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Organic Carbon and Biological Properties of Soils in Various Agro-Ecological Units of Kerala, India

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Authors' contributions

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

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ABSTRACT

A study was carried out in four *agro-ecological units* (AEUs), viz., southern laterites (AEU 8), south central laterites (AEU 9), north central laterites (AEU 10), and the northern laterites (AEU 11) of Kerala, with the objective of detailing the soil fertility status of the study area and unveiling the relationship between *organic carbon* (OC) and various biological properties of soils, like population of phosphorus solubilizers and acid phosphatase activity, by following one-way *analysis of variance* (ANOVA). The findings of the study revealed that the average values of OC among the four AEUs varied from 0.63 to 0.82%, and remarkably, 98% of the collected soils displayed OC content ranging from 0.5 to 1.5%. The mean values for the population of phosphorus solubilizers ranged from 3.12 to 3.34 log cfu g^{-1} soil. The acid phosphatase activity also varied across the study area,

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with mean values ranging from 24.84 to 30.70 µg p-nitrophenol produced g^{-1} soil h^{-1}, and most of the collected soils showed activity between 25 and 50 µg p-nitrophenol produced g^{-1} soil h^{-1}. Implementation of effective soil management practices, in accordance with soil test results, is imperative for the preservation and enhancement of organic carbon levels through the incorporation of organic matter, such as compost and cover crops, while minimizing the excessive use of chemical fertilizers. This approach not only augments organic carbon content but also enhances the biological properties of soils, thereby improving soil fertility and overall soil health.

Keywords: Acid phosphatase activity; agro-ecological units; organic carbon; population of phosphorus solubilizers.

1. INTRODUCTION

Soil is one of the utmost vital components of ecosystems, which promotes plant growth by governing the availability of water, nutrients, and energy [1]. The physical, chemical, and biological characteristics of soil are significantly influenced by organic matter, which is also an important factor that supports the healthy functioning of soil, as it is necessary for human civilization. The chief component of soil organic matter is carbon, which is stated as OC, accounting for 58% of its weight on average. It plays a major role in agricultural production because organic matter helps to improve soil structure, water holding, and cation-exchanging capacity, promoting soil biota and thus exerting positive impacts on soil fertility [2]. Also, OC helps in the cycling of plant nutrients, besides increasing crop yields by improving the physical, chemical, and biological properties of soils [3]. Additionally, it acts as a food source for soil microorganisms, and is a significant metabolite for bacteria. It has also been acknowledged as a tool that could minimize the impact of climate change through sequestration in agricultural soils. Furthermore, over the past few years, there has been a rising focus within the scientific community on the biological attributes of soil. These attributes are noted to exhibit a higher sensitivity to even minor changes compared to chemical or physical properties [4]. Microorganisms, among the native biological constituents of soil, hold a pivotal position in numerous vital biochemical processes, which include the cycling of elements like carbon, nitrogen, phosphorus, and sulphur, as well as facilitating energy transfers within the soil environment [5]. In addition to that, enzyme activity also stands out as a highly valuable parameter for evaluating soil quality. Soil enzymes predominantly originate from microorganisms, but they can also be produced by plant roots and soil-dwelling organisms [6]. In the opinion of several researchers, enzyme activity is the most sensitive measure of the biological as well as chemical status of soil because it participates in all microbiological reactions, including nutrient cycles in the soil, and it responds fast to changes in soil brought about by human-induced or natural factors [7,8].

Kerala, with a total geographic area of 38,864 km^2, is a small strip of land between the Arabian Sea on the west and the Western Ghats and Nilgiri Hills on the east. The soils of Kerala were mostly laterites and basically acidic in reaction [9], having low activity clay and mostly gravelly with low water and nutrient retention ability. Based on climatic variability, landforms, and soils, Kerala has been divided into 23 AEUs, each of which corresponds to a particular soil and climatic conditions. The base-depleted soils are rather infertile, requiring vigilant management to attain better crop yields.

Thus, understanding the OC status, biological properties, and their interplay in the soils of AEUs (AEU 8, 9, 10, and 11) is fundamental not only for sustainable agriculture but also for broader ecosystem management and environmental protection. As we embark on this journey of exploration, we anticipate uncovering valuable knowledge that can guide us towards more resilient and sustainable agricultural practices, helping to secure the future of both Kerala's agricultural communities and its rich natural heritage.

