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Performance of Agricultural Crops under Sandalwood Based Agroforestry System

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Abstract

The present research was carried out in Agroforestry field unit, 'M' block, UAS, GKVK, Bengaluru. The field experiment was conducted in seven year old *Santalum album* plantation during 2022 and 2023, which has three planting densities *viz*., 5m x 5m, 5m x 4m and 5m x 3m. The study aimed to know the influence of different planting densities of Sandal on the growth and productivity of three agricultural crops *viz*., Soybean, Ricebean and Cowpea. The highest Plant height of agricultural crops was found under S_1 (5m x 5m) spacing (67.25 cm) and lowest was in S_3 (46.76 cm). Highest number of branches was recorded by Cowpea under 5m x 5m spacing with Cowpea (12.00). The soil physical properties *viz*., Bulk density and Particle density was found higher with Cowpea (1.41 and 2.65 g cc^{-1}, respectively under 5m x 5m spacing and porosity was found highest with Soybean (47.33 %) in 5m x 5m spacing. The soil pH was acidic in nature, with EC (0.45 to 0.53 dSm^{-1}) and OC (0.41 to 0.44%). Highest available N, P_2O_5 and K_2O (304.11 kg N ha^{-1}, 31.48 kg P_2O_5 ha^{-1} 210.49 kg K_2O ha^{-1}) found in S_1 (5m x 5m) and lowest in S_3 (5m x 3m) spacing. Highest seed yield was recorded by Cowpea (1590 kg ha^{-1}) under 5m x 5m Sandal planting followed by Ricebean (1467 kg ha^{-1}) (T_4) and lowest was recorded by Soybean (1101 kg ha^{-1}). The highest haulm yield was recorded in T_4 (2552 kg ha^{-1}) and lowest was in T_3 (1479 kg ha^{-1}). Cowpea cultivated under Sandal tree spacing of 5m x 5m was found to be best treatment combinations followed by Ricebean and Soybean.

Keywords : Agroforestry system, Cowpea, Ricebean, Sandalwood, Soybean, Spacing

Indian Sandalwood (*Santalum album* L.) is a semi-parasitic medium-sized evergreen tree highly valued worldwide for its fragrant heartwood and essential oil, which are economically important and widely used in various cultural, religious, medicinal and commercial applications. Around 70 per cent of sandalwood seedlings establish haustoria connection with suitable host plants within a month after germination and enabling resource acquisition by creating partial dependence on host plants. The Sandal cultivation faces silvi cultural challenges due to its hemiparasitic nature, the successful establishment of Sandal trees depends on availability and compatibility of host species. Management practices such as planting density, host selection and agricultural crop choices significantly plays a role in survival and growth rate, productivity and long term sustainability of Sandal-based production systems. Recent studies have emphasized that proper host management and spacing significantly enhance nutrient uptake, biomass accumulation and overall system productivity (Venkatesh *et al*., 2023).

Agroforestry system is a suitable land-use approaches, where trees are grown in agricultural fields along with crops simultaneously on same piece of land to enhance soil quality, preserve moisture content, environment stability and overall productivity which improves resource-use efficiency, promote useful biological interactions and designed for better land-use management. The system reduces pressure on natural forests by shifting maximum biomass and wood production and it plays a significant role in increasing farming system and lowering vulnerability to climatic variability (Bado *et al*., 2006). It supports key ecosystem services *viz.,* soil health, carbon storage, water and biodiversity conservation etc. these natural benefits make agroforestry an important strategy for climate smart and sustainable agriculture which meets ecological, economic and social objectives (Handa *et al*., 2016).

Tree-crop competition becomes intense for natural resources *viz.*, light, water, nutrient and space for their normal growth and economic yield. Therefore effective management practices are needed to minimize competitive stress through silvicultural operations, such as canopy pruning which improves light penetration by decreasing shade of the tree, thinning operation that reduces standing density and root pruning that reduces lateral root spread in agroforestry systems. These techniques are recommended under suitable field condition and with specific guidance (Nair *et al*., 2009).

Hence, it is essential to systematically evaluate the growth, yield, biomass production and overall economic returns of intercrops integrated within Sandal-based agroforestry system to identify efficient and profitable combinations. The present research was planned to assess the performance of different agricultural crops were analyzed to determine suitability, compatibility and contribution to system-level biomass and economic value under Sandal-based agroforestry system.

