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Assessing the performance of cocoa grown under different cropping systems in various soils of coastal Andhra Pradesh

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Abstract
A field study was conducted to observe the yield performance of cocoa grown under different cropping systems in various soil types in Andhra Pradesh during 2023-2024. The experiment was laid out in factorial randomized block design (FRBD) with four replications consisting of two factors. The factor one contains cropping systems @ 3 levels *i.e.*, C_1- cocoa under coconut, C_2-cocoa under oil palm and C_3-cocoa as monocrop and the second factor contain soil types @ 2 levels *i.e.*, S_1-Laterite soil and S_2-Alluvial soil. Nutrient analysis like p^H, EC (dSm^{-1}), Organic carbon (%) nitrogen (kg/ha), phosphorous (kg/ha) and potassium (kg/ha), growth parameters *viz.*, tree height, girth of the tree, canopy volume and yield parameters *viz.*, number of pods per tree, fresh bean weight per pod, dry bean weight per pod, yield kg dry bean/tree and yield (t/ha) were recorded. The results revealed that the cocoa under different cropping systems in various soil showed significant difference with respect to growth and yield attributes. Cocoa grown as monocrop under laterite soil recorded the maximum tree height (3.56 m), girth of the tree (63.10 cm), canopy volume (35.56 m^3) and highest Number of pods per tree (92.25), fresh bean weight per pod (144.31 g), dry bean weight per pod (59.02 g), dry bean yield /tree (5.36 kg) and yield (3.64 t/ha).

Keywords: Cocoa, cropping systems, soils, yield, pod, bean

1. Introduction

Cocoa (*Theobroma cacao* L.), belonging to Sterculiaceae family, which includes around 50 genera and 750 species, earned its name from Linnaeus, who called it *Theobroma cacao*, meaning "Food of the Gods," in recognition of its esteemed status. Originating as an understorey plant in the Amazon Basin of South America (Motamayor *et al*., 2002) [12], cocoa is now widely cultivated across the humid tropics (Anushka and Jim, 2018) [3]. It thrives in regions with high rainfall and brief dry periods and also grows well in irrigated tropical coastal areas, benefiting from the shade provided by surrounding palms. The crop has been cultivated for more than a millennium.

Cocoa contains the stimulant theobromine and ranks among the most important beverage crops globally, alongside coffee and tea. Cocoa is a key ingredient in many confectionery products and the primary raw material for chocolate. Its seed coat is used in treatments for liver, bladder and kidney issues, as well as diabetes and serves as a tonic and general remedy. Cocoa is a nutritious crop, containing fats, carbohydrates, proteins and other essential compounds. Additionally, cocoa seeds are used to treat infectious intestinal diseases, diarrhoea, asthma and bronchitis.

In India, Andhra Pradesh holds the top spot in cocoa cultivation area with 36,455 hectares, followed by Tamil Nadu with 30,080 hectares, Kerala with 16,894 hectares and Karnataka with 14,134 hectares. In terms of production, Andhra Pradesh also ranks first, producing 10,384 tonnes, followed by Kerala with 9,188 tonnes, Karnataka with 3,542 tonnes and Tamil Nadu with 2,669 tonnes. In terms of productivity, Andhra Pradesh leads with 950 kg per hectare, followed by Kerala at 850 kg/ha, Karnataka at 525 kg/ha and Tamil Nadu at 350 kg/ha. Notably, Andhra Pradesh's productivity of 950 kg/ha surpasses the national average of 669 kg/ha.

In groves of tall palms where 40-50% sunlight penetration is possible, cocoa excels at absorbing this solar energy, coexisting symbiotically with the primary crop. This not only generates additional income but also improves soil conditions, benefiting both cocoa and the main crop it grows under. Cocoa is cultivated either as a monoculture or in combination with other crops, such as fruit trees (Guiltinan *et al*., 2008) [8] and plantation crops. As a perennial shade-loving tree, cocoa contributes to biodiversity. It has become an essential part of palm-based cropping systems in India, particularly in Andhra Pradesh (Anju and Raju, 2021) [2]. Cocoa is successfully grown as a mixed crop in coconut (*Cocos nucifera* L.) and oil palm (*Elaeis guineensis* Jacq.) plantations that are six years or older in the coastal districts of Andhra Pradesh.

