.73	1.46	1.19	NS	1.58	1.29	NS
Phosphatase ( $\mu\text{g PNP g}^{-1} \text{h}^{-1}$ )									
INM -areca + black pepper gardens	17.23	15.27	16.25	20.48	18.84	19.66	18.86	17.53	18.20
Organic areca + black pepper gardens	20.09	17.06	18.58	24.96	22.47	23.72	21.03	20.41	20.72
ZBNF areca + black pepper gardens	20.70	16.93	18.82	24.40	22.89	23.65	20.85	19.59	20.22
Mean	19.34	16.42		23.28	21.40		20.24	19.18	
Interaction	<b>M</b>	<b>D</b>	<b>M x D</b>	<b>M</b>	<b>D</b>	<b>M x D</b>	<b>M</b>	<b>D</b>	<b>M x D</b>
S. Em. $\pm$	0.55	0.45	0.78	0.36	0.30	0.51	0.33	0.27	0.47
CD at 5%	1.58	1.29	NS	1.04	0.85	NS	0.94	0.77	NS
Urease ( $\mu\text{g NH}_4^+ \text{ released g}^{-1} \text{ soil hr}^{-1}$ )									
INM -areca + black pepper gardens	119.72	111.21	115.47	125.87	116.72	121.29	119.03	116.24	117.64
Organic areca + black pepper gardens	114.32	113.16	113.74	117.05	114.00	115.53	119.44	111.49	115.47
ZBNF areca + black pepper gardens	113.24	109.14	111.19	118.10	112.64	115.37	116.03	112.70	114.37
Mean	115.76	111.17		120.34	114.45		118.17	113.48	
Interaction	<b>M</b>	<b>D</b>	<b>M x D</b>	<b>M</b>	<b>D</b>	<b>M x D</b>	<b>M</b>	<b>D</b>	<b>M x D</b>
S. Em. $\pm$	0.59	0.48	0.83	0.82	0.67	1.16	0.86	0.70	1.22
CD at 5%	1.68	1.37	2.37	2.34	1.91	3.32	2.47	2.01	NS

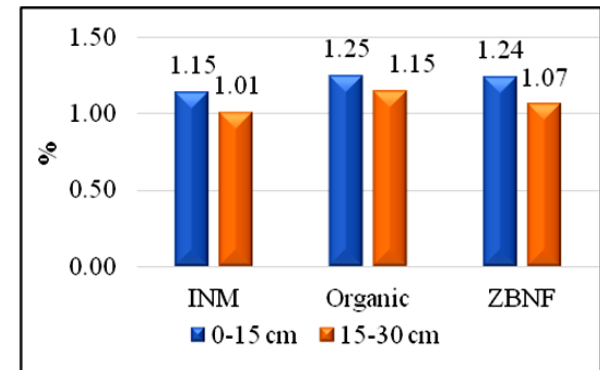
M- Nutrient management practice; D- Soildepth



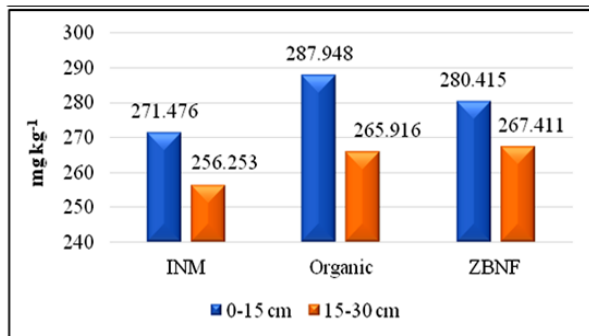
a) Soil OC at Sirsi



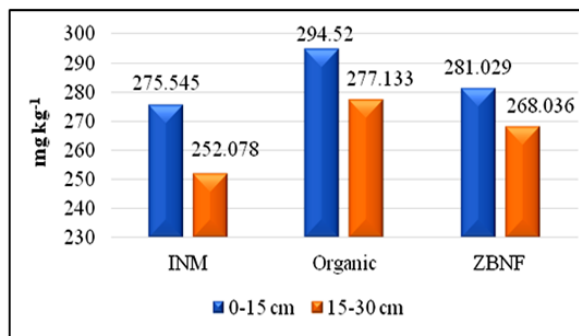
b) Soil OC at Siddapur



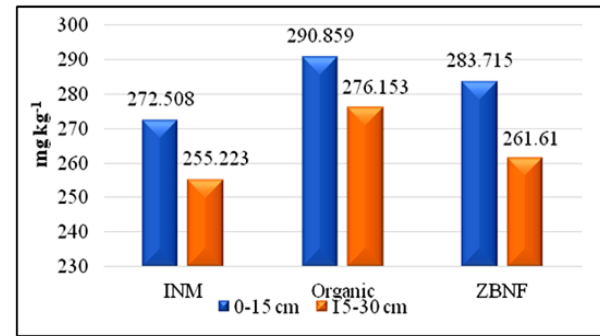
c) Soil OC at Yellapur



d) MBC at Sirsi



e) MBC at Siddapur



f) MBC at Yellapur

Fig. 1. Effect of different nutrient management practices on soil organic carbon and soil microbial biomass carbon in arecanut and black pepper cropping system

The variations in soil MBC among different nutrient management practices may be attributed to variation in soil organic matter content, consequently, the microbial activity. Further, the variation in SOM may be attributed to variation in residue return to soil and the addition of manure. The application of manure had a positive effect on soil organic matter content, which in turn decides the SMBC (Asha, 2016). Similar results have been reported by Geo Jose (2006) and Collins et al. (1992) in the FYM applied plots of long-term manurial trial in Alfisol under rice pulse cropping systems.