Material and Methods

The field experiment was carried out at 'M' block, All India Coordinated Research Project (AICRP) on Agroforestry unit, Zonal Agricultural Research Station (ZARS), Gandhi Krishi Vigyana Kendra (GKVK), University of Agricultural Sciences, Bangalore, Karnataka. The site was located in the Northern part of Bengaluru between 13^0 07' North latitude and 77^0 40' East longitude with an elevation of 923 m above mean sea level. The study area was consisting of 7 year old sandal wood trees with twelve treatment combinations involving three sandalwood spacing levels. The spacing S_1 (5m x 5m), S_2 (5m x 4m), S_3 (5m x 3m) with three intercrops namely, Soybean, Rice bean, Cowpea, comprising T_1 (5 m x 5 m + Soybean), T_2 (5 m x 4 m + Soybean), T_3 (5m x 3m + Soybean), T_4 (5m x 5m + Rice bean) T_5 (5m x 4m + Rice bean), T_6 (5m x 3m + Rice bean), T_7 (5m x 5m + Cowpea), T_8 (5m x 4m + Cowpea), T_9 (5m x 3m + Cowpea), T_{10} (Sole Soybean), T_{11} (Sole Rice bean), T_{12} (Sole Cowpea) replicated four times under strip plot design. The experiment was carried out from July 2022 to June 2024 in seven year old *Santalum album* plot under AICRP on Agroforestry, Bengaluru centre.

Agricultural Crops and Varietal Description

Cowpea : The improved variety of cowpea KBC-9 matures in about 80-85 days, having creamy colour. The crop remains green at harvest hence, suitable for *in-situ* green manure or fodder after harvest of pods and produce seed yield of about 12-13 q ha^{-1}.

Rice bean : The variety of rice bean used for the study was KBN-1, it is a semi erect variety with having capacity to produce green fodder, it yield's about 300-350 q ha^{-1}, dry matter of 57- 63 q ha^{-1}, seed yield is about 5- 6 q ha^{-1} and contains 14.8 per cent crude protein.

Soybean : The variety JSS-335 is used for the study, it is an early duration and very high yielding soybean variety. It posses wide adaptability, good germiability, non-lodging, non- shattering characteristics and having ability to produce seed yield of about 10-13 q ha^{-1}.

Growth and Yield Parameters of Agricultural Crops

Growth parameters of Cowpea, Rice bean and Soybean on plant height and number of branches per plant was measured at 30, 60 DAS and at harvest. The height was measured from ground level to the tip of main shoot and average number of branches per plant at each stage were worked out and recorded from randomly selected five plan.

The yield parameters of Cowpea, Rice bean and Soybean from randomly selected five plants were recorded *viz*., number of pods per plant, number of seed per pod, grain yield, haulm yield per hectare and harvest index calculated by using yield of grain and biomass of the crops.

Growth and Yield Parameters of Agricultural Crops

Soil and its Characteristics : The soil of the experimental site was classified as red sandy loam belonging to the *Alfisol* order. Soil samples were collected from the sandal-based agroforestry plots at depths of 0-30 cm with sampling procedures. The undecomposed litter layer was cleared from the soil surface and collect the samples from shade dried then gently crushed and sieved using 2 mm sieve after removing all visible debris and stored in a moisture-free environment and used for analyzing the physico-chemical properties. The analyzed parameters and adopted methods are presented in (Table 1) and corresponding values obtained were furnished in (Table 2). pH increased with increasing Sandal planting density (Pradeep *et al*., 2023), EC and OC increased with increasing planting density. Improvement in soil organic carbon was associated with greater availability of major nutrients, particularly nitrogen, phosphorus and potassium under high tree density conditions (Ananth Kumar, 2011).

Statistical Analysis : The experimental data generated during investigation were statistically analyzed using the analysis of variance technique appropriate to the experimental design. The data recorded on various observations on growth, yield and soil parameters as

TABLE 1

Methods adopted for soil analysis

Parameters	Methods	References
Soil pH	Potentiometry	Jackson, 1973
Electrical conductivity	Conductometry	
Soil organic carbon	Walkley-Black wet oxidation	Walkley and Black, 1938
Available Nitrogen	Distillation	Subbiah and Asija, 1956
Available Phosphorus	Spectrometry	Jackson, 1973
Available Potassium	Flame photometry	Jackson, 2005

TABLE 2

Initial status of soil chemical properties as influenced by planting density of Sandal based agroforestry

Treatments	pH	EC	OC	Soil nutrient status (kg ha^{-1})		
		dSm^{-1}	%	Available Nitrogen	Available Phosphorus	Available Potassium
5m x 5m (400 plants/ha)	5.98	0.49	0.48	392	39.68	151
5m x 4m (500 plants/ha)	5.85	0.48	0.47	376	34.12	148
5m x 3m (666 plants/ha)	5.78	0.47	0.43	289	28.92	145

Note : EC- Electrical conductivity, OC- Organic carbon detailed by Gomez and Gomez (1984). The significance of treatment effects was evaluated using the 'F' test at 5 per cent probability level. The critical difference (CD) values are given in the Tables at 5 per cent level of significance, wherever the 'F' test was significant otherwise against CD values abbreviation NS (Non-significant) was indicated.