Cocoa is being cultivated in monocultures in order to maximize short-term productivity and profitability, which has been associated with soil erosion and degradation, biodiversity loss, as well as increased susceptibility to climate change impacts and pests and diseases. The growing demand for cocoa beans and products worldwide has been met by expanding the area under cocoa production with productivity per hectare (Andres *et al.*, 2016) [1]. The quality of cocoa beans is significantly affected by different soils apart from different cropping systems. Hence, there is a need to study the performance of cocoa under different cropping systems in varied soil types and comparing them with monoculture to draw valid conclusion on merits and demerits of each system.

2. Materials and Methods

Sixteen farmer's field were selected in the major cocoa growing districts of Andhra Pradesh. The selected plots were cocoa grown as intercrop in coconut, in oil palm plantation and as monocrop with age group of 15-20 years. The size of holdings in each garden is one acre with cocoa spaced at 2.5 x 2.5m. The experiment design followed was factorial randomized block design with 2 factors in 4 replications having 4 trees in each replication. The factor one contains cropping systems @ 3 levels *i.e*., C_{1}- cocoa under coconut, C_{2}-cocoa under oil palm and C_{3}-cocoa as monocrop. The second factor contain soil types @ 2 levels *i.e*., S_{1}-Laterite soil and S_{2}-Alluvial soil.

Soil samples from a depth of 0 to 30 cm, 30 to 60 cm and 60 to 90 cm were collected from selected gardens. The samples of same depth were mixed and quantity was reduced by quartering process and the samples were dried in shade, gently powdered with wooden mallet and sieved to pass through a 2 mm sieve. After sieving, the samples were used for analysis for pH, EC, organic carbon and Macro nutrients-N, P, K.

Taken 20 g of soil was taken in a 50 ml beaker, added 25 ml of distilled water and stirred at least for 5 times in 30 minutes time to allow both medium and water to reach equilibrium. Then pH of the samples was measured in pH meter (Jackson, 1967) [9]. Taken 20 grams of soil was taken in a 100 ml beaker, added 50 ml of distilled water, stirred the suspension intermittently and left it overnight to obtain a clear supernatant solution at room temperature. EC of the samples measured in Conductivity Meter (Model systronics 306) and values were expressed in dSm^{-1} (Jackson 1967) [9]. Organic carbon in growing medium was determined by the wet digestion method of Walkley and Blacks (1934) [20]. Available nitrogen in the soil was estimated by Kjeldahl's method as described by (Jackson, 1973) [10]. Available phosphorus in the soil was determined by Olsen's method using spectrophotometer as described by (Jackson, 1967) [9]. Available potassium in the soil was determined by neutral normal ammonium acetate method using flame photometer (Jackson, 1967) [9].

The observations on growth and yield parameters were recorded from January to May during 2023-2024 and statistically analyzed as per Panse and Sukhatme (1985) [13]. The height of the tree was measured using a measuring tape from ground level to the tip of the canopy and expressed in metre. The girth of the tree was measured at 15 cm above the ground level using a measuring tape and expressed in centimetre. The spread of the tree canopy from east to west and north to south direction was measured using a measuring tape and expressed in metre. The canopy volume was calculated by using height of tree and average spread in both the direction by the formula πrl and expressed in cubic metre.

Whereas, $r = \frac{EW+NS}{4}$

$l = \sqrt{r^2+h^2}$

The total number of cherelles and total number of pods harvested per tree was counted, expressed in numbers for number of pods per tree. The pods were cut opened with a knife and wet beans were collected and weighed by using a weighing balance and fresh bean weight per pod was expressed in grams. The dry bean weight per pod was weighed by using weighing balance after fermentation and drying and expressed in grams. Average dry weight of beans per pod and mean total number of pods harvested per tree were calculated separately and total dry bean yield per tree per year was worked out and expressed in kilograms. Average dry weight of beans per tree and total number of trees per acre were calculated and worked out for yield tonne per hectare.

3. Results

3.1 Nutrient analysis

Soil samples collected from the selected gardens were analyzed for nutrient availability across various cropping systems. The samples were tested for pH, electrical conductivity (EC), organic carbon (OC), available of nitrogen (N), phosphorus (P) and potassium (K) in each cropping system. It was evident from table-1 that pH, EC, Organic carbon, available nitrogen, phosphorus and potassium were in the range of 4.91 to 8.30 and 6.22 to 80.8, 0.089 to 0.364 and 0.073 to 0.540 dS/m^{-1}, 0.32 to 0.65 and 0.32 to 0.65%, 320 to 537and 248 to 550 kg/ha, 20.61 to 54.96 and 22.90 to 54.96 kg/ha, 125 to 275 and 126 to 271 kg/ha in laterite soil and alluvial soil respectively.