2. MATERIALS AND METHODS

A preliminary survey was conducted, and a total of 100 georeferenced representative soil samples of 25 each were collected from four AEUs, viz., AEU 8 (Southern laterites), AEU 9 (South central laterites), AEU 10 (North central laterites), and AEU 11 (Northern laterites). The sampling locations encompassed various regions, including the Athiyanoor, Balaramapuram, Kalliyoor, Kottukal, and Venganoor panchayats/municipalities within

Thiruvananthapuram district for AEU 8, the Kottarakkara, Kulakkada, Mylom, Neduvathoor, and Pavithreswaram panchayats/municipalities within Kollam district for AEU 9, the Chalakudy, Kadukutty, Kodakara, Koratty, and Meloor panchayats/municipalities within Thrissur district for AEU 10, and the Chathamangalam, Koduvally, Mukkam, Omassery, and Peruvayal panchayats/municipalities within Kozhikode district for AEU 11. Collected soils were analysed for OC by means of the wet oxidation method [10] and the biological properties, like the population of phosphorus solubilizers using Pikovskayas's media [11] and acid phosphatase activity by following a colorimetric estimation of p-nitrophenol released [12]. The statistical design followed was one-way ANOVA using the open software GRAPES [13]. The details of the study area are presented in Fig. 1.

3. RESULTS AND DISCUSSION

3.1 Soil OC

Soil OC (Table 1a) showed a significant difference at the panchayat/municipality level in southern laterites (AEU 8) and north central laterites (AEU 10), but no significant difference was showed in south central laterites (AEU 9) and northern laterites (AEU 11). In southern laterites (AEU 8), the mean values of OC varied from 0.63 to 1.01%. The lowest mean value was observed in the soils of Kottukal panchayat (0.63%), while the highest mean value of 1.01% was recorded by the panchayat Kalliyoor. In north central laterites (AEU 10), the mean values of OC ranged from 0.74 to 0.80%. The lowest mean value of 0.74% was noticed in the panchayats Kadukutty and Meloor, while the highest mean value of 0.80% was observed in the panchayat Koratty, which was found to be on par with the panchayat Kodakara (0.79%).

As a whole, the mean values of OC for four AEUs, *viz*., AEU 8, 9, 10, and 11, are presented in Table 1b. As per the data, among the four AEUs, there was a considerable difference with respect to OC. The mean values of OC varied from 0.63 to 0.82%. The lowest mean value of 0.63% was observed in south central laterites (AEU 9), while the highest mean value of 0.82% was recorded by southern laterites (AEU 8), which was found to be on par with the mean value of 0.80% for northern laterites (AEU 11). Frequency distribution analysis of the data (Fig. 2) revealed that the majority of the collected soils (98%) displayed soil OC content ranging from 0.5 to 1.5%, which might be due to the presence of partially decomposed roots and other substances [14, 15]. Also, the presence of a higher particulate OC content, which represents un-complexed organic matter, might have contributed to the higher organic matter content in the soils of southern laterites [16].

3.2 Biological Properties

Various biological attributes, like the population of phosphorus solubilizers and acid phosphatase activity, were analyzed for the soil samples of the study area, and the results obtained are provided in Tables 2a and 2b.

3.2.1 Population of Phosphorus Solubilizers

The scrutiny of the data on the population of phosphorus solubilizers revealed that there was a significant difference at the panchayat/municipality level in the soils of AEU 8, but no significant difference was observed in AEUs 9, 10, and 11 (Table 2a). In southern laterites (AEU 8), the mean values of the population of phosphorus solubilizers ranged from 3.18 to 3.43 log cfu g^{-1} soil, while the lowest mean value of 3.18 log cfu g^{-1} soil was recorded by the panchayat Kottukal. The highest mean value of 3.43 log cfu g^{-1} soil was recorded by the panchayat Kalliyoor, and it was found to be on par with the panchayats Balaramapuram (3.37 log cfu g^{-1} soil), Venganoor (3.37 log cfu g^{-1} soil), and Athiyanoor (3.34 log cfu g^{-1} soil).