Results and Discussion

Effect of Sandal on Plant Height of Agricultural Crops

Plant height of agricultural crops was significantly influenced by sandalwood planting density at 30 DAS and 90 DAS (Table 3). Among the treatment combinations the highest pooled plant height was recorded in T_7 (5m x 5m + Cowpea) at 30, 60 and 90 DAS *i.e.,* 16.6 cm, 42.9 cm and 60.6 cm, respectively and which was significantly superior to closer spacing (5m x 4m and 5m x 3m). Whereas, significantly lower plant height was observed under T_5 and T_6 (Rice bean at closer spacings) with corresponding value of 10.8 cm, 29.1 cm and 40.8 cm, respectively. The sole crops recorded comparatively higher plant height than intercropped treatment. Sole cowpea (T_{12}) recorded the maximum pooled plant height (17.2 cm) due to the absence of tree-crop competition for light, moisture and nutrients, followed by sole soybean (T_{10}) (16.8 cm). Similar observations of reduced agricultural crop growth parameters under increased tree competition effects have been reported by Jose (2009). The better performance of cowpea under wider spacing may be due to its vigorous growth habit, partial shade tolerance, and maximum resource utilization. Leguminous intercrops were also known for its rhizosphere nutrient dynamics through biological nitrogen fixation and root interactions, thereby supporting better growth under tree-based systems Nair *et al.* (2009). The treatments with 5m x 3m spacing shows reduced plant height across all

Table 3

Plant height of agricultural crops at 30, 60 and 90 DAS as influenced by planting density of Sandal (*Kharif* 2022 and 2023)

Treatments	Plant height (cm)								
	At 30 DAS			At 60 DAS			At 90 DAS		
	Kharif 2022	*Kharif* 2023	Pooled	*Kharif* 2022	*Kharif* 2023	Pooled	*Kharif* 2022	*Kharif* 2023	Pooled
T_1: 5m x 5m + Soybean	16.0	15.4	15.7	44.2	37.0	40.6	45.9	42.8	44.3
T_2: 5m x 4m + Soybean	13.4	13.0	13.2	42.4	35.6	39.0	32.3	40.8	36.5
T_3: 5m x 3m + Soybean	15.0	13.3	14.1	41.8	33.9	37.8	37.4	39.1	38.2
T_4: 5m x 5m + Rice bean	13.3	12.1	12.7	38.1	26.8	32.4	41.6	43.7	42.6
T_5: 5m x 4m + Rice bean	11.2	10.4	10.8	36.1	24.7	30.4	43.7	38.6	41.1
T_6: 5m x 3m + Rice bean	13.1	11.9	12.5	36.3	22.0	29.1	45.7	35.9	40.8
T_7: 5m x 5m+ Cowpea	16.8	16.5	16.6	56.3	29.6	42.9	68.3	52.9	60.6
T_8: 5m x 4m + Cowpea	15.0	12.8	13.9	53.1	27.8	40.4	59.1	49.2	54.1
T_9: 5m x 3m + Cowpea	16.3	15.1	15.7	46.0	26.6	36.3	54.7	48.3	51.5
T_{10}: Sole Soybean	17.6	16.1	16.8	45.4	38.9	42.1	49.6	45.5	47.5
T_{11}: Sole Rice bean	15.0	12..9	13.9	40.6	33.0	36.8	46.1	45.3	45.7
T_{12}: Sole Cowpea	16.9	17.5	17.2	57.3	30.8	44.0	70.8	51.2	61.0
S.Em ±	1.2	0.17	0.68	3.4	1.15	2.3	4.1	3.49	1.9
C.D (P=0.05)	3.4	0.50	1.95	9.9	3.39	6.7	11.9	7.29	5.5

intercrops, possibly due to increased canopy shading and below-ground competition from roots.

The wider spacing (5m x 5m) combined with Cowpea as an intercrop was favorable for achieving higher plant height. The ability of Cowpea shows its suitability as an intercrop, while closer spacings restrict growth due to increased interspecific competition stress.

Effect of Sandal on Number of Branches of Agricultural Crops

The data which is presented in Table 4 indicates that the number of branches of agricultural crops increased progressively from 30 DAS to 90 DAS across all treatments. The pooled data on branches indicates that, Treatment T_7 (5m x 5m + Cowpea) recorded significantly higher number of branches (6.0) at 30 DAS, which was on par with T_8 (5m x 4m + Cowpea) and T_9 (5m x 3m + Cowpea) indicating cowpea maintained stable early branching under intercropping systems. Similar trend was observed at 60 DAS. Whereas, Soybean and Rice bean showed moderate branching with pooled values ranging from 8.2 to 8.7 in soybean and 8.5 in Rice bean under wider spacing. Enhanced lateral branching in leguminous crops were often related to nitrogen availability and rhizosphere activity. At 90 DAS, the same treatment T_7 (5m x 5m + Cowpea) maintained the higher number of branches (12.0), indicating sustained vegetative growth and reduced competitive stress under wider spacing. Among soybean treatments, treatment T_2 (5m x 4m + Soybean) and T10 (sole Soybean) were recorded relatively higher branching compared to closer spacing 5m x 3m (9.0). It demonstrated that Cowpea is the most compatible intercrop with respect to branching behavior, particularly under wider spacing in sandalwood-based agroforestry systems and greater branching contribute to improved canopy spread, higher photosynthetic surface area and potential yield advantages. It is consistent with the findings of Lal, 2004 and Nair *et al.,* 2009.

