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Dehydrogenase: A key soil health indicator for Thar Desert, India

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ABSTRACT

A field study was conducted to identify a potential fertility indicator for the soils of the Thar Desert. The study area included eight districts, covering a total of 156,580 km². This region experiences a wide range of climatic conditions, with annual rainfall varying from 177 mm to 409 mm and temperatures fluctuating between 8°C and 46°C. Surface soil samples (0-10 cm depth) were collected from agricultural fields across the region, representing various soil properties and cropping patterns. The soil texture varied from sandy loam to loamy sand, and the wet colour ranged from dark reddish-brown to dark yellowish-brown. The physicochemical and biological properties of the soil samples from different areas of the Thar Desert were as follows: moisture content ranged from 2.19% to 8.73%, bulk density from 1.18 to 1.33 Mg/m³, particle density from 1.82 to 4.11 Mg/m³, pore space percentage from 26.74% to 68.53%, solid space percentage from 31.47% to 73.26%, pH values from 7.69 to 8.43, and electrical conductivity from 0.12 to 0.17 dS/m. Furthermore, the soil organic carbon content ranged from 0.82% to 1.21%, while organic matter content varied between 1.41% and 2.09%. The available nitrogen was found to be between 285.69 and 365.87 kg/ha, phosphorus ranged from 19.84 to 24.77 kg/ha, potassium levels ranged from 214.29 to 314.72 kg/ha, and sulfur levels varied between 16.08 and 23.62 ppm. Additionally, nitrogenase retention time was recorded at 1.391 to 1.547 minutes, phosphatase activity ranged from 269.44 to 343.15 µg p-nitrophenol g^{-1} h^{-1}, and dehydrogenase enzyme activity ranged from 250.33 to 309.34 µg TPF/g/24 h. The results demonstrated that soil properties varied across the Thar Desert. This study provided valuable insights into the physicochemical and biological characteristics of

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the soil in the Thar Desert of Rajasthan, India. Notably, a significant positive correlation (r^2 value of 0.95) was found between dehydrogenase enzyme activity and various soil fertility parameters, suggesting that dehydrogenase could serve as a potential biological indicator of soil fertility.

1 Introduction

The Thar Desert, also known as the Great Indian Desert, covers about 70% of Rajasthan's total landmass, earning it the nickname "Desert State of India." The desert spans approximately 446,000 square kilometres, with around 208,110 square kilometres of this area in India. The annual rainfall in the region ranges from 177 to 409 mm, while temperatures can vary from 8 to 46°C. Geographically, Rajasthan is situated between 23.30° to 30.120° North latitude and 69.300° to 78.170° East longitude (Kumari et al. 2021). Since immemorial, soil has been one of our most fundamental natural resources, used by humans and other living beings, alongside water and plants. However, improper management of these resources has disrupted ecological balance, agricultural productivity, and biodiversity (Rajshri et al. 2021). Soil is a valuable resource crucial in fulfilling our food and fibre needs by providing a medium for plant growth (Naphade et al. 2021). Factors such as soil fertility, management techniques, and climate can significantly impact agricultural yield. While natural elements influence soil fertility, they can often be controlled to enhance the soil's ability to provide essential nutrients to plants (Av and Ghabane 2018).

Its texture and structure influence soil fertility, affecting water retention, aeration, and root penetration. Soils with good structure and texture foster root development and plant nutrient uptake. Organic matter is vital for productive soil, as it contributes nutrients, enhances soil structure, improves water retention, and encourages beneficial microbial activity. Decomposed organic matter gradually releases nutrients that improve soil fertility over time (Wolf et al. 2023). Fertile soil contains adequate amounts of critical macronutrients and micronutrients, such as nitrogen, phosphorus, potassium (NPK), and sulfur. Soil fertility is affected by various microorganisms, including bacteria, fungi, earthworms, and decomposers. These organisms play essential roles in nutrient cycling, organic matter decomposition, and soil aggregation, all contributing to soil health and fertility (Tale and Ingole 2015).

Enzymes present in the soil have been widely studied for their significant contributions to soil fertility, as they facilitate biochemical processes necessary for nutrient cycling, organic matter decomposition, and overall soil health (Meena and Rao 2021). Soil microorganisms, plant roots, and decomposing organic matter produce these enzymes. Notably, phosphatase enzymes hydrolyze organic phosphorus compounds into inorganic phosphate, making phosphorus available for plant uptake. Phosphatase activity is critical for releasing phosphorus from organic matter (Margalef et al. 2017). Nitrogenase enzymes play a vital role in biological nitrogen fixation, converting atmospheric nitrogen (N_2) into ammonia (NH_3) or ammonium (NH_4^+). This process provides an essential nitrogen source for plant nutrition while enhancing soil fertility by increasing nitrogen levels (Threatt and Rees 2023).