Overall, among the four AEUs (8, 9, 10, and 11), there was a significant difference in the population of phosphorus solubilizers (Table 2b). The mean values varied from 3.12 to 3.34 log cfu g^{-1} soil. The lowest mean value of 3.12 log cfu g^{-1} soil was observed in south central laterites (AEU 9). The highest mean value of 3.34 log cfu g^{-1} soil was recorded by southern laterites (AEU 8), and it was on par with soils of AEU 11 (3.25 log cfu g^{-1} soil). The majority of the soils collected (66%) showed a population of phosphorus solubilizers greater than 3 log cfu g^{-1} soil (Fig. 3). This might be due to the presence of more organic matter, which favours microbial growth. Consequently, the population of phosphorus solubilizers was profound in the soils of AEU 8 and 11. The correlation study also disclosed a positive correlation between OC and the population of phosphorus solubilizers (Table 3).

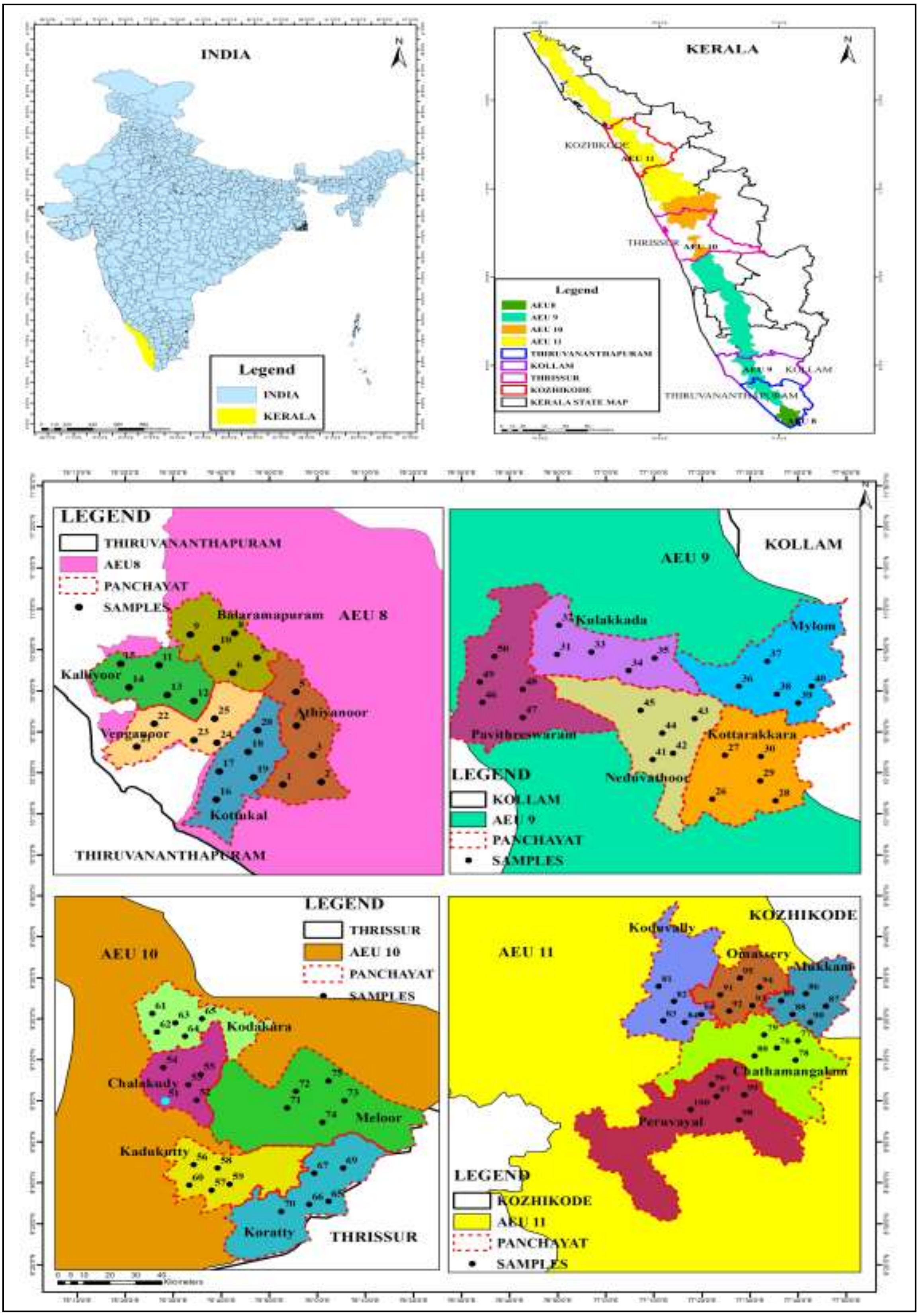

Fig. 1. Location map of soil samples in AEUs 8, 9, 10, and 11 of Kerala

Table 1a. Soil OC content in different panchayats/municipalities of AEUs 8, 9, 10, and 11