TABLE 4

Number of branches of agricultural crops at 30, 60 and 90 DAS as influenced by planting density of Sandal (*Kharif* 2022 and *Kharif* 2023)

Treatments	Number of branches per plant								
	At 30 DAS			At 60 DAS			At 90 DAS		
	Kharif 2022	*Kharif* 2023	Pooled	*Kharif* 2022	*Kharif* 2023	Pooled	*Kharif* 2022	*Kharif* 2023	Pooled
T_1: 5m x 5m + Soybean	4.5	4.0	4.2	9.0	8.5	8.7	10.0	9.0	9.5
T_2: 5m x 4m + Soybean	5.0	4.5	4.7	8.5	8.0	8.2	10.0	10.0	10.0
T_3: 5m x 3m + Soybean	4.5	4.0	4.2	9.0	8.5	8.7	9.0	9.0	9.0
T_4: 5m x 5m + Rice bean	5.0	4.0	4.5	8.5	8.5	8.5	9.0	9.0	9.0
T_5: 5m x 4m + Rice bean	5.0	4.5	4.7	9.0	8.0	8.5	9.0	8.0	8.5
T_6: 5m x 3m + Rice bean	4.5	3.0	3.7	9.0	8.0	8.5	8.5	8.0	8.2
T_7: 5m x 5m + Cowpea	6.0	6.0	6.0	12.0	12.0	12.0	12.0	12.0	12.0
T_8: 5m x 4m + Cowpea	6.0	5.5	5.7	12.0	10.5	11.2	12.0	11.0	11.5
T_9: 5m x 3m + Cowpea	6.0	5.0	5.5	12.0	10.0	11.0	12.0	11.0	11.5
T_{10}: Sole Soybean	4.5	4.5	4.5	9.0	8.5	8.7	10.0	10.0	10.0
T_{11}: Sole Rice bean	4.5	4.5	4.5	8.5	9.0	8.7	9.0	9.99	9.0
T_{12}: Sole Cowpea	6.0	6.0	6.0	12.0	12.0	12.0	12.0	12.00	12.0
S.Em ±	0.17	0.04	0.10	0.17	0.21	0.23	0.22	0.13	0.17
C.D (P=0.05)	0.51	0.13	0.32	0.49	0.61	0.67	0.59	0.38	0.485

TABLE 5

Yield parameters of agricultural crops as influenced by planting density of sandal

Treatments	No. of pods per plant			No. of seeds per pod			Seed yield (g plant-1)			Haulm yield (g plant-1)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2022	Pooled
T1: 5m x 5m + Soybean	30.0	20.0	25.0	3.0	3.0	3.0	6.2	6.0	6.1	8.8	8.1	8.5
T1: 5m x 5m + Soybean	30.0	20.0	25.0	3.0	3.0	3.0	6.2	6.0	6.1	8.8	8.1	8.5
T2: 5m x 4m + Soybean	32.0	20.0	26.0	3.0	3.0	3.0	6.0	5.5	5.7	8.5	8.1	8.3
T3: 5m x 3m + Soybean	29.3	19.3	24.3	3.0	3.0	3.0	5.9	5.1	5.5	7.4	7.3	7.3
T4: 5m x 5m + Ricebean	34.0	23.3	28.6	7.0	7.0	7.0	7.4	6.9	7.1	12.8	12.0	12.4
T5: 5m x 4m + Ricebean	32.3	23.3	27.8	6.0	6.0	6.0	6.9	6.1	6.5	11.2	11.0	11.1
T6: 5m x 3m + Ricebean	31.3	20.0	25.6	6.0	6.0	6.0	7.0	6.0	6.5	11.7	10.9	11.3
T7: 5m x 5m + Cowpea	29.0	22.3	25.6	14.0	9.3	11.6	8.0	7.5	7.7	11.2	9.4	10.3
T8: 5m x 4m + Cowpea	28.3	22.0	25.1	13.0	10.0	11.5	7.8	7.3	7.5	10.8	9.2	10.0
T9: 5m x 3m + Cowpea	26.3	18.0	22.1	12.0	8.6	10.3	7.3	6.9	7.1	10.3	8.3	9.3
T10: Sole Soybean	33.0	20.1	26.3	3.0	3.0	3.0	6.7	6.4	6.5	8.9	8.1	8.5
T11: Sole Rice bean	34.6	25.3	30.0	7.0	7.0	7.0	7.2	7.0	7.1	13.2	13.0	13.1
T12: Sole Cowpea	28.3	24.0	27.0	12.6	10.6	11.6	8.2	7.8	8.0	12.7	10.8	11.7
S.Em ±	0.9	1.2	0.7	0.2	0.6	0.3	0.3	0.1	0.2	0.1	0.2	0.1
C.D (P=0.05)	2.7	3.6	2.2	0.6	1.9	1.0	0.7	0.4	0.6	0.5	0.8	0.5