#### 4. CONCLUSION

It was observed from the current study that in organic areca-black pepper gardens due to higher application of organic nutrient sources resulted in higher organic carbon accumulation, which resulted in higher microbial population. According to the population of microbes, their enzyme activity was also recorded as higher in organic gardens, which was on par with ZBNF areca-black pepper gardens compared to INM areca-black pepper gardens. The higher the application of organic sources, the higher the accumulation of organic carbon in soil, which is the source of nutrients for the soil microbial population. This resulted in more Microbial biomass carbon in organic and ZBNF areca-black pepper gardens at the entire study area. Overall, soil health was very well maintained in this nutrient management practice.

#### ACKNOWLEDGEMENT

The authors acknowledge the Dept. of Soil Science, College of Horticulture Sirsi Uttara Kannada for providing the facilities to conduct this research.

#### DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

#### REFERENCES

Allen, O. N. (1957). *Experiments in soil bacteriology*. Burgess Publication Co.

Asha, S. S. (2016). *Impact of land use systems on nutrient and carbon distribution in soils of Thirthahalli Taluk, Shivamogga district* (M.Sc. thesis). UAHS, Shivamogga, Karnataka, India.

Badiane, N. N. Y., Chotte, L., Pate, E., Masse, D., & Rouland, C. (2001). Use of soil enzyme activities to monitor soil quality in natural and improved fallows in semi-arid tropical regions. *Applied Soil Ecology*, 18, 229–238.

Byrnes, B. H., & Amberger, A. (1989). Fate of broadcast urea in a flooded soil when treated with N-(n-butyl) thiophosphorictriamide, a urease inhibitor. *Fertilizer Research*, 18, 221–231.

Carter, M. R. (1991). Ninhydrin reactive-N released by the fumigation extraction method as a measure of microbial biomass under field conditions. *Soil Biology and Biochemistry*, 23, 139–143.

Casida, L. E., Klein, D. A., & Santoro, T. (1964). Soil dehydrogenase activity. *Soil Science*, 98, 371–376.

Collins, H. P., Rasmussen, P. E., & Douglas, C. L. (1992). Crop rotation and residual management – effects on soil carbon and microbial dynamics. *Soil Science Society of America Journal*, 56, 783–788.

Dai, Z., Xiong, X., Zhu, H., Xu, H., Leng, P., Li, J., ... Xu, J. (2021). Association of biochar properties with changes in soil bacterial, fungal and fauna communities and nutrient cycling processes. *Biochar*, 3, 239–254. <https://doi.org/10.1007/s42773-021-00087-z>

DeForest, J. L., Smemo, K. A., Burke, D. J., Elliott, H. L., & Becker, J. C. (2012). Soil microbial responses to elevated phosphorus and pH in acidic temperate deciduous forests. *Biogeochemistry*, 109, 189–202.

Ge, G., Li, Z., Fan, F., Chu, G., Hou, Z., & Liang, Y. (2010). Soil biological activity and their seasonal variations in response to long-term application of organic and inorganic fertilizers. *Plant and Soil*, 326, 31–44.

Geo, J. (2006). *Organic carbon distribution in soils under long-term rice cropping systems in coastal and southern dry zones of Karnataka* (M.Sc. thesis). UAS, Bangalore, India.

Jenkinson, D. S., & Ladd, J. N. (1981). Microbial biomass in soil measurement and turnover. In E. A. Paul & J. N. Ladd (Eds.), *Soil biochemistry* (pp. 415–471). Marcel Dekker.

