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Enhancing soil fertility: comparative analysis of arecanut monocropping and intercropping with cocoa

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Abstract

Soil health is one of the important properties that decide the status of soil fertility. The main objective of the present study was to conduct a comparative analysis of soil health status between arecanut monocropping and intercropping with cocoa. We analysed and compared the soil pH, bulk density, moisture content, nutrient availability (N, P, K) and microbial diversity of the soil in arecanut+cocoa and arecanut monocrop systems at 0-30 cm and 30-60 cm soil depths. Our investigation revealed that the available macronutrient content reduced with depth in arecanut sole and intercropping with cocoa. At 0-30 cm soil depth, the available nitrogen (N), Phosphorus (P) and potassium (K) in intercropping system was 256 kg/ha,16 kg/ha and 117 kg/ha, respectively, whereas the nutrients were 202 kg/ha, 21 kg/ha and 125 kg/ha in monocropping system. The soil organic carbon (SOC) was high in the intercropping system (1.6%.) compared to monocropping (1.0%). Similarly, the HCl extractable micronutrient (Cu, Zn, Fe and Mn) content in the soil was higher in the arecanut intercropping system. The study revealed higher levels of SOC, available P, K, micronutrients, in the arecanut+cocoa system compared to arecanut monocropping. This suggests that adopting mixed cropping with cocoa can enhance soil fertility.

Keywords: Soil fertility, pH, soil organic carbon, fungal diversity, nutrient

Introduction

Arecanut (*Areca catechu* L.) is one of the major commercially important plantation crops grown in India and SE Asia. It is a crop of warm and humid climate, mainly grown in India and other Southeast Asian countries. In India it is mainly grown in the states of Karnataka, Kerala and Assam which contribute to 87% of total area of the crop in the country. In Assam- Cachar, Karimganj, and Hailakandi are the major arecanut growing districts. Arecanut cultivation is highly dependent on favourable climate and soil conditions, thriving in regions with warm and humid tropical climates. The soil characteristics in Assam that support arecanut production include several key factors.

Arecanut thrives in well-drained soils, which ensure adequate aeration for root health. A loamy soil texture, composed of sand, silt, and clay, provides an ideal structure for its robust growth. A slightly acidic to neutral pH level, typically between 5.8 and 6.8, promotes

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optimal nutrient uptake. High organic matter content enhances fertility and moisture retention, supporting overall soil health. (Rao,2009). Assam's warm, humid climate, complemented by moderate rainfall, provides the necessary conditions for arecanut growth. Production of arecanut in the last two to three years has fallen (Borah,2020).The decline in arecanut production can be attributed to several factor. Among them Soil health is a very important parameter for the growth of arecanut (Bhat *et al*., 2014). Soil health defines status of various physical, chemical and biological characteristic of soil (Vishwanath *et al.,* 2022). The chemical indicators of soil health include soil nutrients and pH (Bhat *et al*.,2024). Soil health can be improved by incorporating intercropping in arecanut cultivation. By integrating complementary crops into the arecanut plantation, farmers can enhance soil fertility, structure, and overall ecosystem resilience. The adoption of the intercropping system in arecanut improves the soil health and productivity. Many crops like cocoa, black pepper, clove, and banana are ideal for intercropping (Bavappa *et al.,1986)*

Cocoa (*Theobroma cacao* L.) is regarded as a green product because it is ecologically friendly, carbon-neutral, and climate-smart nature (Schroth *et al*., 2016; Sdrolia and Zarotiadis, 2019). Studies by Rajab *et al.,* (2016) provide evidence that the farm soil in cocoa intercropping system exhibit superior soil health compared to those in cocoa monocropping system. Sujhata *et al.,*(2016) documented an enhancement in soil fertility status, including pH, soil organic carbon (SOC), available P, and K, in the arecanut-cocoa mixed cropping system compared to fallow land. Intercropping increases SOC and N content over 7 years in a field experiment that compared rotational strip intercrop systems and ordinary crop rotations (Cong *et al*., 2015). Improved soil health, when cocoa is grown as an intercrop, is attributed to its crucial role in maintaining the productivity, and provision of environmental services in terrestrial ecosystems (Hartemink, 2005).

Hence, the present study was formulated with the objective of elucidating the differences in the soil physical and chemical parameters among arecanut monocropping system and arecanut-cocoa cropping system followed in Assam.