Panchayat/Municipality	OC (%)
Southern laterites (AEU 8)	
Athiyanoor	0.80 [b]
Balaramapuram	0.76 [b]
Kalliyoor	1.01 [a]
Kottukal	0.63 [c]
Venganoor	0.92 [a]
SEd (±)	**0.059**
SEm (±)	**0.042**
CD (0.05)	**0.124**
South central laterites (AEU 9)	
Kottarakkara	0.66
Kulakkada	0.62
Mylom	0.61
Neduvathoor	0.62
Pavithreswaram	0.64
SEd (±)	**0.041**
SEm (±)	**0.029**
CD (0.05)	**NS**
North central laterites (AEU 10)	
Chalakudy	0.75 [bc]
Kadukutty	0.74 [c]
Kodakara	0.79 [ab]
Koratty	0.80 [a]
Meloor	0.74 [c]
SEd (±)	**0.020**
SEm (±)	**0.014**
CD (0.05)	**0.041**
Northern laterites (AEU 11)	
Chathamangalam	0.79
Koduvally	0.79
Mukkam	0.78
Omassery	0.83
Peruvayal	0.81
SEd (±)	**0.027**
SEm (±)	**0.019**
CD (0.05)	**NS**

Table 1b. Soil OC content in AEUs 8, 9, 10, and 11

AEU	OC (%)	
	Mean±SD	**Range**
Southern laterites (AEU 8)	0.82±0.16 [a]	0.53-1.09
South central laterites (AEU 9)	0.63±0.06 [c]	0.50-0.71
North central laterites (AEU 10)	0.77±0.04 [b]	0.71-0.85
Northern laterites (AEU 11)	0.80±0.04 [ab]	0.71-0.89
SEd (±)	**0.026**	
SEm (±)	**0.018**	
CD (0.05)	**0.051**	