Effect of Palnting Densities of Sandal on Yield Parameters of Agricultural Crops

The data pertaining to yield parameters of agricultural crops under sandal-based agroforestry system is shown in Table 5. Significantly higher number of pods per plant (pooled 28.6) was recorded in T_4 (5m x 5 m + Ricebean) followed by T_2 (5m x 4 m + Soybean) (pooled 26) and T_7 (5 m x 5 m + Cowpea) (pooled 25.6) and lowest pod number was observed in T_9 (5m x 3m + Cowpea) (pooled 22.1). Improved pod formation under wider spacing may be attributed to reduced canopy shading and better availability of growth resources, which favors reproductive development in legumes. The similar type of results were also reported by Singh *et al.* (2010). Similarly, number of seeds per pod of Soybean showed uniform (3.0 seeds pod^{-1}) across all planting densities, Ricebean recorded 6.0 to 7.0 seeds per pod, with slight year-wise variation and Cowpea ranged from 10.3 to 11.6, with the highest observation seen in T_7 (5m x 5m + Cowpea). Similar spacing-related yield responses in legume intercrops have been noted by Pandey (2007). Higher seed yield was recorded under T_7 (5m x 5m + Cowpea) (7.7 g plant^{-1}) followed by T_4 (5 m x 5 m + Ricebean) (7.1 g plant^{-1}) and minimum pooled seed yield recorded in T_3 (5m x 3m + Soybean) (5.5 g plant^{-1}) occurred in S_3 spacing indicating yield reduction under closer tree spacing. Pooled haulm yield ranged from 12.4 g plant^{-1} (T_4) to 7.3 g plant^{-1} (T_3), exhibited the highest haulm yield among intercrops with 12.4 g in T_4 (5m x 5m + Rice bean) under 5m x 5m spacing reflecting greater vegetative biomass due to improved light interception and photosynthetic activity.

Intercrops under sandal spacing 5m x 5m consistently had highest number of pods, number of seeds per pod, seed yield and haulm yield (g plant^{-1}). Among intercrops, ricebean showed higher number of pods and haulm yield (g plant^{-1}) whereas cowpea recorded the higher number of seeds per pod and seed yield attributes indicating system reliability, better compatibility with sandalwood.

Effect of Sandalwood Planting Density on Seed Yield, Haulm Yield and Harvest Index of Agricultural Crops

The result clearly demonstrated that sandalwood planting density significantly affected the seed yield, haulm yield and harvest index (Table 6). The wider spacing of 5 m x 5 m consistently produced higher

TABLE 6

Yield of agricultural crops as influenced by planting density of Sandal based agroforestry system

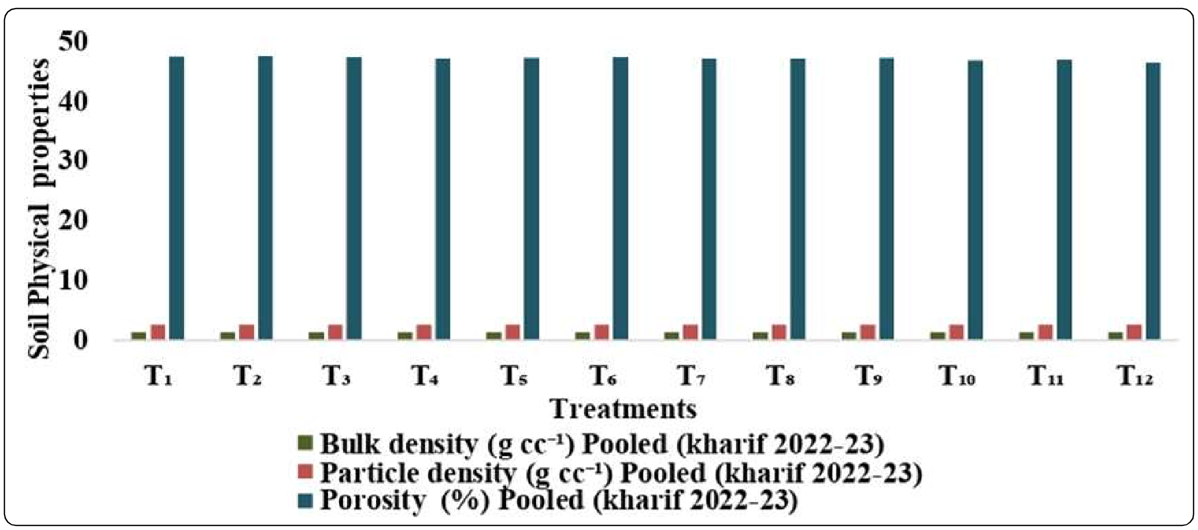
Treatments	Seed yield (g plant-1)			Haulm yield (g plant-1)			Harvest index (%)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T1: 5m x 5m + Soybean	1272	1231	1252	1820	1679	1749	0.41	0.42	0.42
T2: 5m x 4m + Soybean	1219	1118	1168	1727	1646	1687	0.41	0.40	0.41
T3: 5m x 3m + Soybean	1181	1021	1101	1491	1467	1479	0.44	0.41	0.43
T4: 5m x 5m + Rice bean	1518	1416	1467	2641	2462	2552	0.37	0.37	0.37
T5: 5m x 4m + Rice bean	1402	1240	1321	2278	2235	2257	0.38	0.36	0.37
T6: 5m x 3m + Rice bean	1401	1201	1301	2342	1869	2106	0.37	0.39	0.38
T7: 5m x 5m + Cowpea	1642	1539	1590	2304	1935	2120	0.42	0.44	0.43
T8: 5m x 4m + Cowpea	1585	1483	1534	2201	2196	2198	0.42	0.40	0.41
T9: 5m x 3m + Cowpea	1461	1381	1421	2062	1668	1865	0.42	0.45	0.43
T10: Sole Soybean	1489	1280	1384	1978	1620	1799	0.43	0.44	0.44
T11: Sole Rice bean	1600	1400	1500	2933	2606	2770	0.35	0.35	0.35
T12: Sole Cowpea	1822	1560	1691	2822	2160	2491	0.39	0.42	0.41
S.Em ±	52.6	32.7	34.0	277.1	53.2	185.3	0.01	0.01	0.01
C.D (P=0.05)	154.2	96.0	99.8	812.8	156.1	543.4	0.03	0.02	0.04