Dehydrogenase activity indicates microbial metabolic activity in the soil and is frequently used to assess soil microbial health. Dehydrogenase enzymes are involved in oxidation-reduction reactions within microbial cells; higher activity levels in fertile soil indicate a robust microbial community, contributing to improved soil fertility (Aseri and Tarafdar 2006). The future of sustainable agriculture relies on maintaining long-term soil fertility, environmental conservation, and global food security amid challenges such as climate change, population growth, and land degradation. This study assesses soils' physicochemical and biological characteristics from various regions within the Thar Desert, Rajasthan. Understanding soil health indicators that reflect overall soil fertility is vital for comprehending the soil ecosystem and predicting future agricultural productivity.

2 Materials and methods

2.1 Soil sampling

Soil samples were collected from eight locations in the Thar Desert, spanning Rajasthan, India. The selected areas include (1) Sikar, (2) Jhunjhunu, (3) Churu, (4) Nagaur, (5) Bikaner, (6) Barmer, (7) Jodhpur, and (8) Jaisalmer (Figure 1). Samples were taken from a depth of 0-10 cm. The locations of the soil samples were recorded using a GIS system on a portable mobile app (Table 1). After collection, the samples were processed and analyzed for their physicochemical and biological properties using standard laboratory techniques.

2.2 Field History

A field history of cultivation practices and rainfall data for 2022-2023 has been recorded in Table 1.

2.3 Characterization of physical properties of soil

The soil samples were sieved through a 2mm mesh to analyze their physical properties. This included determining soil texture using the Bouyoucos hydrometer method (1927), assessing soil colour with the Munsell soil colour chart (1954), and measuring soil moisture using the gravimetric method outlined by Taylor (1955). Additionally, we determined bulk density, particle density, percent pore space, and percent solid space using a 100 ml graduated measuring cylinder, following the method described by Muthuvel et al. (1992).

