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Assessment of physico-chemical properties of soil and carbon sequestration of natural sal (*Shorea robusta*) forest under different regimes of Jharkhand

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Abstract
The present investigation on entitled "Assessment of Physico-chemical Properties of Soil and Carbon Sequestration of Natural Sal (Shorea robusta) Forest under Different Regimes of Jharkhand" was carried out during 2023-2024 at the Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj to access the soil physico-chemical properties, biomass estimation and correlation studies. 20 x 20 m experimental plots were demarcated within the three Natural Sal Forest of Jharkhand. For assessing the physico-chemical properties of soil, the soil samples were collected from four depths i.e. 0 – 15, 15-30, 30-45 and 45-60 cm from five quadrants laid at each forest. The soil of the natural Sal forests was acidic in nature across all forests. The highest percent of organic carbon (2.10%) was found in Fudi Forest (F_1, Q_4). The nitrogen, phosphorus, and potassium (N, P, and K) content in all Sal forests ranged from moderate to high. The highest amount of biomass accumulation was observed in Fudi Sal forest (782.96 Mg ha^{-1}). The highest rate of carbon sequestration was observed in Fudi Forest, which sequestered 1862.21 Mg ha^{-1} of carbon, the largest amount among the three forests. Correlation studies revealed a perfect positive correlation among all vegetative parameters at each of the four soil depths (r = 1.000).

Keywords: Sal forest, biomass, correlation, soil, carbon sequestration

Introduction
Soil, often known as the 'silent partner' of the biosphere, is a secret powerhouse that fuels essential ecological processes and carbon cycling (Montgomery, 2007) [13]. It is a permanent surface material that covers most land. It is made up of both organic and inorganic materials. In addition to being a source of water and nutrients, soil gives agricultural crops their structural support. The chemical and physical characteristics of soils differ widely (Hillel, D., 2004). Various processes, including weathering, microbiological activity, and leaching, interact to create a wide variety of soil types. Each type has unique advantages and disadvantages in terms of agricultural output (Jenny, H., 1994) [11].

The forest is a vital component of the global carbon cycle and has a large capacity to absorb and store carbon, making it a viable means of mitigating climate change. The process of extracting atmospheric carbon dioxide and storing it in terrestrial ecosystems for a longer period of time is known as the "carbon sequestration phenomenon." Through photosynthesis, the carbon taken from the atmosphere is fixed to produce organic compounds (Alexandrov 2007) [1]. As a result, atmospheric carbon enters the body of the plant and is retained for a longer period of time in various tree parts. Reducing the carbon source and increasing the carbon sink are the two ways to lower CO^2. Terakunpisut *et al.*, (2007) [19].

Forest soil's physio-chemical properties vary over time and space due to a number of natural factors. These factors include variations in altitude, climate, vegetation cover, and microbial activities. Vegetation is a major factor in the formation of soil; for instance, plant tissue (both aboveground litter and belowground root detritus) is the primary source of soil organic matter, which affects physiochemical characteristics of soil like pH, texture, nutrient availability, and water holding capacity (WHC) (Paudel and Sah 2003) [16].

Sal (*Shorea robusta)* is a large deciduous tree (nearly semi-evergreen in very moist conditions).

It is moderate to slow growing and attain height of 30–50 m with a diameter of 3–3.5 m in favorable conditions. The species is dominantly distributed on the plains and foothills of the Himalayas and also along the valleys in India. (Gautam and Devoe 2006) [7]. Have demarcated the spread of Sal forests in India ranging from Uttarakhand in the north to Andhra Pradesh in the south and Tripura in the east; covering, Uttar Pradesh (UP), Bihar, Haryana, West Bengal, Madhya Pradesh, Odisha, Chhattisgarh, Maharashtra, Sikkim, Assam, Jharkhand and Meghalaya

Aboveground biomass (AGB) refers to the total mass of living plant material above the soil surface, including stems, leaves, branches, and reproductive structures. AGB plays a crucial role in the carbon cycle as it acts as a significant carbon sink, capturing and storing carbon dioxide from the atmosphere through the process of photosynthesis. In forest ecosystems, AGB is a critical indicator of forest health and productivity, influencing biodiversity, habitat structure, and ecosystem services Various methods, including remote sensing, allometric equations, and field measurements, are employed to estimate AGB, each with its strengths and limitations (Brown, 1997) [4].

Belowground biomass (BGB) encompasses all the living plant material beneath the soil surface, such as roots, rhizomes, and tubers. BGB is fundamental to plant growth and ecosystem stability as it facilitates water and nutrient uptake, anchors plants in the soil, and contributes to soil organic matter through root turnover and decomposition. BGB also plays a pivotal role in the carbon cycle by storing a substantial amount of carbon and influencing soil carbon dynamics. However, BGB is often less studied than AGB due to the difficulty of accessing and measuring root systems. (Jackson *et al.,* 1996; Mokany *et al*, 2006) [10, 12].

