Physico-chemical Analysis of Soil Samples of Bhadra, District Hanumangarh, Rajasthan (India)

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Abstract: Soil quality is a critical factor influencing agricultural productivity, environmental sustainability, and ecosystem functioning. The present study was conducted to evaluate the physicochemical characteristics and nutrient status of soils from ten villages of the Bhadra block, Hanumangarh district, Rajasthan, namely Gogameri, Ramsara, Mundaria Bara, Kirada Bara, Bhadra, Sahuwala, Ajeetpura, Jogiwala, Gheu, and Kalana. Soil samples were collected during winter, summer, and rainy seasons over two consecutive years (2023 and 2024) to assess seasonal and inter-annual variations in soil properties. Parameters analysed included pH, water holding capacity (WHC), electrical conductivity (EC), sodium, potassium, calcium, and phosphorus. The study demonstrates that soils of the Bhadra block possess generally stable fertility conditions with moderate seasonal fluctuations in physicochemical parameters.

Keywords: Soil, Physicochemical, Bhadra, Water holding capacity, Electrical conductivity, Soil nutrients, Seasonal variation.

Introduction: -

Soil is a fundamental natural resource that sustains terrestrial ecosystems and serves as the foundation for agricultural production (Gama, 2023; Kabato et al., 2025). The physical and chemical characteristics of soil influence plant growth, nutrient cycling, water retention, and overall land productivity (Umair et al., 2025; Qin et al., 2026). Assessment of soil properties provides valuable information regarding soil fertility, environmental quality, and the suitability of land for agricultural and ecological purposes. In arid and semi-arid regions, where climatic conditions and limited water availability significantly affect soil development, periodic evaluation of soil quality becomes essential for sustainable land management (Maghchiche, 2021; Chen et al., 2023; Ghonimy et al., 2026). Rajasthan, being one of the largest states of India, is characterized by diverse soil types and varying agro-climatic conditions. Hanumangarh district, located in the north-western part of the state, is an important agricultural region where soil fertility plays a crucial role in crop production and rural livelihoods (Kumar and Chander, 2018). The Bhadra region of Hanumangarh district experiences unique environmental and agricultural conditions that influence the physicochemical composition of its soils. Understanding these soil characteristics is necessary for evaluating nutrient status, identifying soil constraints, and recommending suitable management practices. Therefore, this study looked at important characteristics such as pH, electrical conductivity, moisture and the presence of nutrients like phosphorus, calcium, sodium and potassium, as well as common salts.

Material and Methods: -

Study Area:

The current research was performed in the Bhadra block of Hanumangarh district, Rajasthan, situated between 74°51′46.8″ and 75°29′16.8″ East longitude and 28°49′40.8″ and 29°14′49.2″ North latitude.

Fig 1: Map of Study Area

Soil Sample Collection:

Soil samples were collected from 10 different locations/villages of the Bhadra block and analyzed for different parameters. The ten sampling sites selected for the present study represent a diverse geographical spread within the Bhadra block of Hanumangarh district, Rajasthan, encompassing both central and peripheral locations. These sites—Gogameri, Ramsara, Mundaria Bara, Kirada Bara, Bhadra, Sahuwala, Ajeetpura, Jogiwala, Gheu and

Kalana—were strategically chosen to capture variations in soil properties and nutrient status under differing agro-ecological conditions, land-use patterns and degrees of anthropogenic influence.

Soil Analysis:

Following methods were used for soil analysis:

1. **Soil pH** – Measured using an electrical pH meter.
2. **Water Holding Capacity** – Assessed by the Keen box method (Piper, 1950).
3. **Electrical Conductivity** – Determined using a conductivity meter.
4. **Sodium and Potassium** – Estimated with the help of a Flame Photometer.
5. **Calcium and Phosphorus** – Calcium content measured following the Purohit and Mathur (1970), while phosphorus was estimated using Whatman's filter paper No. 42.