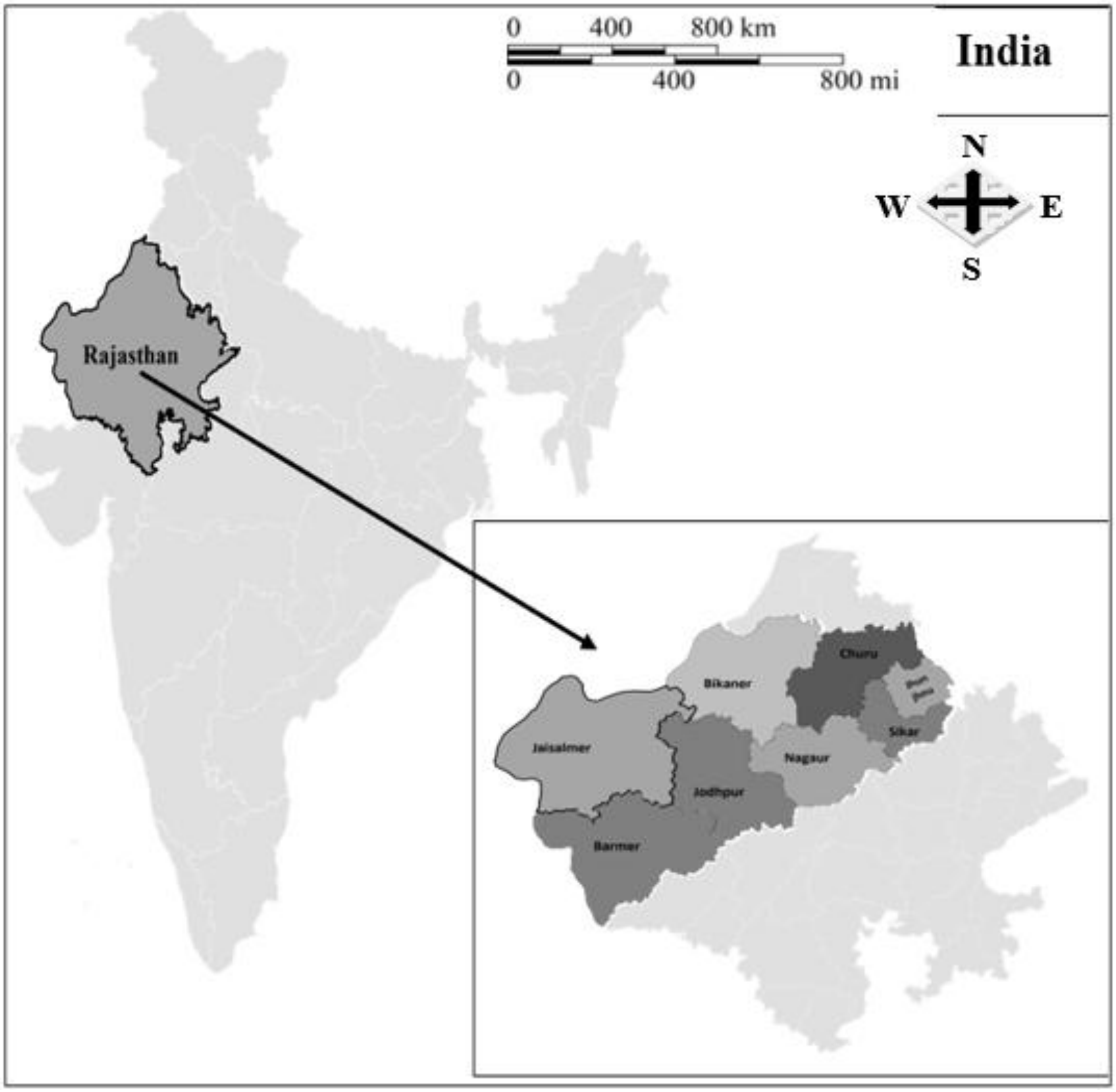

Figure 1 Map showing the soil sample locations from various regions of the Thar Desert, Rajasthan

Table 1 Soil field history of various regions of the Thar Desert, Rajasthan District's

S. No	Area	Field history of Thar Desert soil			
		Latitude(N)	Longitude (E)	Rainfall (mm)	Temperature (°C)
1.	Sikar	27.6094° N	75.1398° E	407.1	10-36
2.	Jhunjhunu	28.1317° N	75.4022° E	408.8	9-37
3.	Churu	28.2925° N	74.9707° E	334.2	8-38
4.	Nagaur	27.1983° N	73.7493° E	369.5	9-38
5.	Bikaner	28.0229° N	73.3119° E	247.2	9-42
6.	Barmer	25.7521° N	71.3967° E	272.7	12-43
7.	Jodhpur	26.2389° N	73.0243° E	292.6	12-40
8.	Jaisalmer	26.9157° N	70.9083° E	176.9	12-46

2.4 Characterization of chemical properties of soil

The chemical properties of soil, including pH (Jackson 1958) and electrical conductivity (EC), are measured using a digital EC meter (Wilcox 1950). Organic carbon (OC) and organic matter (OM) are determined by the wet-oxidation method or rapid titration method (Walkley 1947). Available nitrogen is assessed using the Kjeldahl method (Subbiah and Asija 1956). The amount of accessible phosphorus is calculated using a spectrophotometer with the colourimetric technique (Olsen et al. 1954). Potassium is measured with a flame photometer (Toth and Prince 1949). The turbidometric approach estimates the available sulfur (Chesnin and Yien 1950).

2.5 Characterization of biological properties of soil

The biological properties of soil, such as nitrogenase activity, were measured using the gas chromatography (GC) method (Dilworth 1966). The soil's dehydrogenase activity (Casida et al. 1964) and phosphatase activity (Tabatabai and Bremner 1969) were determined using a spectrophotometer.

2.6 Statistical analysis

Statistical analysis of the data was performed using Microsoft Excel 365, including calculations for standard error and the creation of bar graphs.

3 Results & Discussion

3.1 Physical parameters of Thar desert soil

The observed soil texture in the Thar Desert of Rajasthan ranged from sandy loam to loamy sand. In wet conditions, the soil colour varied from dark reddish-brown (2.5YR2/3) to dark yellowish-brown (10YR4/4), while in dry conditions, it changed from reddish-brown (2.5YR4/3) to yellowish-brown (10YR5/4). Soil moisture at different depths ranged from 2.19% to 8.73% (Table 2). The bulk density of the soil samples varied across different areas of the Thar Desert, ranging from 1.18 to 1.33 Mg m^{-3} (Table 3), and it was observed to increase with depth. Additionally, the particle density ranged from 1.82 to 4.11 Mg m^{-3} (Table 3),

Table 2 Physical properties of Soil from various regions of Thar Desert, Rajasthan