Materials and Methods

Study area

The research was carried out at ICAR, CPCRI, Kahikuchi, characterized by sub-humid climatic conditions. Located at 20º18'N latitude and 91º78'E longitude, the region receives an annual rainfall ranging from 2500 to 3000 mm. The climate exhibits maximum mean temperatures between 18 and 38ºC, with minimum temperatures ranging from 8 to 22ºC. Two distinct cropping systems viz., arecanut mono cropping and arecanut + cocoa cropping system were chosen for the study.

Soil collection and preparation

The soil samples were collected randomly from five different locations of arecanut monocrop and arecanut-cocoa cropping system fields. Soil samples were collected at 0-30 and 30-60 cm depths in the arecanut root zone at 60 cm distance from the palm trunk in triplicates. Samples were air-dried, ground, and sieved through a 2mm sieve.

Soil analysis

Soil samples were analysed for pH, organic carbon, available N, P and K using standard procedures. (Jackson 1973). Soil pH was determined in a 1:2.5 soil water suspension following the method described by Jackson (2005). Soil moisture and bulk density were determined using the oven-dry method using following formulae

$$MC\ (\%) = \frac{(\text{Weight of the fresh soil (g)} - \text{Weight of the oven dried soil}}{(\text{Weight of oven dried soil (g)}} \times 100 \quad Eq(1)$$

$$\text{Bulk density } (g/cm^3) = \text{Soil volume } (cm^3)/\text{Soil mass } (g) \quad Eq\ (II)$$

Soil Organic carbon (SOC) content was determined using the Walkley and Black wet oxidation method, while available nitrogen content was estimated by the Kjeldahl method. Available phosphorus (P) was estimated using the ascorbic acid reductant method for colour development following extraction with Bray's reagent. Available K was estimated using the ammonium acetate extraction method. Micronutrients (iron, manganese, zinc, copper) were analysed using hydrochloric acid (HCl) as an extractant and Atomic Absorption Spectrophotometer. The soil moisture content was determined using the gravimetric method. Freshly collected soil sample weighting 10 g were placed in a hot air oven at 105°C till a constant weight was achieved. The soil was weighed after drying and the percentage of moisture content was calculated using Equation (I) and expressed as percentage soil moisture content on a dry weight basis.

Statistical analysis

Analysis of variance was conducted using R software Version 4.0.3 [R Core Team, 2020]. The summary statistics and significance of differences between crop type, soil depth, and soil parameters, including their interactions, were determined using the Fisher-LSD test via the agricolae package [De Mendiburu and Simon, 2015]. Additionally, Kendall's correlation coefficient and a heat map of Spearman's rank correlation coefficients for soil parameters across depths and cropping patterns were generated using R.

Results and Discussion

Soil physical parameters

Physical parameters of the soil form the basic properties of the soil fertility. Though these parameters cannot be modified quickly, the practices adopted in farming and the systems adopted determine the soil physical parameters. The bulk density of the soil changes with addition of more organic manures. Bulk density indicates the aeration of the soil. The study indicated that the bulk density under arecanut monocropping was significantly higher (1.2 g/cm^3) as compared to arecanut -cocoa cropping system (0.9 g/cm^3) (Table 1). The reduction in bulk density was about 25%. Arecanut-cocoa cropping system produces more organic matter through cocoa prunings and leaf fall which adds more organic matter to soil compared to arecanut monocropping (Sujatha *et al.*, 2015). This could be a reason for variation in the bulk density of soil between arecanut monocropping and arecanut-cocoa cropping system. Soil moisture content was significantly higher under the intercropping system at both the depths (24 and 22% at 0-30 and 30-60 cm respectively) compared to the monocropping system (20%) and 18% at 0-30 and 30-60 cm respectively) (Table 1). The arecanut-cocoa cropping system is known to have low atmospheric temperature and higher shade level leading to low evaporation compared to arecanut monocropping. Thus, we find variation in soil moisture content in the different systems. The interaction effect of cropping system and soil depth indicated variation in different soil parameters (Fig. 1.). The difference in BD at 0-30 cm depth between intercopping and monocropping were less compared to the difference at 30-60 cm. The intercropping with cocoa, a dicot, with its root growth might have helped in keeping the BD at low level.