Result: -

Soil pH:

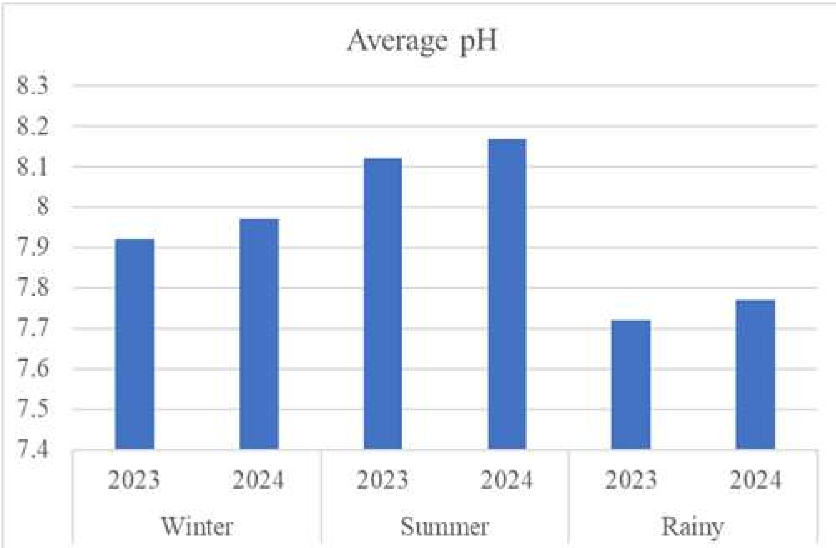
The pH values of the soil samples from Bhadra block ranged from 7.20 to 8.85, indicating neutral to moderately alkaline soils. This alkalinity is characteristic of the arid climate, low rainfall, and high evapotranspiration of the region, which favor the accumulation of basic cations in the soil. Seasonal variation followed the trend Summer > Winter > Rainy, with the highest average pH recorded in summer (8.12–8.17) and the lowest during the rainy season (7.72–7.77). Higher summer pH values may be attributed to salt concentration through evaporation, whereas rainfall-induced leaching slightly reduced soil alkalinity during the monsoon. Spatial variation was also observed, with Site 2 showing the highest pH values (up to 8.85) and Site 9 the lowest (7.20), likely due to differences in soil properties, drainage conditions, irrigation practices, and salt accumulation.

Table 1: pH level in soil samples of Bhadra block

Sample site	Winter		Summer		Rainy	
	2023	2024	2023	2024	2023	2024
Site 1	8.20	8.25	8.40	8.45	8.00	8.05
Site 2	8.62	8.65	8.82	8.85	8.42	8.48
Site 3	8.00	8.05	8.20	8.25	7.80	7.85
Site 4	7.80	7.85	8.00	8.05	7.60	7.65
Site 5	7.70	7.75	7.90	7.95	7.50	7.55

Site 6	8.10	8.15	8.30	8.35	7.90	7.95
Site 7	7.60	7.65	7.80	7.85	7.40	7.45
Site 8	8.20	8.25	8.40	8.45	8.00	8.05
Site 9	7.40	7.45	7.60	7.65	7.20	7.25
Site 10	7.60	7.65	7.80	7.85	7.40	7.45
Average	**7.92**	**7.97**	**8.12**	**8.17**	**7.72**	**7.77**

Fig 2: pH level in soil samples of Bhadra block



Water holding capacity:

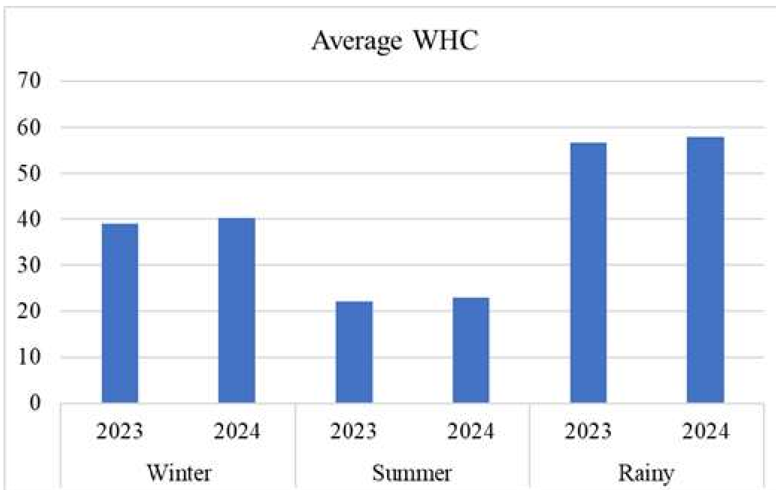
WHC of soils in the Bhadra block showed clear seasonal variation, being highest during the rainy season, moderate in winter, and lowest in summer. Average WHC values increased from 56.6% (2023) to 57.9% (2024) during the rainy season, from 39.06% to 40.18% in winter, and from 22.16% to 23.05% in summer. Higher WHC during the rainy season was associated with increased soil moisture availability, while lower summer values reflected high evaporation and dry conditions. Site 1 consistently recorded the highest WHC, whereas Sites 2, 4, and 6 showed comparatively lower values. The slight increase in WHC from 2023 to 2024 suggests improved soil moisture retention.