S. No	Area	Physical properties of soil at 0-10 cm depth			
		Soil Texture	Soil Colour		Soil Moisture (%)*
			Wet condition	Dry condition	
1.	Sikar	Sandy loam	Dark reddish brown	Reddish brown	8.00 ± 0.83
2.	Jhunjhunu	Sandy loam	Dark reddish brown	Reddish brown	7.06 ± 0.87
3.	Churu	Sandy loam	Dark reddish brown	Reddish brown	8.73 ± 0.24
4.	Nagaur	Sandy loam	Dark reddish brown	Reddish brown	7.65 ± 0.91
5.	Bikaner	Loamy sand	Dark yellowish brown	Yellowish brown	2.65 ± 0.86
6.	Barmer	Loamy sand	Dark yellowish brown	Yellowish brown	2.19 ± 0.91
7.	Jodhpur	Loamy sand	Dark yellowish brown	Yellowish brown	3.47 ± 1.01
8.	Jaisalmer	Loamy sand	Dark yellowish brown	Yellowish brown	4.28 ± 1.50

*Data are mean of replicates, ± Standard Error of mean

Table 3 Physical properties of Soil from various regions of Thar Desert, Rajasthan

S. No	Area	Physical properties of soil at 0-10 cm depth			
		BD (Mg m-3)	PD (Mg m-3)	Pore Space (%)	Solid Space (%)
1.	Sikar	1.30 ± 0.02	4.11 ± 0.49	67.50 ± 3.15	32.50 ± 3.15
2.	Jhunjhunu	1.25 ± 0.04	4.11 ± 0.49	68.53 ± 4.45	31.47 ± 4.45
3.	Churu	1.18 ± 0.04	2.17 ± 0.17	45.20 ± 2.58	54.80 ± 2.58
4.	Nagaur	1.25 ± 0.04	2.89 ± 0.24	56.40 ± 2.04	43.60 ± 2.04
5.	Bikaner	1.33 ± 0.04	4.11 ± 0.49	66.43 ± 4.46	33.57 ± 4.46
6.	Barmer	1.33 ± 0.04	2.89 ± 0.24	53.33 ± 3.33	46.67 ± 3.33
7.	Jodhpur	1.30 ± 0.02	2.24 ± 0.14	41.11 ± 4.84	58.89 ± 4.84
8.	Jaisalmer	1.33 ± 0.04	1.82 ± 0.10	26.74 ± 1.03	73.26 ± 1.03

Data are mean of replicates, ± Standard Error of mean

increasing with soil depth. The increase in particle density was linked to factors including soil depth, water quality, and their interaction (Kumar et al., 2018).

These variations were primarily attributed to differences in clay, silt, and organic carbon and the low water holding capacity (WHC) typical of sandy soils due to their high sand concentration and low clay content. An uneven pattern emerged across different soil strata, with increased clay concentration at certain sites improving water-holding capacity. Similar findings were reported by Sharma et al. (2010). The percentage of pore space in the soil varied from 26.74% to 68.53%, while the percentage of solid space ranged from 31.47% to 73.26% (Table 3). Soils with high organic matter content exhibited increased porosity. However, the percentage of pore space decreased with increasing soil depth, a trend consistent with the study conducted by Choudhary et al. (2020).

3.2 Chemical parameters of Thar desert soil

3.2.1 Soil pH

The Thar Desert of Rajasthan soil is primarily neutral to alkaline, with a pH range of 7.69 to 8.43. This finding aligns with studies conducted in the Kanpur region (Saxena et al. 2021). Research shows that the pH of soil in most villages of the Kanpur Nagar district in India ranges from 7.03 to 9.75, indicating that the soil is neutral to alkaline in nature (Ladwani et al. 2012; Saxena et al. 2021). Soil pH is crucial for regulating the solubility and mobility of heavy metals. At acidic pH levels, heavy metals such as nickel, lead, and cadmium become more soluble and bioavailable to plants, as noted by Wang et al. (2018). However, the slightly alkaline pH found in the uncultivated soil of this study is not likely to significantly affect overall soil fertility since these pH values remain close to neutral (Dewangan et al. 2023). Generally, pH values tend to increase with soil depth (Rajshri et al. 2021). Low pH levels may result from a lack of organic matter or insufficient bacterial activity during nitrification processes in the soil, which produces acids (Ladwani et al. 2012).

3.2.2 Electrical Conductivity (ds m^{-1})

The surface soil samples' electrical conductivity (EC) in the study area ranged from 0.12 to 0.17 dS/m, below one (Table 4). These findings are consistent with those reported by Saxena et al. (2021), who observed similar EC values in most areas of the Kanpur Nagar district in India, ranging from 0.07 to 0.35 dS/m. This suggests that the soil contains safe soluble salts for crop production. Additionally, the decline in electrical conductivity (EC) may be due to the complex precipitation of salts and their subsequent plant uptake. This decrease in EC in cultivated soils agrees with the findings of Geetha et al. (2017). The low EC levels can likely be attributed to good drainage conditions, which facilitate the removal of released bases through percolation, as noted by Ladwani et al. (2012). In summary, the soil in the study area is suitable for crop cultivation due to its low soluble salt content, resulting from effective drainage.