Table 1: Nutrient analysis of soils

S. No.	Parameters	Laterite soil	Alluvial soil
1	pH	4.91-8.30	6.22-8.08
2	EC (dSm^{-1})	0.089-0.364	0.073-0.540
3	Organic carbon (%)	0.32-0.65	0.32-0.65
4	Nitrogen (kg/ha)	320.00-537.00	248.00-550.00
5	Phosphorus (kg/ha)	20.61-54.96	22.90-54.96
6	Potassium (kg/ha)	125.00-275.00	126.00-271.00

3.2 Growth parameters

The data pertaining to tree height, girth and canopy volume of cocoa were significantly influenced by cropping systems in various soil. Among cropping systems, maximum tree height (3.56m), girth of the tree (63.10 cm) and canopy volume (35.56 m^3) was recorded in cocoa grown as monocrop. Among various soil, maximum tree height (4.81m) and canopy volume (33.89 m^3) was found significant in laterite soil whereas canopy volume in various soils. The interaction between cropping systems and various soils were found statistically significant with maximum canopy volume was recorded in cocoa grown as monocrop (42.88 m^3) in laterite soil whereas least canopy volume recorded in cocoa under oil palm (23.67 m^3) in laterite soil (Table 2).

Table 2: Vegetative parameters of Cocoa in different cropping systems in various soils

Cropping systems	Tree height (m)			Girth of the tree (cm)			Canopy volume (m^3)		
	Soil types		Means	Soil types		Means	Soil types		Means
	S_1	S_2		S_1	S_2		S_1	S_2	
C_1	5.25	3.57	4.41	54.43	57.10	55.76	35.12	27.14	31.13
C_2	3.86	3.26	3.56	50.50	49.00	49.75	23.67	24.80	24.24
C_3	5.33	4.73	5.03	62.37	63.83	63.10	42.88	28.25	35.56
Means	4.81	3.85		55.77	56.64		33.89	26.73	
Factors	S E(m)±		CD at 5%	S E(m)±		CD at 5%	S E(m)±		CD at 5%
C	0.22		0.67	1.51		4.56	1.97		5.95
D	0.18		0.55	1.24		NS	1.61		4.86
C×D	0.31		NS	2.14		NS	2.79		8.41

3.3 Yield parameters

It was observed from the Table 3 that number of pods per tree, fresh bean weight per pod (g), dry bean weight per pod (g), and yield (kg dry bean per tree) were significantly influenced by the cropping systems and various soils whereas dry bean weight per pod (g) and their interactions between cropping systems and various soils were non- significant. Among different cropping systems, the highest number of pods per tree (91.94), fresh bean weight per pod (138.04 g), dry bean weight per pod (52.86 g) and dry bean yield per tree (4.97 kg) was recorded in cocoa grown as monocrop whereas maximum number of pods per tree (78.67), fresh bean weight per pod (121.66), dry bean weight per pod (47.61 g) and dry bean yield per tree (3.48 kg) was recorded in cocoa tree grown under laterite soil. The least number of pods per tree (53.56), fresh bean weight per pod (89.94 g), dry bean weight per pod (36.76g) and dry bean yield per tree (1.57 kg) was recorded in cocoa grown as intercrop in oil palm plantations. With respect to soils, minimum number of pods per tree (71.68), fresh bean weight per pod (112.59 g), dry bean weight per pod (41.16g) and dry bean yield per tree (3.04 kg) were observed in cocoa grown in alluvial soils.

The interactive effect of cropping systems and soils on yield and yield attributing parameters *viz.*, number of pods per tree, fresh bean weight per pod, dry bean weight per pod, and dry bean yield per tree were statistically non -significant.

Among cropping systems and soils, the highest yield (t/ha) was recorded in cocoa grown as monocrop in laterite soil (3.64) followed by cocoa as monocrop in alluvial soil (3.10) and least was recorded in cocoa as intercrop in oil palm (0.58) in alluvial soil (Fig 1).

4. Discussion

Cocoa grown in different cropping systems in various soils revealed that cocoa as monocrop gave better results in term of growth, yield parameters. This could be attributed that cocoa tree growth in intercropping systems can be slower compared to monocultures, the absence of competition for sunlight allows cocoa trees to grow taller and optimize photosynthesis. Without the shading effect of other plants, as found in intercropping systems, cocoa trees can achieve unrestricted vertical growth and abundant light promotes the development of a broader canopy, allowing the tree to extend its branches to maximize light absorption for photosynthesis. In intercropping systems, however, the presence of other crops with extensive root systems can limit the availability of water and nutrients for cocoa trees, leading to restricted tree height, girth of the tree and canopy expansion. These observations are consistent with the findings of Schneider *et al*. (2017) [19], Asigbaase *et al*. (2021) [5] and Mattalia *et al*. (2022) [11].