Table 2: Water holding capacity in soil samples of Bhadra block

Sample site	Winter		Summer		Rainy	
	2023	**2024**	**2023**	**2024**	**2023**	**2024**
Site 1	43.8	45.0	25.0	26.0	62.5	64.0

Site 2	36.0	37.2	20.6	21.5	51.4	53.0
Site 3	39.1	40.0	22.3	23.2	55.8	57.0
Site 4	36.0	37.0	20.6	21.4	51.4	52.6
Site 5	39.6	40.5	22.6	23.4	56.6	57.8
Site 6	36.1	37.0	20.6	21.4	51.5	52.6
Site 7	42.9	44.0	24.6	25.3	61.4	62.5
Site 8	43.3	44.5	24.7	25.5	61.8	63.0
Site 9	36.7	37.6	21.0	21.8	52.4	53.5
Site 10	43.1	44.0	24.6	25.4	61.6	62.8
Average	**39.06**	**40.18**	**22.16**	**23.05**	**56.6**	**57.9**

Fig 3: Water holding capacity in soil samples of Bhadra block



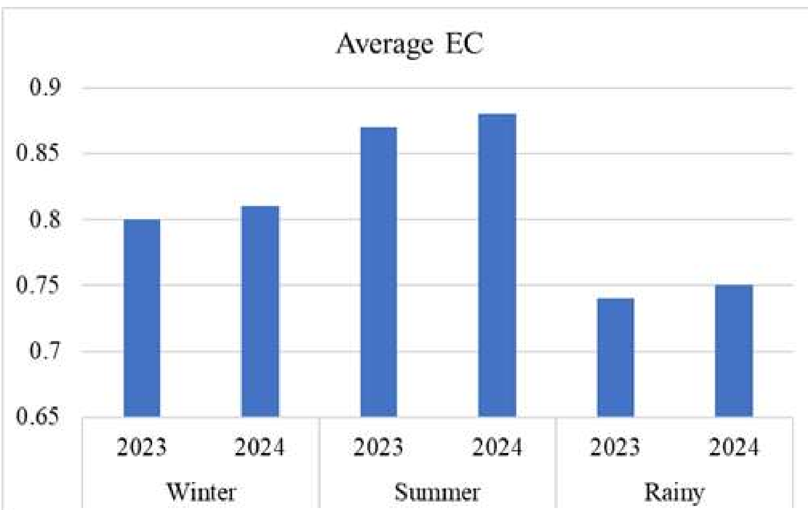
Electrical Conductivity:

The analysis of Electrical Conductivity (EC) in soil samples of the Bhadra block during 2023 and 2024 showed a clear seasonal trend, with the highest values recorded in summer, followed by winter, and the lowest during the rainy season. Average EC values were 0.80, 0.87, and 0.74 dS/m in winter, summer, and rainy seasons, respectively, in 2023, with a slight increase observed in 2024. Higher summer EC values can be attributed to evaporation-induced salt concentration, whereas lower rainy-season values resulted from salt leaching due to precipitation. Winter values remained intermediate. The findings indicate seasonal influences on soil salinity, with certain sites showing consistently higher EC levels, suggesting localized effects of irrigation, drainage, and soil characteristics that may require site-specific management.