3.2.3 Organic Carbon (%)

The study revealed significant soil organic carbon content variations across different fields and depths. Organic carbon percentages ranged from 0.82% to 1.21% (Table 4). Generally, arid soils in Rajasthan exhibit low organic carbon (OC) content, ranging from 0.01% to 0.84%, with a mean of 0.16%. Most of these soils are deficient in OC, primarily due to high temperatures, low rainfall, sparse vegetation, and sandy texture, which promote rapid oxidation, as reported by several researchers (Singh et al. 2007; Kumar et al. 2011, 2019). These findings align with those of Gautam et al. (2018), who reported organic carbon percentages of 0.10% to 0.59% in the red sandy soils of the Mirzapur district in India. A decline in organic carbon concentration with increasing soil depth was observed, consistent with previous research by

Table 4 Chemical properties of soil from various regions of Thar Desert, Rajasthan

S. No	Area	Chemical properties of soil at 0-10 cm depth			
		Soil pH	Soil EC (ds m^{-1})	Soil OC (%)	Soil OM (%)
1.	Sikar	8.34 ± 0.11	0.14 ± 0.009	0.82 ± 0.01	1.41 ± 0.03
2.	Jhunjhunu	8.43 ± 0.12	0.14 ± 0.009	0.94 ± 0.01	1.62 ± 0.01
3.	Churu	8.39 ± 0.15	0.14 ± 0.006	0.82 ± 0.01	1.41 ± 0.03
4.	Nagaur	7.98 ± 0.09	0.12 ± 0.003	1.04 ± 0.01	1.79 ± 0.01
5.	Bikaner	8.12 ± 0.12	0.15 ± 0.003	1.10 ± 0.01	1.90 ± 0.02
6.	Barmer	7.69 ± 0.10	0.17 ± 0.006	1.06 ± 0.01	1.83 ± 0.02
7.	Jodhpur	8.03 ± 0.06	0.12 ± 0.007	1.21 ± 0.01	2.09 ± 0.02
8.	Jaisalmer	8.33 ± 0.12	0.17 ± 0.006	1.15 ± 0.01	1.99 ± 0.02

Data are mean of replicates, ± Standard Error of mean

Bhatti et al. (2016). This trend is likely due to the higher application of farmyard manure (FYM) and plant residues on the soil surface compared to deeper layers. The study demonstrated that soil organic carbon content varies spatially and vertically, with higher levels typically found in surface soils.

3.2.4 Organic matter (%)

The study revealed significant soil organic matter content variation across different fields and depths. The percentages of organic matter ranged from 1.41% to 2.09% (Table 4). Low organic matter content in soil can be detrimental, as it decreases the soil's ability to absorb heavy metals. A decline in organic matter concentration was observed with increasing soil depth, consistent with previous research conducted by Bhatti et al. (2016).

3.2.5 Available Nitrogen (kg/ha)

The available nitrogen (N) content in soil samples from the Thar Desert ranged from 285.69 to 370.02 kg/ha (Table 5). These findings are consistent with previous research conducted by Bhavya et al. (2018). In contrast, the available nitrogen levels in Bengaluru, Karnataka, ranged from 101.62 to 122.85 kg/ha. The results indicate a significant decrease in enzyme activity in forest soils compared to desert soils. This difference may be attributed to excess nitrogen deposition and soil acidification in forest ecosystems, as Zhong et al. (2022) reported. The nitrogen levels indicate low availability in the soil, which decreases with increasing soil depth. Additionally, these values are below the recommended limits established by Jaiswal (2014), suggesting nitrogen deficiency in the soil. Like the Thar Desert, nitrogen content decreases with increasing soil depth.

3.2.6 Available Phosphorus (kg/ha)

Available phosphorus (P) levels in soil samples varied from 19.84 to 24.77 kg/ha across different fields and depths (Table 5). Similar findings were reported in a previous study, which indicated that available phosphorus in soils showed significant variability, ranging from 1.19 to 96.6 kg/ha, with a mean of 13.3 kg/ha. This suggests a low to medium phosphorus status. Notably, 48.7% of the area had low P levels, while 46.9% exhibited medium P content. The deficiency of phosphorus in arid soils can be attributed to their inherently low P status, low organic matter content, and the formation of calcium phosphate (Ca-P) in soils with high calcium carbonate ($CaCO_3$) concentrations (Kumar et al. 2021). The phosphorus levels observed fall within the suggested upper limit provided by Jaiswal (2014), indicating sufficient phosphorus for optimal crop growth. Higher phosphorus concentrations were recorded in the topsoil layers. These findings are consistent with the previous research conducted by Bhavya et al. (2018). Similarly, in Bengaluru, Karnataka, available phosphorus in the soil ranged from 24.51 to 26.56 kg/ha, decreasing with soil depth. These levels were classified as medium, suggesting suitable soil conditions for crop production. The variation in phosphorus content across different mound segments likely correlates with the clay content of the mound soil, as reported by Lopez Hernandez et al. (2006). As observed in the study area, phosphorus concentrations were highest in the surface layer and decreased with increased depth.