Therefore, the present study aims to assess physico-chemical properties (soil texture, pH, electrical conductivity, soil organic carbon percent, soil water holding capacity, percent porosity, available nitrogen, available phosphorus and available potassium), tree biomass and carbon stock (above and below ground) and carbon sequestration of three Natural Sal Forests of Jharkhand, India.

2. Materials and Methods

2.1 Experimental Site and Location

Jharkhand lies between 23° 36' 36.651" N latitudes and 85° 16' 47.767" E longitudes. The state covers an area of 79,710 Km^2 out of which 23.22 Lakh Hectares (29.33%) are under forests, it comprises of the Chotanagpur Plateau, which forms a part of Deccan bio-geographic province. Description of the Natural Sal forests under study:

a) **Fudi, Khunti (F_1):** This forest is situated in the newly created Khunti district, earlier a sub-division of Ranchi district was carved out of Ranchi district of Jharkhand. GPS coordinate of the Fudi is 23° 10' 53.29" N latitude and 85° 16' 40.76" E longitude. Part of the South Chotanapur Division. It has an undulating, it is hilly, forested, and relatively poor for agriculture. The soil texture is Silty loam.

b) **Indra, Hazaribagh (F_2):** The district of Hazaribagh is situated in the north east part of North Chotanagpur Division. GPS coordinate of the Indra is 23° 50' 34.61" N latitude and 85° 26' 42.60" E longitude. This area is full of several plateaus, mountains and valleys. The forest has Silty clay loam type of soil texture

c) **Semra, Ramgarh (F_3):** This forest is situated on National Highway-33. It has hilly areas and a large forest land. GPS coordinate of the Semra is 23° 46' 39.70" N latitude and 85° 28' 46.30" E longitude. It is the part of Chotanagpur plateau. The soil texture is Silty loam.

Fig 1: India map

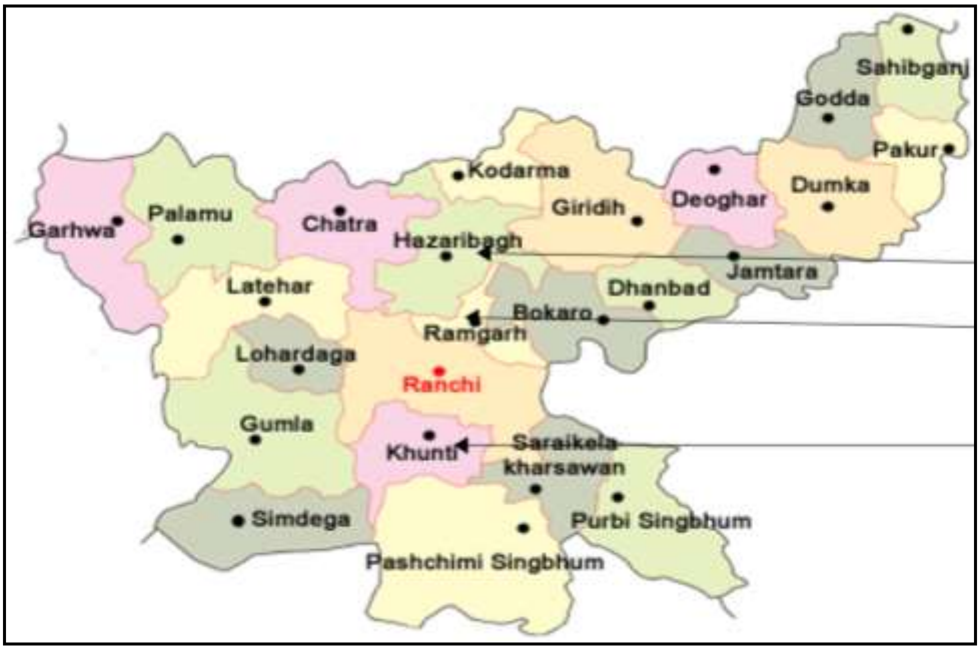

Fig 2: State map

Climate and Weather

Jharkhand falls under the Tropical-Monsoon climatic region. The average annual rainfall in the state is 1,400 mm with more than 4/5th rainfall occurs between months June to September. It also gets rainfall from the branch of monsoon from the Arabian Sea. There are also variations in rainfall varying from below 1,200 mm to 1,800 mm. The winter months are cool, while hot and dry summers. The coldest and hottest months are January and May, respectively. The temperature begins to rise from the month of February and reaches its maximum in May.