yield than 5m x 4m and 5m x 3m spacing. The maximum pooled seed yield (1590 kg ha^{-1}) was observed in T_7 (5m x 5m + Cowpea), whereas minimum seed yield was obtained in T_3 (5m x 3m + Soyabean) (1101 kg ha^{-1}). It might be due to reduction in above and below ground competition enabling better soil moisture, greater solar radiation and root proliferation. Significantly higher pooled haulm yield (2552 kg ha^{-1}) was recorded under T_4 (5m x 5m + Ricebean) and lowest (1479 kg ha^{-1}) was recorded under T_3 (5m x 3m + Soybean). It reflects vegetative biomass accumulation. Harvest Index ranged from 0.41 to 0.43 with T_7 (0.43) showing the highest pooled value due to high economic growth of plant, whereas other treatments ranged between 0.35 to 0.38 due to biomass-heavy growth reported by Ong *et al.* (2000) and Singh *et al.* (2010).

Wider spacing of 5m x 5m planting of sandal showed favorable result for seed and biomass yield of all agricultural crops. Cowpea and soybean showed superiority over ricebean in terms of harvest index. Overall, Cowpea recorded the highest seed productivity, demonstrating strong compatibility under the system indicating no severe reproductive stress despite competition.

Effect of Sandalwood Planting Density and Agricultural Crops on Soil Physical Properties

The data pertaining to changes in soil physical properties namely bulk density, particle density and porosity as influenced by sandal planting density and agricultural crops are shown in Fig. 1. Bulk density values remained within a range of 1.37 to 1.41 g cc^{-1}, indicating moderately compact but favorable soil conditions for root growth and agroforestry operations. The higher BD recorded in T_7 (5 m x 5 m + Cowpea) (pooled 1.41 g cc^{-1}) and lower on par BD values of 1.38 g cc^{-1}) were recorded in T_2, T_3, T_5 and T_6, respectively. This was due to leaf litter addition and minimal soil disturbance which in turn helped in maintaining stable BD. Particle density remained same across different treatments, ranging between 2.61 to 2.65 g cc^{-1}. The highest PD value was recorded in T_7 (5m x 5m + Cowpea) (pooled 2.65 g cc^{-1}) and lowest recorded in T_6 (5m x 3m + Ricebea) was (pooled 2.61 g cc^{-1}). Porosity values ranged between 46.38 to 47.52 per cent, suggesting good soil aeration and infiltration. The highest porosity was recorded in T_2 (5m x 4m + Soybean) (pooled 47.51 %) and lowest seen in T_{12} (Sole Cowpea) (pooled 46.40 %). This indicated stable soil structure in intensive intercropping of Sandal-



Note : T1: 5m x 5m + Soybean T2: 5m x 4m + Soybean T3: 5m x 3m + Soybean T4: 5m x 5m + Ricebea T5: 5m x 4m + Ricebean T6: 5m x 3m + Ricebean T7: 5m x 5m + Cowpea T8: 5m x 4m + Cowpea T9: 5m x 3m + Cowpea T10: Sole Soybean T11: Sole Ricebean T12: Sole Cowpea