3.2.7 Available Potassium (kg/ha)

The available potassium (K) concentrations in soil samples ranged from 214.29 to 314.72 kg/ha (Table 5). These findings align with previous research by Khanday et al. (2018) and Abba et al. (2014), which reported available potassium levels between 290.03 and 397.45 kg/ha in the Ganderbal district of Kashmir Valley, India. Several factors likely contribute to the higher available potassium observed in the surface layers, including the intense weathering of potassium-bearing minerals, the release of readily available potassium from decomposing organic materials, the application of potassium fertilizers, and the upward movement of potassium from

Table 5 Available N, P, K, and S from soils of various regions of Thar desert, Rajasthan

S. No	Area	Soil macronutrients (at 0-10 cm depth)			
		Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Available S (ppm)
1.	Sikar	285.69 ± 3.07	19.87 ± 0.37	214.29 ± 1.35	16.12 ± 0.45
2.	Jhunjhunu	317.73 ± 1.37	22.52 ± 0.21	265.81 ± 2.61	17.21 ± 0.40
3.	Churu	292.51 ± 7.05	19.84 ± 0.33	226.24 ± 1.71	16.08 ± 0.30
4.	Nagaur	338.34 ± 3.66	23.74 ± 0.13	228.48 ± 2.33	16.62 ± 0.33
5.	Bikaner	348.04 ± 4.27	24.67 ± 0.10	284.11 ± 2.92	21.08 ± 0.25
6.	Barmer	347.58 ± 2.60	23.43 ± 0.16	238.19 ± 2.27	19.16 ± 0.33
7.	Jodhpur	370.02 ± 9.11	24.77 ± 0.12	314.72 ± 1.29	23.62 ± 0.29
8.	Jaisalmer	365.87 ± 8.12	24.73 ± 0.13	288.96 ± 2.96	22.50 ± 0.26

Data are mean of replicates, ± Standard Error of mean

lower depths through the capillary rise of groundwater. The study revealed that the available potassium status was adequate across the entire study area at various depths. Notably, potassium availability was highest in the topsoil and decreased rapidly with increasing depth (Bhavya et al. 2018).

3.2.8 Available Sulphur (ppm)

The available sulfur (S) levels in soil samples were sufficient, ranging from 16.08 to 23.62 ppm across various fields and depths (Table 5). These levels indicate an adequate supply of sulfur in the soil, which aligns with the findings of Kour and Jalali (2008) regarding sulfur availability in different agro-climatic zones of the Jammu Region, India. The high sulfur content observed in the surface horizons is likely due to increased organic matter. The highest concentration of available sulfur was found in the topsoil, with a gradual decrease noted as soil depth increased (Saxena et al. 2021).

3.3 Biological Parameters

3.3.1 Dehydrogenase activity

Soil dehydrogenase activity (DHA) was measured spectrophotometrically, ranging from 250.33 to 309.34 µg TPF/g/24h (Table 6). These results are consistent with previous research by Adak et al. (2014), which examined dehydrogenase activity in typical Ustocrepts soil under subtropical conditions in Lucknow, India. In contrast to their typically nutrient-limited state, desert soils with increased nitrogen (N) levels may have overcome these limitations. The potential abundance of nitrogen could support the survival and reproduction of a broader range of bacteria, thereby promoting greater bacterial diversity (Chen et al. 2024). Additionally, increased dehydrogenase activity and microbial biomass were associated with higher nutrient inputs. Furthermore, soil management practices influence soil dehydrogenase activity and strongly correlate with organic matter content (Kaur and Kaur 2021).

3.3.2 Phosphatase activity

Soil phosphatase activity was measured spectrophotometrically, with values ranging from 269.44 to 343.15 µg p-nitrophenol g^{-1} h^{-1} (Table 6). These results are consistent with those reported by Margalef et al. (2017) and align with global patterns of phosphatase activity observed in natural soils. It is important to note that various factors, such as soil type and climate across different biomes, influence phosphatase activity. A strong correlation between phosphatase activity and indicators like precipitation suggests that ecosystem productivity significantly affects phosphate cycling.