2.3 Physico-chemical analysis of soil

The soils samples were collected from three different Natural Sal Forest and they were air-dried, ground, and passed through a 2-mm-size sieve for laboratory analysis. Soil samples were analyzed for soil texture Bouyoucos, (1927) [3], bulk density (Mg m^{-3}), particle density (Mg m^{-3}), percent pore space, water holding capacity (Muthuvel *et al*., 1992) [14], pH (w/v) (Jackson, 1958) [10], EC (dS m^{-1}) at 25 ˚C (Wilcox, 1950), Organic Carbon percent (Walkley and Black, 1947), Available Nitrogen (kg ha^{-1}) (Subbiah and Asiija, 1956) [18], Available Phosphorus (kg ha^{-1}) (Olsen *et al*., 1954) [15], Available Potassium (kg ha^{-1}) (Toth and Prince, 1949) [20] and Soil carbon density (Mg C ha^{-1}) from the different quadrants of forests.

2.4 Estimation of Tree Biomass and Carbon Content

20 x 20 m experimental plots were demarcated within the three Natural Sal forests. Biomass of trees was estimated by dimension analysis of sample trees based on Diameter at breast height (DBH) using following volume equations. The volume of standing trees was estimated by using the following general volume equation for Shorea robusta in Jharkhand and expressed in m^3.

$$V=(0.022585-0.70158\times D+8.714\times D^2)$$

Where, V= Volume (m^3), D = Diameter at breast height (m)

Above ground tree biomass (Mg ha^{-1})

The total tree biomass was calculated by multiplying the stem biomass with the biomass expansion factor of the species (Appendix I)

Below ground tree biomass (Mg ha^{-1})

Belowground biomass of tree roots is calculated by multiplying the aboveground biomass by a factor of 0.26.

Belowground biomass of trees= Aboveground biomass of trees x 0.26

Total tree biomass

Total tree biomass is the sum of total aboveground biomass and belowground biomass of trees.

Total carbon in trees

Total carbon in tree **=** Total tree biomass multiplied by a factor of 0.45 due to the fact that around 45% carbon is found in the total biomass of trees (Woomer, 1990) [23].

Total carbon in trees= Total biomass x 0.45

Carbon stock

Carbon stock was estimated as per the formula mentioned by IPCC (2006)

$$\text{Carbon stock} = \text{Biomass} \times 0.5$$

Rate of carbon sequestration

Rate of carbon sequestration was calculated by as per total carbon sequestration and divided by age of plantation.

$$\text{Rate of carbon sequestration} = \frac{\text{Total carbon}}{\text{Age of plantation}}$$

CO_2 sequestration

CO_2 was estimated as per the formula suggested by Pearson *et al.*, (2007) [17]

CO_2 sequestered = Biomass carbon stock × 3.67

Total carbon sequestration:

TCS= Total carbon sequestration in trees + Total carbon sequestration in litter + Soil OC %.

Statistical analysis

The data recorded during the course of the investigation was subjected to statistical analysis by analysis of variance (ANOVA) technique. The significant and non-significant of treatment effect was judged with the help of 'F' (variance ratio) table. The experiment was laid out in ANOVA: Two-Factor Without Replication. The significant difference between the mean were tested against the critical difference at 5% level for testing the hypothesis.

(i) Standard deviation $(s) = \sqrt{\frac{\sum ni=1(\bar{x}-xi)}{N-1}}$

Where;

(ii) Standard error (S.E) = $\frac{SD}{\sqrt{n}}$

(iii) Linear Correlation by Pearson's

Data analysis was done by using latest version software Microsoft Excel 365.

3. Results and Discussion

Physico-chemical properties of soil of Natural Sal Forest of different regimes of Jharkhand.