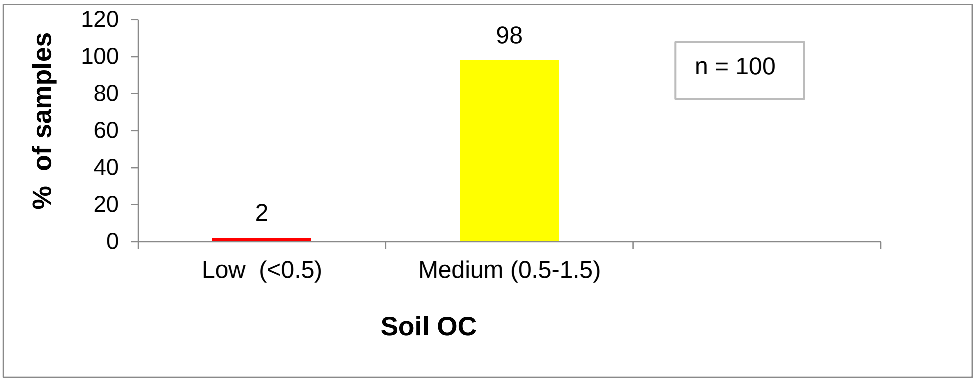

Fig. 2. Frequency distribution of soil OC (%) in AEUs 8, 9, 10, and 11

3.2.2 Acid Phosphatase Activity

Acid phosphatase activity in different panchayats/municipalities in the soils of the AEUs 8, 9, 10, and 11 showed a significant difference (Table 2a). In southern laterites (AEU 8), the mean values of acid phosphatase activity ranged from 23.05 to 36.53 µg p-nitrophenol produced g^{-1} soil h^{-1}. The lowest mean value of 23.05 µg p-nitrophenol produced g^{-1} soil h^{-1} was recorded by the panchayat Kottukal, while the highest mean value of 36.53 µg p-nitrophenol produced g^{-1} soil h^{-1} was recorded by the panchayat Kalliyoor, and it was found to be on par with the panchayat Venganoor (33.72 µg p-nitrophenol produced g^{-1} soil h^{-1}). In south central laterites (AEU 9), the mean values of acid phosphatase activity varied from 18.25 to 36.53 µg p-nitrophenol produced g^{-1} soil h^{-1}. The lowest mean value of 18.25 µg p-nitrophenol produced g^{-1} soil h^{-1} was recorded by the panchayat Kottarakkara, while the highest mean value of 36.53 µg p-nitrophenol produced g^{-1} soil h^{-1} was recorded by the panchayat Mylom, and it was found to be on par with panchayat Kulakkada (33.72 µg p-nitrophenol produced g^{-1} soil h^{-1}). In north central laterites (AEU 10), the mean values of acid phosphatase activity ranged from 20.00 to 30.69 µg p-nitrophenol produced g^{-1} soil h^{-1}. The lowest mean value of 20.00 µg p-nitrophenol produced g^{-1} soil h^{-1} was recorded by the panchayat Kodakara, while the highest mean value of 30.69 µg p-nitrophenol produced g^{-1} soil h^{-1} was recorded by the panchayat Kadukutty, and it was found to be on par with panchayat Chalakudy (29.01 µg p-nitrophenol produced g^{-1} soil h^{-1}). In northern laterites (AEU 11), the mean values of acid phosphatase activity ranged from 18.15 to 31.17 µg p-nitrophenol produced g^{-1} soil h^{-1}. The lowest mean value of 18.15 µg p-nitrophenol produced g^{-1} soil h^{-1} was recorded by the panchayat Omassery, while the highest mean value of 31.17 µg p-nitrophenol produced g^{-1} soil h^{-1} was recorded by the panchayat Koduvally, and it was found to be on par with panchayats Peruvayal (28.15 µg p-nitrophenol produced g^{-1} soil h^{-1}) and Mukkam (27.06 µg p-nitrophenol produced g^{-1} soil h^{-1}).

Inclusively, among the four AEUs, the mean values of acid phosphatase activity differed from 24.84 to 30.70 µg p-nitrophenol produced g^{-1} soil h^{-1} (Table 2b). The lowest mean value of 24.84 µg p-nitrophenol produced g^{-1} soil h^{-1} was observed in northern laterites (AEU 11). The highest mean value of 30.70 µg p-nitrophenol produced g^{-1} soil h^{-1} was noticed in south central laterites (AEU 9), and it was found to be on par with AEU 8 (30.31 µg p-nitrophenol produced g^{-1} soil h^{-1}). Also, the majority of soils (62%) recorded the acid phosphatase activity between 25 and 50 µg p-nitrophenol produced g^{-1} soil h^{-1} (Fig. 4). This might be due to the presence of higher organic matter. Because higher organic matter in soils can lead to enhanced microbial and enzyme activity [17]. Furthermore, the ideal pH of the soil for the activity of acid phosphatase is 4.0-6.5, and at the same time, most of the soils in Kerala are acidic in nature [9], which was found to be favourable for phosphatase enzyme activity.

3.3 Correlation Study

In the present study, a correlation analysis was also employed to investigate the interplay between soil organic carbon (OC) and various biological properties like the population of phosphorus-solubilizing microorganisms and acid phosphatase activity (Table 3). This analysis utilised Pearson's correlation coefficient, a statistical tool that quantifies the strength and direction of linear relationships between variables, and the results revealed that soil

Table 2a. Population of phosphorus solubilizers and acid phosphatase activity in the soils of different panchayats/municipalities of AEUs 8, 9, 10, and 11