Soil chemical parameters

The study indicates that intercropping significantly influences soil nutrient status. Specifically, intercropping arecanut with cocoa has a notable impact on soil organic carbon (SOC), and potassium (K) content, zinc

Table 1. Bulk density (g/cm^3) and soil moisture content (%) in different cropping system and depth

Parameters	Depth (cm)		Sig/NS	Cropping System		Sig/NS
	0-30	30-60		Arecanut (Monocrop)	Arecanut cocoa system	
BD (g/cm3)	0.96	1.08	Sig	1.08	0.96	Sig
SMC (%)	22	20	Sig	19	23	Sig

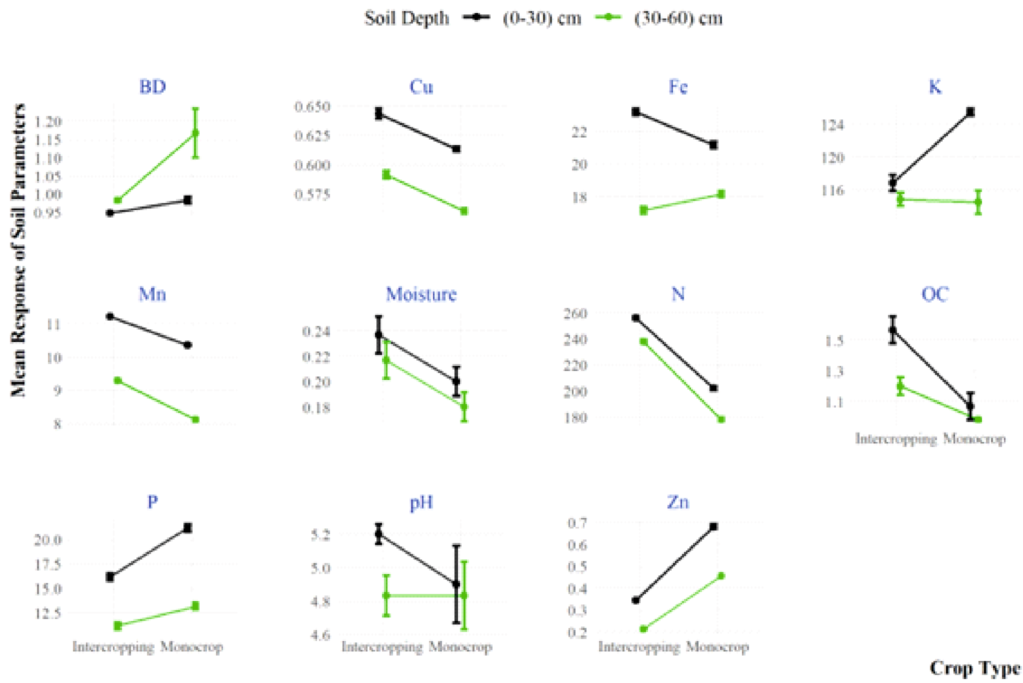


Figure 1. Two-way interaction plot with error bars for soil parameters. This plot illustrates the variation in mean responses of soil parameters at different soil depths (0-30 cm and 30-60 cm) under different cropping patterns (intercropping and mono-cropping). Soil parameters are measured as follows: pH (standard), OC (%), N (Kg/h), K (Kg/h), P (Kg/h), Fe (ppm), Zn (ppm), Cu (ppm), Mn (ppm), BD (g/cm^3), and Moisture (%).

(Zn) content of soil. Soil chemical parameters which indicate the soil fertility status included the soil organic carbon content, pH, major and micronutrients. The values varied significantly between depths of sampling (Table 2). The soil pH was not significantly different between 0-30 and 30-60 cm. However other parameters differed significantly. The values of soil organic carbon, available nitrogen, available phosphorus, available potassium, available iron, zinc, copper and manganese were significantly higher at 0-30 cm depth compared to 30-60 cm depth. Between the cropping systems, all nutrient parameters showed significant difference except soil pH. Organic carbon was higher under the arecanut – cocoa system (1.40%) compared to arecanut monocropping (1.04%). Arecanut – cocoa system generated more organic residues and resulted in higher organic carbon compared to arecanut monocropping. Higher organic carbon in the multiple cropping systems over monocropping has been reported earlier (Bhat *et al*., 2024). Similar finding was found with available nitrogen also. However, the available P and K were higher under arecanut