- The Soil textural class was found Silt loam for F_1, F_3 and Silt Clay Loam for F_2 The sand, silt and clay percent varied from 51.56 to 60.28% sand, 20.28 to 30.00% silt and 17.44 to 26.44% clay in silt loam.
- The Bulk density of different forest of Jharkhand varied from 1.04 Mg m^{-3} to 1.25 Mg m^{-3}. The maximum Bulk density 1.25 Mg m^{-3} was found in F_3 Q_4 (Semra) and F_1 Q_5 of (Fudi) and minimum bulk density was recorded 1.05 Mg m^{-3} in F_1Q_1 (Fudi) The bulk density was found to increase with the soil depth in all forest due to increase in tree roots over time and space and also due to compaction in the subsurface comparatively.
- The Particle density of different forest of Jharkhand varied from 2.00Mg m^{-3} to 2.70 Mg m^{-3}. The maximum particle density was 2.71 Mg m^{-3} found in F_3 Q_4 (Semra) and minimum Particle density was recorded 2.00 Mg m^{-3} in F_1 Q_1 (Fudi). The Bulk density increase was found to increase with soil depth in all forest.
- The percent pore space of different forest of Jharkhand varied from 43.75% to 58.33%. The maximum % pore space was 57.89% found in F_2 Q_3 (Indra) and minimum % pore space was recorded 43.75% in F_1 Q_4 (Fudi). The % Pore space was found to increase with soil depth in all forest.
- The percent WHC of different forest of Jharkhand varied from 40.23% to 48.77%. The maximum Water Holding Capacity (%) was 48.77 found in F_1 Q_2 (Fudi) and minimum Water Holding Capacity (%) was recorded 40.23 in F_2 Q_5 (Indra). The water holding capacity (%) was found to increase with soil depth in all forests.
- The soil pH of different forest of Jharkhand varied from 4.70 to 6.50. The maximum pH was 6.50 found in F_2 Q_1 (Indra) and minimum pH was recorded 4.73 in F_1 Q_5 (Fudi). The soil was found to be moderately acidic to strongly acidic. Soil pH increased with increasing soil depth; this could be due to high accumulation of litter in upper soil surface which released acids by decomposition.
- The soil EC of different forest of Jharkhand varied from 0.05 to 0.28dS m^{-1}. The maximum EC was 0.28 found in F_1 Q_5 (Fudi) and minimum EC was recorded 0.05 in F_2 Q_5 (Indra). The EC was found to be little low across all Sal Forest
- The percent OC of different forest of Jharkhand varied from 0.75% to 1.98%. The maximum percent OC was 2.10 found in F_1 Q_4 (Fudi) and minimum percent OC was recorded 0.75 in F_2 Q_1 (Indra). It is a known fact that higher soil organic matter occurs more commonly in cooler than warmer climates.
- The available N content of different forest of Jharkhand varied from 213.24 to 326.14 kg ha^{-1} and its content was low to moderate in all Sal forests. The maximum available N was 326.14 Kg ha^{-1} found in F_2 Q_4 (Indra) and minimum available N was recorded 213.25 Kg ha^{-1} in F_1 Q_2 (Fudi).
- The available P content of different forest of Jharkhand varied from 6.03 to 19.32 kg ha^{-1}. All the forests have low to medium available P content. The maximum available P was 19.32 Kg ha^{-1} found in F_3 Q_5 (Semra) and minimum available P was recorded 6.03 Kg ha^{-1} in F_1 Q_5 (Fudi).
- The available K content of different forest of Jharkhand varied from 85.02 to 392 kg ha^{-1}. All the forests have low to medium available K content. The maximum available K was 392 Kg ha^{-1} found in F_2 Q_3 (Indra) and minimum available K was recorded 85.02 Kg ha^{-1} in F_3 Q_5 (Semra).

The carbon density (Mg ha^{-1}) content of different forest of Jharkhand varied from 12.60 to 35.91 Mg ha^{-1}. The maximum soil organic carbon was recorded in Fudi, (F_1) Sal Forest (35.91 Mg ha^{-1}) (F_1Q_4) and this was followed by Indra, (F_2) Sal Forest with (32.67 Mg ha^{-1}) (F_2Q_5). Minimum soil organic carbon was seen in Indra, (F_2) Sal Forest with (12.60 Mg ha^{-1}). (F_2Q_1).

Table 1: Bulk density, particle density, pore space and water holding capacity of soil of different natural Sal Forest of Jharkhand at 0-15, 15- 30, 30-45 and 45-60 cm depth