3.3.3 Nitrogenase activity

Nitrogenase activity was assessed by measuring the conversion of acetylene (C_2H_2) to ethylene (C_2H_4) using gas chromatography, with retention times ranging from 1.391 to 1.547 minutes (Table 6). These results are consistent with those reported by Wu et al. (2009) regarding nitrogenase activity in the biological soil crusts of the Gurbantunggut Desert in Northwestern China. Nitrogen fixation in all crusts is vital in maintaining soil fertility in sparsely vegetated areas and provides fixed nitrogen to nearby plants. These findings indicate that species composition should be considered when estimating nitrogen inputs in desert ecosystems.

Dehydrogenase activity (DHA) shows a strong positive correlation (r) with other parameters, and its regression r^2 value is 0.95 (Table 7). This indicates that DHA is a reliable indicator of other soil health parameters, making it an excellent measure for assessing healthy soils (Figure 2). It is well established that the excessive use of fertilizers in recent years has led to the degradation of many productive fields. Identifying and measuring soil qualities has

Table 6 Dehydrogenase, Phosphatase, and Nitrogenase activity from soils of various regions of Thar desert, Rajasthan

S. No	Areas	Biological properties of soil at 0-10 cm depth.		
		Dehydrogenase (Conc.) (µg TPF $g^{-1}24h^{-1}$)	Phosphatase (Conc.) (µg p-nitrophenol gh^{-1})	Nitrogenase (Conc.) (nmol C_2H_4 $m^{-2}h^{-1}$)
1.	Sikar	250.33 ± 2.84	268.02 ± 0.82	1.391 ± 0.04
2.	Jhunjhunu	270.00 ± 1.42	293.54 ± 0.96	1.425± 0.03
3.	Churu	260.16 ± 1.42	277.84 ± 0.84	1.403± 0.04
4.	Nagaur	278.20 ± 0.82	300.19 ± 0.57	1.449± 0.03
5.	Bikaner	291.31 ± 2.17	329.36 ± 0.27	1.515± 0.03
6.	Barmer	288.03 ± 0.82	313.83 ± 0.57	1.516± 0.02
7.	Jodhpur	309.34 ± 1.42	342.36 ± 0.57	1.547± 0.03
8.	Jaisalmer	301.97 ± 1.42	333.80 ± 0.42	1.513± 0.02

Data are mean of replicates, ± Standard Error of mean

Table 7 Matrix of linear correlation (r) between enzymes with chemical parameters of Thar desert, Rajasthan

S. No	Parameters	Dehydrogenase	Phosphatase
1.	pH	0.455	0.418
2.	EC	0.155	0.178
3.	Organic Carbon	0.982^{**}	0.976^{**}
4.	Organic Matter	0.983^{**}	0.977^{**}
5.	Available Nitrogen	0.983^{**}	0.970^{**}
6.	Available Phosphorus	0.926^{**}	0.937^{**}
7.	Available Potassium	0.853^{**}	0.881^{**}
8.	Available Sulfur	0.936^{**}	0.951^{**}