Panchayat/Municipality	Population of phosphorus solubilizers (log cfu g^{-1} soil)	Acid phosphatase activity (µg p-nitrophenol produced g^{-1} soil h^{-1})
Southern laterites (AEU 8)		
Athiyanoor	3.34 [a]	31.17 [bc]
Balaramapuram	3.37 [a]	27.06 [cd]
Kalliyoor	3.43 [a]	36.53 [a]
Kottukal	3.18 [b]	23.05 [d]
Venganoor	3.37 [a]	33.72 [ab]
SEd (±)	**0.075**	**2.320**
SEm (±)	**0.053**	**1.641**
CD (0.05)	**0.156**	**4.840**
South central laterites (AEU 9)		
Kottarakkara	3.18	18.25 [c]
Kulakkada	3.12	33.72 [ab]
Mylom	3.12	36.53 [a]
Neduvathoor	3.06	32.90 [b]
Pavithreswaram	3.12	32.10 [b]
SEd (±)	**0.100**	**1.609**
SEm (±)	**0.071**	**1.138**
CD (0.05)	**NS**	**3.357**
North central laterites (AEU 10)		
Chalakudy	3.18	29.01 [ab]
Kadukutty	3.16	30.69 [a]
Kodakara	3.06	20.00 [c]
Koratty	3.37	23.91 [bc]
Meloor	3.28	22.98 [c]
SEd (±)	**0.104**	**2.659**
SEm (±)	**0.073**	**1.880**

Panchayat/Municipality	Population of phosphorus solubilizers (log cfu g^{-1} soil)	Acid phosphatase activity (µg p-nitrophenol produced g^{-1} soil h^{-1})
CD (0.05)	**NS**	**5.547**
Northern laterites (AEU 11)		
Chathamangalam	3.18	19.64 [b]
Koduvally	3.22	31.17 [a]
Mukkam	3.25	27.06 [a]
Omassery	3.34	18.15 [b]
Peruvayal	3.28	28.15 [a]
SEd (±)	**0.115**	**2.108**
SEm (±)	**0.081**	**1.491**
CD (0.05)	**NS**	**4.398**

Table 2b. Population of phosphorus solubilizers and acid phosphatase activity in the soils of AEUs 8, 9, 10, and 11

AEU	Population of phosphorus solubilizers (log cfu g^{-1} soil)		Acid phosphatase activity (µg p-nitrophenol produced g^{-1} soil h^{-1})	
	Mean±SD	**Range**	**Mean±SD**	**Range**
Southern laterites (AEU 8)	3.34±0.14 [a]	3.00–3.60	30.31±5.92 [a]	17.21–39.60
South central laterites (AEU 9)	3.12±0.15 [c]	3.00–3.30	30.70±6.93 [a]	17.00–39.60
North central laterites (AEU 10)	3.21±0.19 [bc]	3.00–3.48	25.32±5.57 [b]	16.89–35.26
Northern laterites (AEU 11)	3.25±0.18 [ab]	3.00–3.48	24.84±5.99 [b]	14.00–33.72
SEd (±)	**0.046**		**1.732**	
SEm (±)	**0.033**		**1.225**	
CD (0.05)	**0.092**		**3.438**	