Forest	Quadrant	Bulk density (Mg m^{-3})				Particle density (Mg m^{-3})				Pore space (%)				WHC (%)			
		0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm
F_1	$F_1 Q_1$	1.18	1.11	1.10	1.05	2.50	2.22	2.22	2.00	52.94	50.55	50.00	47.37	44.12	42.43	41.35	40.42
	$F_1 Q_2$	1.18	1.18	1.08	1.06	2.51	2.50	2.22	2.13	55.29	52.94	51.35	50.00	48.77	47.14	45.71	44.44
	$F_1 Q_3$	1.11	1.20	1.21	1.08	2.50	2.67	2.50	2.11	55.56	53.13	50.00	48.65	45.59	42.86	41.67	40.54
	$F_1 Q_4$	1.14	1.18	1.23	1.11	2.50	2.50	2.60	2.22	54.29	52.94	52.47	43.75	44.44	42.42	41.76	40.63
	$F_1 Q_5$	1.11	1.16	1.25	1.14	2.67	2.50	2.40	2.22	58.33	53.76	50.00	48.57	48.57	44.44	43.75	40.30
F_2	$F_2 Q_1$	1.18	1.16	1.14	1.12	2.50	2.50	2.22	2.22	52.94	51.10	48.57	47.98	45.46	43.08	42.65	41.94
	$F_2 Q_2$	1.18	1.14	1.21	1.11	2.63	2.35	2.41	2.22	57.78	50.00	49.70	48.57	45.00	44.12	43.03	40.63
	$F_2 Q_3$	1.18	1.11	1.05	1.04	2.60	2.52	2.50	2.21	58.33	57.89	55.29	50.00	47.06	46.36	45.29	42.42
	$F_2 Q_4$	1.18	1.18	1.10	1.05	2.50	2.22	2.15	2.10	52.94	50.55	47.37	47.06	45.59	44.12	42.42	41.12
	$F_2 Q_5$	1.21	1.18	1.11	1.08	2.60	2.50	2.50	2.22	57.58	55.56	52.94	51.35	45.00	44.12	42.12	40.23
F_3	$F_3 Q_1$	1.19	1.18	1.17	1.08	2.63	2.50	2.50	2.22	55.56	52.94	52.94	51.35	46.88	45.16	44.51	41.27
	$F_3 Q_2$	1.19	1.18	1.11	1.10	2.69	2.50	2.35	2.22	55.95	52.94	52.78	50.00	46.06	44.78	41.18	40.91
	$F_3 Q_3$	1.18	1.16	1.08	1.10	2.50	2.50	2.11	2.22	55.56	52.94	48.65	48.57	43.75	42.63	41.23	40.63
	$F_3 Q_4$	1.25	1.16	1.14	1.13	2.70	2.50	2.15	2.22	57.71	53.76	50.00	48.57	45.45	43.75	42.08	41.23
	$F_3 Q_5$	1.17	1.15	1.11	1.08	2.50	2.40	2.10	2.20	56.76	52.05	50.00	48.13	46.88	46.14	44.30	41.94
	Mean	1.18	1.16	1.14	1.09	2.58	2.46	2.33	2.18	55.83	2.87	50.80	48.66	45.91	44.24	42.87	41.24
	F-Test	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	S.Em. (±)	0.01	0.01	0.02	0.01	0.08	0.11	0.16	0.06	0.50	0.52	0.54	0.48	0.38	0.38	0.39	0.28
	SD	0.04	0.03	0.06	0.03	0.02	0.03	0.04	0.01	1.92	2.02	2.11	1.87	1.48	1.47	1.50	1.10

Table 2: pH, EC, Organic carbon (%) available Nitrogen (Kg ha^{-1}) of soil of different natural Sal Forest of Jharkhand at 0-15, 15- 30, 30-45 and 45-60 cm depth

Forest	Quadrant	pH				EC				Organic carbon (%)				Available Nitrogen (Kg ha^{-1})			
		0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm
F_1	$F_1 Q_1$	4.97	5.15	5.16	5.22	0.11	0.07	0.09	0.09	1.35	1.20	1.20	1.05	288.51	277.22	275.97	250.88
	$F_1 Q_2$	4.83	4.92	5.00	5.01	0.11	0.11	0.12	0.11	1.58	1.35	1.20	0.90	275.97	265.93	250.88	213.25
	$F_1 Q_3$	4.97	5.12	5.30	5.36	0.09	0.11	0.13	0.12	2.03	1.65	1.20	0.90	288.51	263.42	250.88	225.79
	$F_1 Q_4$	4.78	4.70	5.37	5.40	0.12	0.11	0.11	0.13	2.10	1.50	1.35	0.90	275.97	263.42	238.34	225.79
	$F_1 Q_5$	4.73	4.86	4.98	5.02	0.11	0.13	0.11	0.11	1.58	1.20	1.20	1.05	288.51	263.42	250.88	238.34
F_2	$F_2 Q_1$	6.29	6.31	6.45	6.50	0.06	0.09	0.09	0.13	1.65	1.35	1.20	0.75	313.60	288.51	263.42	250.88
	$F_2 Q_2$	5.73	5.90	6.14	6.17	0.11	0.09	0.06	0.07	1.65	1.20	1.35	1.20	301.06	288.51	263.42	238.34
	$F_2 Q_3$	5.30	5.44	6.23	6.30	0.12	0.06	0.08	0.08	1.80	1.65	1.50	1.05	313.60	288.51	263.42	250.88
	$F_2 Q_4$	5.27	5.40	5.43	5.60	0.08	0.06	0.06	0.06	1.50	1.35	1.35	1.20	326.14	313.60	275.97	238.34
	$F_2 Q_5$	5.23	5.14	5.74	6.18	0.11	0.07	0.05	0.05	1.80	1.13	1.05	0.90	313.60	263.42	238.34	225.79
F_3	$F_3 Q_1$	5.81	5.61	5.33	5.63	0.12	0.10	0.09	0.10	1.20	1.05	1.05	0.95	288.51	263.42	238.34	225.79
	$F_3 Q_2$	4.95	5.82	5.97	5.99	0.11	0.07	0.07	0.07	1.35	1.20	0.98	0.91	301.06	288.51	263.42	238.34
	$F_3 Q_3$	5.14	5.25	5.44	5.91	0.12	0.07	0.11	0.07	1.65	1.35	1.20	1.05	288.51	263.42	250.88	238.34
	$F_3 Q_4$	5.50	5.56	5.80	5.83	0.11	0.12	0.10	0.09	1.50	1.35	1.20	0.90	275.97	263.42	250.88	238.34
	$F_3 Q_5$	5.33	5.33	5.62	5.84	0.07	0.10	0.06	0.05	1.13	1.05	0.98	0.90	275.97	263.42	238.34	225.79
	Mean	5.26	5.37	5.60	5.73	0.11	0.10	0.09	0.09	1.59	1.31	1.20	0.97	294.37	274.55	254.2	234.9
	F-Test	S	S	S	S	NS	NS	NS	NS	S	S	S	S	S	S	S	S
	S.Em. (±)	0.11	0.11	0.12	0.12	0.01	0.01	0.01	0.01	0.07	0.05	0.04	0.03	4.22	4.01	3.35	2.86
	SD	0.43	0.43	0.45	0.46	0.04	0.05	0.02	0.03	0.27	0.19	0.15	0.12	16.33	15.53	12.96	11.09