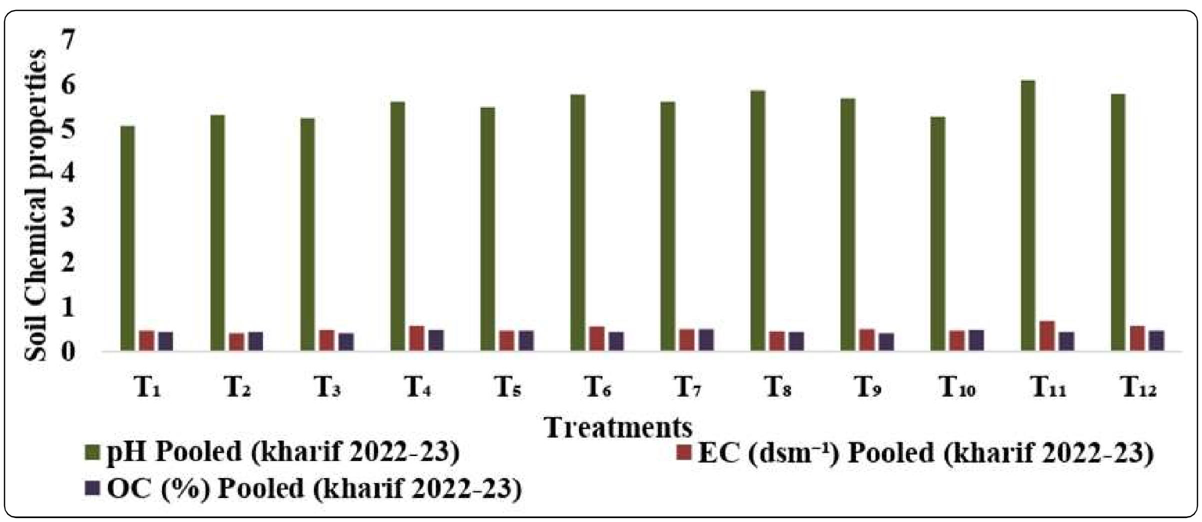
Fig. 1 : Changes in soil physical properties as influenced by Sandal planting density and agricultural crops

based agroforestry system.

The result demonstrated that intercropping of Soybean, Ricebean and Cowpea under sandalwood plantations did not adversely affect soil physical properties rather it maintained a favorable soil conditions. This highlights the adoption of ecological compatibility and sustainability of sandalwood-based agroforestry system.

Effect of Sandal Planting Density and Agricultural Crops on Soil Chemical Properties

The data pertaining to pH, EC and OC of soil as influenced by sandal planting density and agricultural crops are depicted in Fig. 2. The pooled data showed that the soil pH ranges from 5.07 to 6.09, indicating slightly acidic conditions across treatments. However, numerically higher soil pH was recorded under ricebean and cowpea-based systems, particularly at wider spacings. The maximum pH value of 6.09 was observed under T_{11} (sole Ricebean), followed by T_8 (5m x 4m + Cowpea) (5.86) and T_4 (5m x 5m + Ricebean) (5.60), which may be attributed to greater base cation return through residues and enhanced microbial mineralization which helps neutralize soil acidity, whereas in Soybean- based intercropping treatments recorded comparatively lower pH values, with the minimum pooled pH observed under T_1 (5m x 5m + Soybean) was (5.07). Similar legume-induced moderation of soil pH has been reported by (Sanchez, 1995). Electrical conductivity values ranged from 0.40 to 0.68 dSm^{-1}, remaining well below the threshold of salinity hazard. The treatment T_{11} (Sole Ricebean) recorded the highest EC (pooled value of 0.68 dSm^{-1}), followed by T_4 (5m x 5m + Ricebean) (0.58 $dS\ m^{-1}$) and T_{12} (sole cowpea) (pooled .58 dSm^{-1}). Soybean-based intercropping systems generally recorded lower EC values. Slight increases in EC under legume-based treatments may result from greater release of soluble ions through biomass decomposition and root exudation. This data is consistent with observations documented by Lal, 2004 and Jose, 2009. Soil organic carbon values ranging from 0.41 to 0.50 per cent (pooled). The highest OC content was recorded under T_7 (5m x 5m + Cowpea) (0.50%) and sole cowpea T_{12} (0.46%), closely followed by T_4 (5m x 5m + Ricebean) (0.49%). This is due to higher biomass return, root turnover, and residue incorporation which enhance soil carbon pools. Soybean-based intercropping treatments recorded comparatively lower OC values, with the minimum pooled OC observed under T_3 (5m x 3m + Soybean)



Note : T1: 5m x 5m + Soybean T2: 5m x 4m + Soybean T3: 5m x 3m + Soybean T4: 5m x 5m+ Ricebea T5: 5m x 4m + Ricebean T6: 5m x 3m + Ricebean T7: 5m x 5m + Cowpea T8: 5m x 4m + Cowpea T9: 5m x 3m + Cowpea T10: Sole Soybean T11: Sole Ricebean T12: Sole Cowpea

Fig. 2 : Changes in soil chemical properties as influenced by Sandal planting density and agricultural crops