Table 2 Soil fertility parameters in different cropping system and depth

Parameters	Depth (cm)		Sig/NS	Cropping System		Sig/NS
	0-30	30-60		Arecanut (Monocrop)	Arecanut cocoa system	
pH	5.05	4.80	NS	4.85	5.00	NS
OC (%)	1.35	1.09	Sig	1.04	1.40	Sig
N (kg/ha)	229.1	208.2	Sig	190.1	247.2	Sig
P (kg/ha)	18.5	12	Sig	17	13.5	Sig
K (kg/ha)	121	114	Sig	119	116	Sig
Fe (mg/kg)	22	17.5	Sig	19.5	20	Sig
Cu (mg/kg)	0.63	0.58	Sig	0.59	0.62	Sig
Zn (mg/kg)	0.51	0.33	Sig	0.57	0.28	Sig
Mn (mg/kg)	10.80	8.70	Sig	9.22	10.24	Sig

monocropping compared to arecanut – cocoa cropping system. Bhat *et al.,* (2024) found that the areca-cocoa system exhibited an increase in SOC levels while showing a decrease in potassium (K) content and soil pH. More crops in multiple cropping systems removed more nutrients and less was left in the soil. Even though more organic residues were produced in the multiple cropping system, they add very less amount of P and K which resulted in less P and K content in soil. The trend was similar with Zn availability as both arecanut and cocoa need more Zn. Such variation in soil nutrient levels is reported by earlier workers (Manikandan *et al*., 1987).

The interaction effect of soil depth and cropping system showed variation with respect to soil fertility parameters (Fig 1.). With regard to pH, the differences between cropping systems was minimum at 30-60 cm soil depth and at surface level the pH with intercropping was significantly higher compared to monocropping. Addition of more organic residues through leaf fall of cocoa might have resulted in increased pH over years. Such findings have been reported earlier by Bhat *et al.* (2024). Similar result has been observed with regard to organic carbon also where in the difference in organic carbon content was less (22%) at 30-60 cm soil depth between intercropping and monocropping and at surface soil depth, the organic carbon content was much higher (47%). Addition of more organic residues in the intercropping system through the intercrop in the surface layer might have increased the organic carbon content of the surface layer. The nutrients, nitrogen, copper, manganese and the moisture content showed similar trends at both the soil depths under intercropping and monocropping with lesser quantity at 30-60 cm soil depth. Available soil potassium remain same at 30-60 cm soil depth between intercropping and monocropping while it was significantly higher with monocropping compared to intercropping at 0-30 cm soil depth. Nelliat (1978) noted similar results in an arecanut-cocoa system. The decrease in available potassium is due to high potassium consumption characteristic of cocoa plants. This indicates cocoa is a heavy K feeding plant.The trend in Zn and P availability was similar at both depths and both systems with lower values at 30-60 cm soil depth.