Table 3: Available Phosphorus (Kg ha^{-1}), Available Potassium (Kg ha^{-1}), Soil carbon density (Mg C ha-1) of soil of different natural Sal Forest of Jharkhand at 0-15, 15- 30, 30-45 and 45-60 cm depth

Forest	Quadrant	Available Phosphorus (Kg ha^{-1})				Available Potassium (Kg ha^{-1})				Soil carbon density (Mg C ha^{-1})			
		0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm	0-15 cm	15-30 cm	30-45 cm	45-60 cm
F_1	F_1 Q_1	8.28	7.21	7.11	6.52	257.60	246.40	240.80	235.20	23.90	19.80	19.98	16.53
	F_1 Q_2	8.10	7.57	7.21	7.01	272.16	268.80	264.32	248.64	27.88	23.89	19.44	14.31
	F_1 Q_3	8.21	7.50	7.17	6.78	291.00	280.00	246.00	235.00	33.72	29.70	21.78	14.58
	F_1 Q_4	9.31	8.21	7.32	7.16	296.80	268.80	246.40	230.72	35.91	26.55	24.90	14.98
	F_1 Q_5	9.02	8.12	7.60	6.03	268.80	257.60	235.20	212.80	26.22	20.88	22.50	17.95
F_2	F_2 Q_1	12.01	11.34	9.15	7.80	392.00	369.60	358.40	201.60	29.21	23.49	20.52	12.60
	F_2 Q_2	13.28	10.24	9.18	7.60	347.20	336.00	336.00	224.00	29.21	20.52	24.50	19.98
	F_2 Q_3	12.29	10.26	9.20	7.10	392.00	347.20	324.80	224.00	31.86	27.47	23.62	16.38
	F_2 Q_4	14.27	12.24	10.19	7.12	380.80	369.60	358.40	224.00	26.55	23.89	22.27	18.90
	F_2 Q_5	11.32	8.20	8.17	7.13	392.00	380.80	358.40	235.20	32.67	19.91	17.48	14.58
F_3	F_3 Q_1	17.48	16.24	14.12	13.90	123.20	100.80	89.60	89.60	21.42	18.58	18.42	15.39
	F_3 Q_2	19.32	17.65	15.45	12.76	134.40	112.00	112.00	100.80	24.10	21.24	16.31	14.93
	F_3 Q_3	18.54	16.76	14.54	13.01	235.20	145.60	112.00	89.60	29.21	23.49	19.44	17.32
	F_3 Q_4	17.80	16.65	15.23	12.65	246.40	145.40	135.60	100.80	28.13	23.49	20.52	15.25
	F_3 Q_5	19.32	17.54	14.54	13.01	224.00	134.40	89.60	85.02	19.74	18.11	16.23	14.58
	Mean	13.2	11.72	10.41	9.04	283.57	250.8	233.8	182.4	27.98	22.73	20.53	15.88
	F-Test	S	S	S	S	S	S	S	S	S	S	S	S
	S.Em. (±)	1.11	1.06	0.86	0.77	22.39	25.89	26.50	17.12	1.17	0.86	0.71	0.51
	SD	4.29	4.11	3.33	2.99	86.71	100.6	102.6	66.32	4.51	3.33	2.75	1.96

Vegetative parameters of Natural Sal Forest of different regimes of Jharkhand.