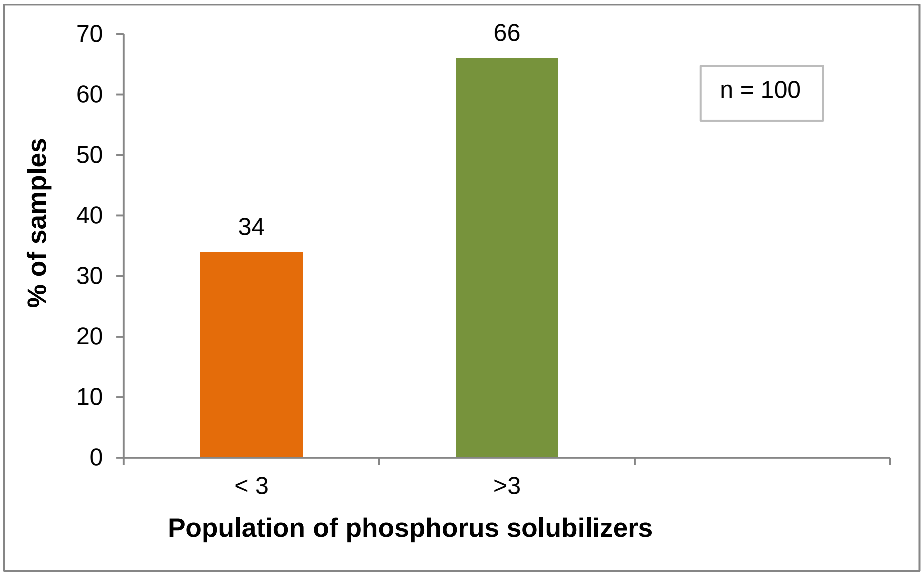

Fig. 3. Frequency distribution of the population of phosphorus solubilizers (log cfu g^{-1} soil) in the soils of AEUs 8, 9, 10, and 11

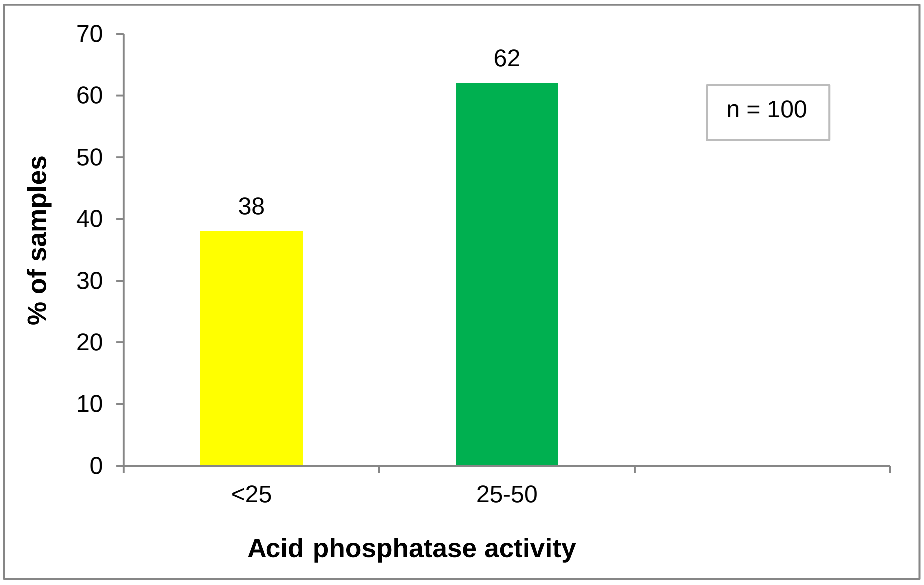

Fig. 4. Frequency distribution of acid phosphatase activity (µg p-nitrophenol produced g^{-1} soil h^{-1}) in the soils of AEUs 8, 9, 10, and 11

Table 3. Correlation between OC and biological properties in the soils of AEUs 8, 9, 10, and 11

	OC	**Population of phosphorus solubilizers**	**Acid phosphatase activity**
OC	1		
Population of phosphorus solubilizers	0.424**	1	
Acid phosphatase activity	0.065	-0.042	1

***Significant at 1% level*

OC exhibited a positive correlation with the population of phosphorus solubilizers (r = 0.424**), which indicates that higher levels of OC in the soil may promote the growth and activity of phosphorus solubilizing organisms. This, in turn, could potentially enhance the availability of phosphorus to plants. This insight is valuable for agricultural and environmental studies as it sheds light on the link between soil components and microbial communities that impact nutrient cycling.

4. CONCLUSION

The study area predominantly consisted of soil OC content ranging from 0.50 to 1.50%, accompanied by the population of phosphorus solubilizers consistently exceeding 3 log cfu g^{-1} soil and acid phosphatase activity between 25 and 50 µg p-nitrophenol produced g^{-1} soil h^{-1} in the entirety of the research. Implementation of effective soil management practices, in accordance with soil test results, is imperative for the preservation and enhancement of organic carbon levels. This could be achieved through the incorporation of organic matter, such as compost and cover crops, while minimizing the excessive use of chemical fertilizers. This approach not only augments organic carbon content but also enhances the biological properties of soils, thereby improving soil fertility and overall soil health. Furthermore, this information is pivotal for informed decision-making to improve soil quality, encourage nutrient cycling, and increase agricultural production and productivity while protecting the environment.

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COMPETING INTERESTS

The authors have declared that no competing interests exist.

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