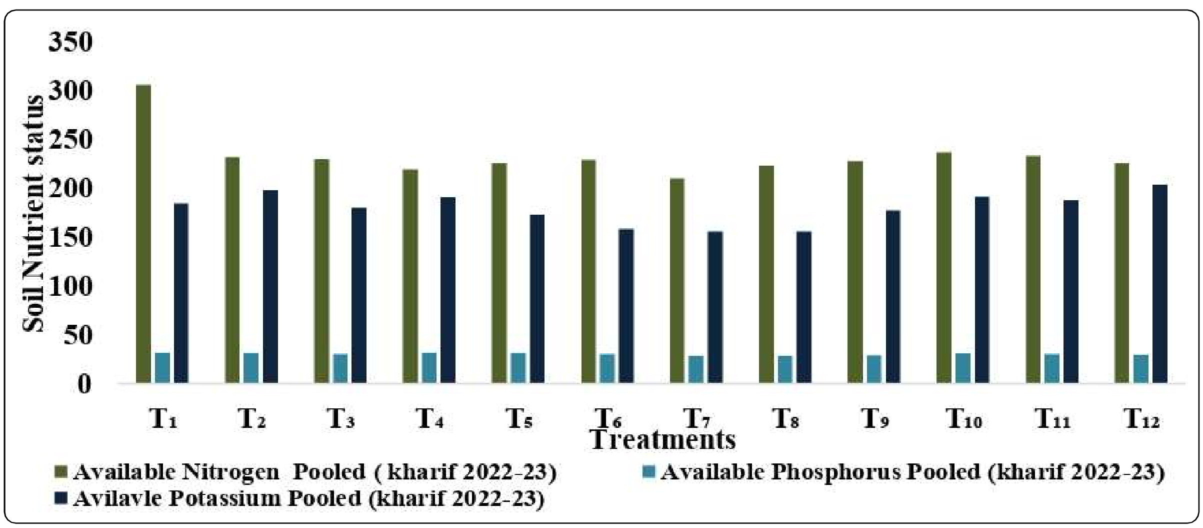
(pooled 0.41%). These findings are in close agreement with the findings of Nair *et al.* (2009), Lal (2004) and Palm *et al.* (2001).

Effect of Sandal Planting Density and Agricultural Crops on Soil Nutrient Status

The data regarding available nitrogen, phosphorus and potassium content in soil is shown in Fig. 3. Available nitrogen status in soil ranged from 210.3 to 306.5 kg ha^{-1} (pooled data). The highest available nitrogen was recorded under T_1 (5m x 5m + Soybean) (306.5 kg ha^{-1}), followed by sole soybean T_{10} (Sole Soybean) (237.3 kg ha^{-1}) and ricebean-based intercropping systems. The greater nitrogen availability under soybean treatments may be attributed to efficient biological nitrogen fixation, higher nodulation, and nitrogen-rich residue addition. Similar enhancements in soil available nitrogen status has been reported by Nair *et al.* (2009).

The status of available phosphorus ranged from 28.0 to 32.1 kg ha^{-1} (pooled data). The highest available phosphorus was recorded under T_1 (5m x 5m + soybean) (32.1 kg ha^{-1}), closely followed by T_4 (5m x 5m + ricebean) (31.9 kg ha^{-1}) and sole soybean T_{10} (Sole Soybean) (31.1 kg ha^{-1}). Enhanced phosphorus availability under soybean and ricebean systems may be attributed to organic acid exudation from legume roots, which facilitates solubilization of native soil phosphorus and improves its availability. Cowpea-based intercropping treatments recorded comparatively lower phosphorus availability, with the minimum pooled value under T_7 (5m x 5m + cowpea) (pooled 28.0 kg ha^{-1}). Similar improvements in soil phosphorus under legume-based cropping systems have been reported by Hinsinger (2001).

Available potassium content ranged from 155.9 to 204.1 kg ha^{-1} in pooled data. The highest potassium availability was recorded under sole cowpea T_{12} (pooled 204.1 kg ha^{-1}), followed by sole soybean T_{10} (pooled 191.6 kg ha^{-1}) and T_4 (5m x 5m + Ricebean) (pooled 191.0 kg ha?¹) due to improving nutrient cycling through litter inputs and deep-root nutrient retrieval by return of crop residues and recycling of potassium from deeper soil layers by sandalwood roots. The variation in potassium availability among treatments may be attributed to differential uptake patterns of intercrops.



Note : T1: 5m x 5m + Soybean T2: 5m x 4m + Soybean T3: 5m x 3m + Soybea T4: 5m x 5m + Ricebea T5: 5m x 4m + Ricebean T6: 5m x 3m + Ricebean T7: 5m x 5m + Cowpea T8: 5m x 4m + Cowpea T9: 5m x 3m + Cowpea T10: Sole Soybean T11: Sole Ricebean T12: Sole Cowpea

Fig. 3 : Changes in soil available nutrient status as influenced by Sandal planting density and agricultural crops

Overall, the study clearly indicated that Soybean intercropping, particularly under wider planting sandal at 5m x 5m, is most effective in enhancing soil available nitrogen and phosphorus, whereas Cowpea contributed relatively higher potassium availability under sole cropping. Ricebean treatments showed intermediate performance across all macronutrients.

Sandalwood planted at 5m x 5m spacing consistently showed the remarkable result in growth, productivity and soil nutrient status. Cowpea recorded significantly higher seed yield under Sandal. Yield attributes of agricultural crops remained stable across both the seasons indicating system reliability. Legume intercrops demonstrated good ecological and productive compatibility with sandalwood.

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