- The highest total above ground biomass was recorded in Fudi, (F_1) Sal Forest (782.96 Mg ha^{-1}) and lowest total over ground biomass was found in Semra, (F_3) Sal Forest (478.622 Mg ha^{-1}).
- The highest total below ground biomass was recorded in Fudi, (F_1) Sal Forest (203.571 Mg ha^{-1}) and lowest total over ground biomass was found in Semra, (F_3) Sal Forest (124.44 Mg ha^{-1}).
- The highest total biomass was recorded in Fudi, (F_1) Sal Forest (986.54 Mg ha^{-1}) followed by Indra, (F_2) Sal Forest with (845.57 Mg ha^{-1}) while the lowest total biomass was found in Semra, (F_3) Sal Forest (603.06 Mg ha^{-1})
- The highest rate of biomass accumulation was recorded in Fudi, (F_1) Sal Forest (32.88 Mg ha^{-1} yr^{-1}) followed by Indra, (F_2) Sal Forest with (28.18 Mg ha^{-1} yr^{-1}) while the lowest rate of biomass accumulation was found in Semra, (F_3) Sal Forest (20.10 Mg ha^{-1} yr^{-1})
- Highest above ground carbon sequestration was recorded in root biomass in Fudi, (F_1) Sal Forest (1436.73 Mg ha^{-1}) followed by Indra, (F_2) Sal Forest with (1231.43 Mg ha^{-1}) and Lowest above ground carbon sequestration in root biomass was observed in Semra, (F_3), Sal Forest with (878.26 Mg ha^{-1}).
- The highest below ground carbon sequestration was recorded in Fudi, (F_1) Sal Forest (372.5 Mg ha^{-1}) followed by Indra, (F_2) Sal Forest with (320.01 Mg ha^{-1}). Lowest below ground carbon sequestration was observed in Semra, (F_3), Sal Forest with (228.34 Mg ha^{-1}).
- Total carbon sequestration was found to be highest in Fudi, (F_1) Sal Forest (1862.21 Mg ha^{-1}) followed by Indra, (F_2) Sal Forest with (1603.44 Mg ha^{-1}) while the lowest total carbon sequestration was observed in Semra, (F_3), Sal Forest with (1158.60 Mg ha^{-1}).
- The highest rate of carbon sequestration was recorded in Fudi, (F_1) Sal Forest (62.07 Mg ha^{-1} yr^{-1}) followed by Indra, (F_2) Sal Forest with (53.44 Mg ha^{-1} yr^{-1}) while the lowest rate of carbon sequestration was found in Semra, (F_3) Sal Forest (38.62 Mg ha^{-1} yr^{-1}

Table 4: Aboveground biomass accumulation (Mg ha-1), Belowground biomass accumulatio n (Mg ha-1), Total biomass accumulation (Mg ha-1), 4.17 Rate of biomass accumulation (Mg ha-1 yr-1), Above ground carbon Sequestration (Mg ha-1), Below ground carbon sequestration (Mg ha-1), Total carbon sequestration (Mg ha-1), 4.21 Rate of carbon sequestration (Mg ha-1 yr-1) of soil of different natural Sal Forest of Jharkhand.

Forest	ABG (Mg ha-1)	BGB (Mg ha-1)	TBA (Mg ha-1)	RBA (Mg ha-1 yr-1)	TACS (Mg ha-1)	TBCS (Mg ha-1)	TCS (Mg ha-1)	RCS (Mg ha-1)
Fudi (F1)	782.96	203.57	986.54	32.88	1436.73	372.5	1862.21	62.07
Indra (F2)	671.09	174.48	845.57	28.18	1231.43	320.01	1603.44	53.44
Semra (F3)	478.62	124.44	603.06	20.10	878.26	228.34	1158.6	38.62
Mean	644.23	167.50	811.73	27.05	1182.14	306.95	1541.42	51.38
S.Em. (±)	88.88	23.11	111.99	3.73	163.09	72.96	205.47	6.85
SD	153.94	40.02	193.97	6.46	282.48	42.12	355.88	11.86

Correlation studies

Pearson correlation coefficient (r) between physico-chemical properties of soil profile (0-15 cm)

The results of the correlation matrix between physico-chemical properties of the soil profile (0-15 cm) are shown in Table 4.22. Bulk density (BD) was positively correlated with available phosphorus (P) (r = 0.53), while it had a negative correlation with organic carbon percentage (OC%) (r = -0.38). Particle density (PD) was positively associated with porosity percent (% PS) (r = 0.65) and water holding capacity (WHC) (r = 0.48). Porosity % showed a moderate positive correlation with WHC (r = 0.37) and electrical conductivity (EC) (r = 0.35). WHC was moderately negatively associated with OC (t/ha) (r = -0.32). OC % was strongly positively correlated with potassium (K) (r =

0.57) and OC (t/ha) (r = 0.98) and was negatively related to P (r = -0.59). The pH had a moderate positive correlation with nitrogen (N) (r = 0.37) and P (r = 0.36). EC was moderately negatively associated with N (r = -0.38) and K (r = -0.29) but was moderately positively correlated with P (r = 0.32). Nitrogen (N) had a positive association with K (r = 0.60). Phosphorus (P) was negatively associated with K (r = -0.49) and OC (t/ha) (r = -0.52). Furthermore, K was positively related to OC (t/ha) (r = 0.61).