In intercropping, cocoa yields are typically around 75% of those produced in monocultures. Several studies have highlighted the negative impact of increasing shade levels on cocoa yield. Cocoa trees tend to develop more slowly in intercropping compared to monocultures, which may contribute to the generally unfavorable views some farmers hold towards growing cocoa under shaded conditions. The positive relationship between cocoa tree vigor, yield and the amount of light received has been observed. For cocoa trees aged 1 to 9 years, yields ranged from 0 to 0.4 kg per tree. The lower yield of cocoa in oil palm systems is likely due to reduced light availability, as cocoa leaves reach light saturation at 800 $mmol.m^{-2}.s^{-1}$. Similar findings are reported by Blaser *et al.*, 2018 [6], Clough *et al.*, 2009 [7], Riedel *et al.*, 2019 [17], Schneider *et al.*, 2017 [19], Ruf, 2011 [18] and Reddy and Suresh 2009 [16].

Table 3: Yield parameters of cocoa in different cropping systems grown in various soils

Cropping systems	No. of pods/tree			Fresh bean weight/pod (g)			Dry bean weight/pod (g)			Yield (kg dry bean/tree)		
	Soils		Mean	Soils		Mean	Soils		Mean	Soils		Mean
	S_1	S_2		S_1	S_2		S_1	S_2		S_1	S_2	
C_1	84.44	75.59	80.02	127.10	119.70	123.40	46.60	40.49	43.54	3.41	3.10	3.25
C_2	59.31	47.81	53.56	93.58	86.30	89.94	37.22	36.30	36.76	1.68	1.45	1.57
C_3	92.25	91.63	91.94	144.31	131.78	138.04	59.02	46.70	52.86	5.36	4.57	4.97
Mean	78.67	71.68		121.66	112.59		47.61	41.16		3.48	3.04	
Factors	S E(m)±		CD at 5%	S E(m)±		CD at 5%	S E(m)±		CD at 5%	S E(m)±		CD at 5%
C	2.38		7.17	3.56		10.72	1.40		4.21	0.17		0.51
D	1.94		5.85	2.90		8.75	1.14		3.44	0.14		0.42
C×D	3.36		NS	5.03		NS	1.98		5.95	0.24		NS

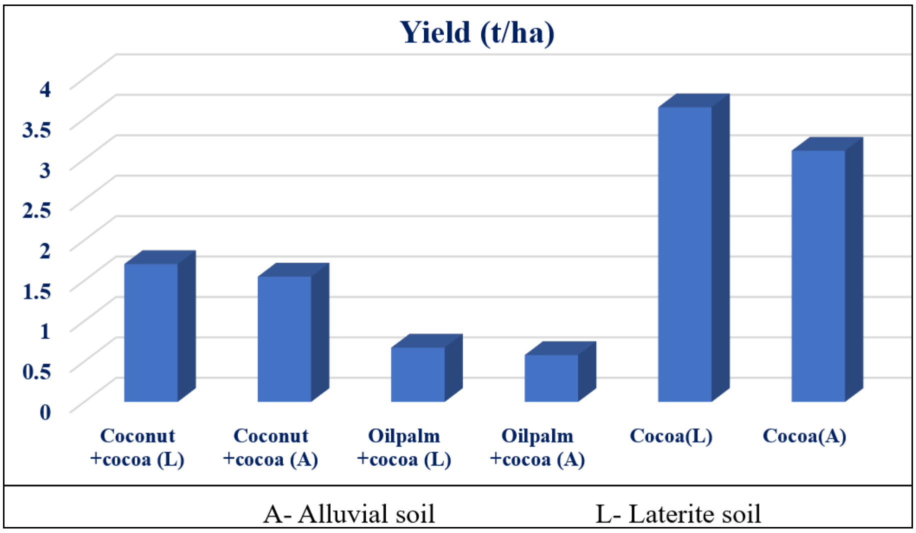

Fig.1 Yield (t/ha) under different cropping systems in various soils

Conclusion

In nutshell, cocoa grown as monocrop in laterite soils recorded the maximum tree height, girth of the tree, canopy volume, number of pods per tree, fresh bean weight per pod, dry bean weight per pod, dry bean yield per tree (kg) and yield (t/ha) when compared to cocoa grown as intercrops in the coconut and oilpalm plantations.

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Conflict of Interest

The authors declare no conflicts of interest relevant to this article.

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