$p < 0.05$; $^{**}p < 0.01$; EC – Electrical conductivity

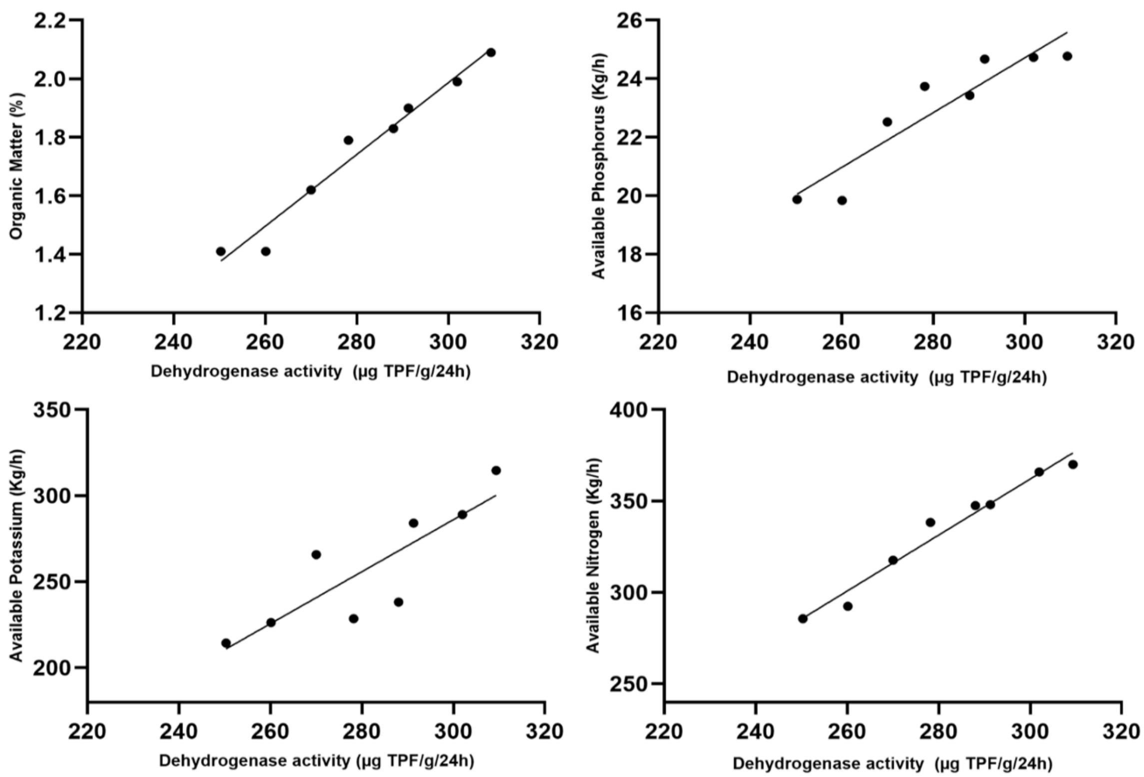

Figure 2 Linear regression equation between dehydrogenase activity and organic matter, available (N, P, K)

become increasingly important to prevent further deterioration. Robust soil health data is essential for providing farmers with reliable recommendations to restore soil fertility.

To maintain ecosystem sustainability and stability, it is crucial to implement appropriate actions, including rigorous soil health monitoring, particularly in degraded agricultural lands. Dehydrogenase as an indicator can help us understand the soil ecosystem and its ability to support cultivation, which will, in turn, enhance the agricultural economy.

Soil dehydrogenase activity is a critical aspect of overall soil enzymatic activity and serves as a sensitive indicator of various environmental factors, both biotic and abiotic. It reflects the health of soil microorganisms, and any deviations from normal activity may indicate ecosystem disturbances or the presence of toxic substances. By assessing dehydrogenase activity, we gain valuable insights into soil health. Healthy soils with high dehydrogenase activity are often associated with elevated levels of other enzymes, such as phosphatase and nitrogenase, as well as readily available nutrients, including nitrogen, phosphorus, potassium, and sulfur.

This information can guide sustainable agricultural practices and improve crop yields. A deeper understanding of the role of this enzyme can further enhance its use as a diagnostic tool for soil health management.

The Thar Desert, also known as the Great Indian Desert, is a vast arid region in the northwestern part of the Indian subcontinent. Although the soil fertility in the Thar Desert is generally considered medium, there can be significant variations across different areas. The activity of the dehydrogenase enzyme serves as a valuable indicator of soil health and fertility. By measuring this enzyme's activity, scientists and farmers can gain important insights into the overall microbial health of the soil. However, it is essential to recognize that the effectiveness of dehydrogenase activity as a soil health indicator may vary based on specific soil and environmental conditions.

Conclusions

This study concluded that soil fertility, nutrient concentrations, and enzymatic activities, specifically dehydrogenase, are important indicators of soil health. Soil microbial biomass significantly influences various soil enzymes, including phosphatase, nitrogenase, and dehydrogenase, along with organic carbon and the availability of nutrients such as nitrogen (N), phosphorus (P), potassium (K), and sulfur. Analysis of soil parameters in selected areas of the Thar Desert, particularly Jodhpur and Jaisalmer, revealed favourable conditions for crop growth. The soil in these regions exhibited a texture ranging from sandy loam to loamy sand, a neutral to alkaline pH, and normal electrical conductivity. While sufficient sulfur was present in the topsoil, organic carbon, organic matter, and nitrogen levels were moderate. Additionally, potassium and phosphorus levels were in the medium range. A decrease in bulk density was inversely correlated with organic matter content. The correlation of dehydrogenase with various soil fertility parameters was positive, indicating that dehydrogenase activity strongly indicates biological activity and soil fertility. Combining organic inputs, such as farmyard manure, with inorganic nutrient sources is recommended to maintain soil fertility. Given its favourable fertility status and productivity, the soil in the Thar Desert is suitable for cultivating various crops, including legumes, cotton, maize, mustard, and wheat. Furthermore, dehydrogenase activity can be a reliable indicator for assessing soil health. Monitoring this activity provides valuable insights into soil quality, allows for evaluating the impact of different management practices, and aids farmers and researchers in making informed decisions to promote sustainable agricultural practices.

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Conflict of interest

The authors declare no conflict of interest.

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