Table 5: Pearson correlation coefficient (r) between physico-chemical properties of soil profile (0-15 cm)

	BD	PD	% PS	WHC	OC%	pH	EC	N	P	K	OC(t/ha)
BD	1.00										
PD	0.35	1.00									
% PS	0.08	0.65	1.00								
WHC	-0.22	0.48	0.37	1.00							
OC%	-0.38	-0.23	0.04	-0.26	1.00						
pH	0.44	-0.04	-0.10	-0.16	-0.24	1.00					
EC	0.46	0.38	0.35	-0.26	0.06	-0.14	1.00				
N	0.13	-0.10	-0.13	-0.15	0.11	0.37	-0.38	1.00			
P	0.53	0.21	0.18	-0.13	-0.59	0.36	0.32	-0.01	1.00		
K	-0.04	-0.33	-0.03	-0.15	0.57	0.20	-0.29	0.60	-0.49	1.00	
OC (t/ha)	-0.21	-0.18	0.07	-0.32	0.98	-0.17	0.15	0.16	-0.52	0.61	1.00

*Note: BD=Bulk Density, PD= Particle Density, % PS= % Pore Space WHC= Water holding capacity, OC%= Organic Carbon, EC= Electrical Conductivity, N= Nitrogen, P= Phosphorus, K= Potassium, OC (t/ha) = Carbon density (t/ha)

Pearson correlation coefficient (r) between soil (at 0-15 cm depth) and vegetation parameters

The results of the correlation matrix between soil parameters at a 0-15 cm depth and vegetation parameters are shown in Table 4.26. The above-ground biomass (AGB), below-ground biomass (BGB), total biomass (TBA), root organic carbon stock (ROCS), total above-ground carbon stock (TAGCS), and total below-ground carbon stock (TBGCS) all had perfect positive correlations with each other (r = 1.000). These perfect correlations indicate that these variables are directly and positively related to each other. Bulk density (BD) showed a very strong positive correlation with all vegetation parameters (AGB, BGB, TBA, ROCS, TAGCS, and TBGCS), with r values of 0.932 to 0.933. This suggests that as bulk density increases, all the vegetation parameters also increase. Organic carbon percent (OC%) displayed a strong negative correlation with AGB, BGB, TBA, ROCS, TAGCS, and TBGCS, with r values of -0.999. This indicates that as the organic carbon percent decreases, all the vegetation parameters increase. Organic carbon (t/ha) also showed a strong negative correlation with the vegetation parameters (AGB, BGB, TBA, ROCS, TAGCS, and TBGCS), with r value of -0.999. Additionally, OC (t/ha) had a moderate positive correlation with OC% (r = 0.983) and a weak negative correlation with BD (r = -0.211).

Table 6: Pearson correlation coefficient (r) between soil (at 0-15 cm depth) and vegetation parameters

	AGB	BGB	TBA	ROCS	AGCS	BGCS	BD	OC %	OC (t/ha)
AGB	1.000								
BGB	1.000	1.000							
TBA	1.000	1.000	1.000						
ROCS	1.000	1.000	1.000	1.000					
AGCS	1.000	1.000	1.000	1.000	1.000				
BGCS	1.000	1.000	1.000	1.000	1.000	1.000			
BD	0.932	0.932	0.932	0.932	0.932	0.933	1.000		
OC %	-0.999	-0.999	-0.999	-0.999	-0.999	-0.999	-0.383	1.000	
OC (t/ha)	-0.999	-0.999	-0.999	-0.999	-0.999	-0.999	-0.211	0.983	1.000

*Note: ABG= Above ground biomass, BGB= Below ground biomass, TBA= Total biomass accumulation, ROCS= Rate of carbon sequestration, AGCS= Above ground carbon sequestration, BGCS= Below ground carbon sequestration, BD= Bulk density, OC%= Organic carbon %,

Conclusion

It is concluded from this investigation that the soil of the natural Sal forests was acidic in nature across all forests. The electrical conductivity of the Sal forests was low across all sites. The highest percent of organic carbon (2.10%) was found in Fudi Forest (F_1, Q_4). The nitrogen, phosphorus, and potassium (N, P, and K) content in all Sal forests ranged from moderate to high. Soil characteristics appear to have a strong influence on the vegetation of the study area, and vice versa. Carbon stock and CO_2 calculations showed varying results across the three natural Sal forests in Jharkhand. The highest rate of carbon sequestration was observed in Fudi Forest, which sequestered 1862.21 Mg ha^{-1} of carbon, the largest amount among the three forests. Correlation studies revealed a perfect positive correlation among all vegetative parameters at each of the four soil depths (r = 1.000). These findings can inform sustainable forest management practices and contribute to global efforts to mitigate climate change, highlighting the importance of preserving and enhancing these vital forest ecosystems for future generations.

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