- Karikatti, P., Bhat, S. N., Balanagoudar, S. R., Mastanareddy, B. G., Veeresh, H., & Satyanarayana Rao. (2020). Long term effect of organic, integrated and inorganic nutrient management practices on soil properties in a Vertisol. *International Journal of Current Microbiology and Applied Sciences*, 9(01).
- Krishnakumar, S., Saravanan, A., Natarajan, S. K., Veerabadran, V., & Mani, S. (2005). Microbial population and enzymatic activity as influenced by organic farming. *Research Journal of Agricultural and Biological Sciences*, 1(1), 85–88.
- Liu, L., Gao, Y., Yang, W., Liu, J., & Wang, Z. (2024). Community metagenomics reveals the processes of nutrient cycling regulated by microbial functions in soils with P fertilizer input. *Plant and Soil*, 499(1), 139–154. <https://doi.org/10.1007/s11104-023-06005-9>
- Maestre, F. T., Puche, M. D., Guerrero, C., & Escudero, A. (2011). Shrub encroachment does not reduce the activity of some soil enzymes in Mediterranean semiarid grasslands. *Soil Biology and Biochemistry*, 43, 1746–1749.
- Maurya, B. R., Vimal, S., & Dhyani, P. P. (2011). Enzymatic activities and microbial population in agri-soils of Almora district of central Himalaya as influenced by altitudes. *International Journal of Soil Science*, 6, 238–248.
- Nagaraja, M. S. (1997). *Biomass turnover, nutrient status and biological processes among different land use systems* (Ph.D. thesis). UAS, Bangalore.
- Nannipieri, P., Kandeler, E., & Ruggiero, P. (2002). Enzyme activities and microbial and biochemical processes in soil. In R. G. Burns & R. P. Dick (Eds.), *Enzymes in the environment: Activity, ecology and applications* (pp. 1–33). Marcel Dekker.
- Nthebere, K., Prakash, T. R., Bhimireddy, P., Chandran, L. P., Gudapati, J., Admala, M., & Prasad, K. (2025). Conservation agricultural practices promoted arbuscular mycorrhizal fungal colonization and glomalin content on sandy clay loam of southern India. *Heliyon*, 11(1). <https://doi.org/10.1016/j.heliyon.2024.e12345>
- Nthebere, K., Prakash, T. R., Bhimireddy, P., Chandran, L. P., Gudapati, J., Admala, M., & Prasad, K. (2022). Conservation agricultural practices promoted arbuscular mycorrhizal fungi and glomalin on sandy clay loam of southern India. SSRN. <https://doi.org/10.2139/ssrn.4929951>
- Piotrowska-Długosz, A., Długosz, J., Frać, M., Gryta, A., & Breza-Boruta, B. (2022). Enzymatic activity and functional diversity of soil microorganisms along the soil profile—A matter of soil depth and soil-forming processes. *Geoderma*, 416, 115779. <https://doi.org/10.1016/j.geoderma.2022.115779>
- Rao, D. L. N., & Ghai, S. K. (1989). Urease and dehydrogenase activity of alkali and reclaimed soils. *Australian Journal of Soil Research*, 23, 661–665.
- Reddy, M. N., Devi, M. C., & Sridevi, N. V. (2000). Evaluation of turmeric cultivars for VAM colonization. *Indian Phytopathology*, 56(4), 465–466.
- Shen, W., Lin, X., Shi, W., Min, J., Gao, N., Zhang, H., Yin, R., & He, X. (2010). Higher rates of nitrogen fertilization decrease soil enzyme activities, microbial functional diversity and nitrification capacity in a Chinese polytunnel greenhouse vegetable land. *Plant and Soil*, 337, 137–150.
- Sriramachandrasekharan, M. V., & Ravichandran, M. (2011). Enzyme dynamics and soil properties in paddy soil fertilized with mineral and green manure N sources. *Agricultural Segment*, 2(2), AGS/1558.
- Tabatabai, M. A. (1984). Soil enzymes. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), *Methods of soil analysis, part 2* (pp. 903–947). American Society of Agronomy, Soil Science Society of America.
- Tabatabai, M. A. (1994). Soil enzymes. In R. W. Weaver, J. S. Angle, & P. S. Bottomley (Eds.), *Methods of soil analysis, part 2: Microbiological and biochemical properties* (SSSA Book Series No. 5, pp. 775–833). Soil Science Society of America.
- Tabatabai, M. A., & Bremer, J. M. (1969). Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biology and Biochemistry*, 1, 301–307.
- Tejada, M., Benítez, C., Gómez, I., & Parrado, J. (2011). Use of bio stimulants on soil restoration: Effects on soil biochemical properties and microbial community. *Applied Soil Ecology*, 49, 11–17.
- Wani, S. P., & Lee, K. K. (1995). Microorganisms as biological inputs for sustainable agriculture. In P. K. Thampam (Ed.), *Organic agriculture* (pp. 39–76). Peekay Tree Crops Development Foundation.

- Watts, D. B., Allen, T. H., Feng, Y., & Prior, S. A. (2010). Soil microbial community dynamics as influenced by composted dairy manure, soil properties, and landscape position. *Soil Science*, 175, 474–486.
- Wu, H., Cui, H., Fu, C., Li, R., Qi, F., Liu, Z., ... Qiao, M. (2024). Unveiling the crucial role of soil microorganisms in carbon cycling: A review. *Science of the Total Environment*, 909, 168627. <https://doi.org/10.1016/j.scitotenv.2023.168627>

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2025): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

*Peer-review history:*  
*The peer review history for this paper can be accessed here:*  
<https://pr.sdiarticle5.com/review-history/136664>