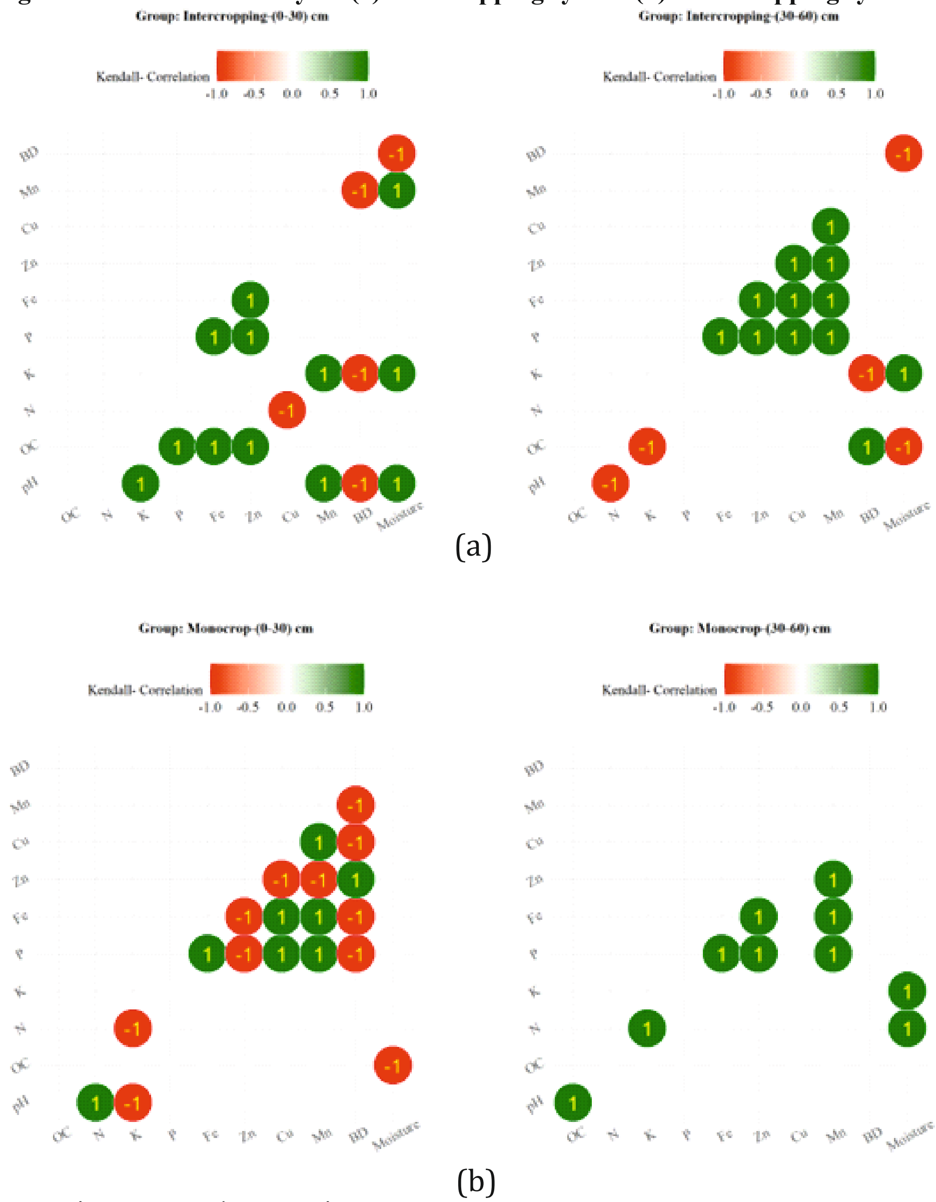
The non-parametric correlation analysis of soil parameters using Kendall's correlation coefficient at different soil depths (0-30 cm and 30-60 cm) under different cropping patterns (intercropping and mono-cropping) indicted interaction with respect to different parameters as well (Fig. 2.). Kendall's tau coefficient ranges from -1 to 1, indicating the strength and direction of ordinal associations between variables: +1 signifies a perfect positive correlation, -1 signifies a perfect negative correlation, and 0 indicates no association. Here, red represents a negative direction, and green represents a positive direction.

Cocoa trees have a unique ability to recycle nutrients through the natural process of leaf litter decomposition. When cocoa leaves fall to the ground, they begin to decompose,

Table 3. Interaction effect of cropping system and soil depth on soil fertility parameters

Parameters	Intercropping (Arecanut + Cocoa)		Monocropping (Arecanut)		Significance
	0-30 cm	30-60 cm	0-30 cm	30-60cm	
pH	5.3	4.8	4.9	4.8	NS
OC (%)	1.57	1.20	1.07	0.98	NS
N (kg/ha)	256.1	238.1	202.1	178.1	NS
P (kg/ha)	16.2	11.2	21.2	13.2	Sign
K (kg/ha)	116.8	114.8	125.5	114.5	Sign
Fe (mg/kg)	23.2	17.2	21.2	18.2	Sign
Cu (mg/kg)	0.64	0.59	0.61	0.56	NS
Zn (mg/kg)	0.34	0.21	0.68	0.46	Sign
Mn (mg/kg)	11.21	9.30	10.35	8.12	Sign

Figure 2. Correlation Analysis. (a) intercropping system (b) monocropping system



releasing nutrients such as nitrogen, phosphorus, potassium, and other essential elements back into the soil. This process helps replenish soil nutrients, ensuring that the cocoa trees have access to the necessary elements for growth and development. Moreover, the dense canopy formed by cocoa trees provides shade, which helps retain soil moisture and temperature, creating suitable conditions for microbial activity involved in the decomposition process. This causes higher moisture content in areca-cocoa intercropping system. The fertility of soils under cocoa plantations with well-established canopies can be sustained for extended periods, contributing to the long-term health and productivity of the cocoa trees.

Conclusion

The study revealed that the soil fertility including the soil physical properties were improved with the adoption of arecanut-cocoa cropping system as compared to arecanut monocropping. Hence, intercropping of cocoa in arecanut garden helps in sustainable arecanut farming in North East. The study also affirmed the earlier findings of low potassium content in soil under the cropping system indicating the need to give additional application of potassium fertilizer.

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