Table 3: EC (ds/m) level in soil samples of Bhadra block

Sample site	Winter		Summer		Rainy	
	2023	2024	2023	2024	2023	2024
Site 1	0.82	0.84	0.89	0.91	0.76	0.78
Site 2	0.87	0.89	0.94	0.96	0.81	0.83
Site 3	0.82	0.84	0.89	0.90	0.76	0.77
Site 4	0.84	0.85	0.91	0.92	0.78	0.79
Site 5	0.71	0.72	0.78	0.79	0.65	0.66
Site 6	0.89	0.91	0.96	0.98	0.83	0.85
Site 7	0.77	0.78	0.84	0.85	0.71	0.72
Site 8	0.72	0.73	0.79	0.80	0.66	0.67
Site 9	0.74	0.75	0.81	0.82	0.68	0.69
Site 10	0.81	0.83	0.88	0.89	0.75	0.76
Average	**0.80**	**0.81**	**0.87**	**0.88**	**0.74**	**0.75**

Fig 4: EC (ds/m) level in soil samples of Bhadra block



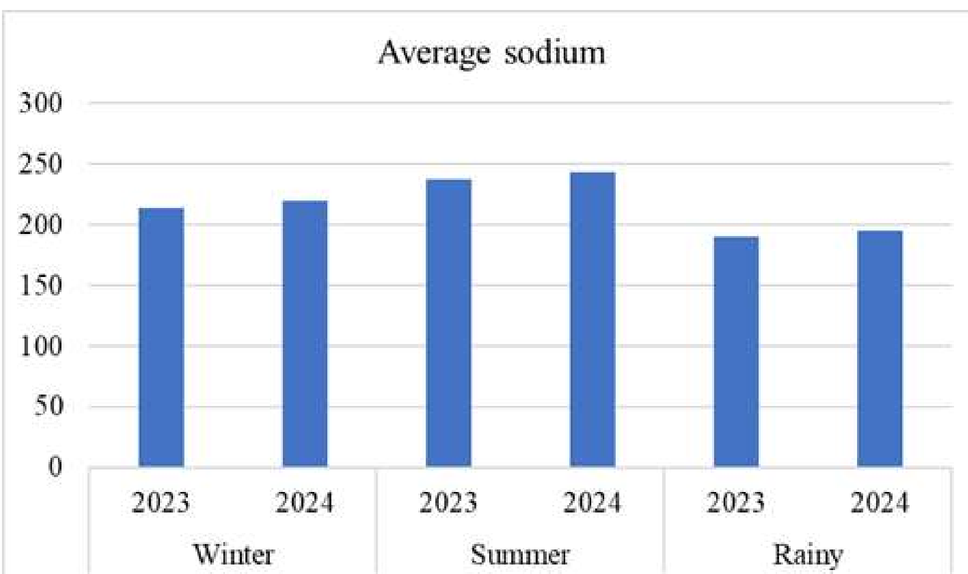
Sodium:

The sodium content of soils in the Bhadra block showed a clear seasonal pattern, following the trend summer > winter > rainy season during both years of study. The highest values were recorded in summer (237.78–243.61 mg/kg), likely due to high evaporation and limited leaching, while the lowest concentrations occurred during the rainy season (190.02–194.87 mg/kg) because of monsoonal leaching of soluble salts. Winter values were intermediate (214.33–219.89 mg/kg). Spatial variation was also observed, with Site 7 consistently recording the highest sodium levels and Site 4 the lowest. A slight increase in sodium content from 2023 to 2024 suggests gradual salt accumulation, possibly due to saline groundwater irrigation and poor drainage. Continuous sodium build-up may adversely affect soil structure, permeability, and plant growth in the region.

Table 4: Sodium (mg/kg) level in soil samples of Bhadra block

Sample site	Winter		Summer		Rainy	
	2023	**2024**	**2023**	**2024**	**2023**	**2024**
Site 1	211.63	215.86	235.14	240.84	188.11	192.67
Site 2	203.40	207.35	226.00	231.13	180.80	184.90
Site 3	225.37	230.88	250.41	256.67	200.33	205.34
Site 4	195.00	199.88	216.67	221.33	173.34	177.50
Site 5	202.50	207.06	225.00	229.50	180.00	183.60
Site 6	200.54	205.05	222.82	228.17	178.26	182.54
Site 7	233.27	238.89	259.19	265.02	207.35	212.02
Site 8	225.25	230.80	250.28	256.54	200.22	205.31
Site 9	226.22	231.88	251.35	257.63	201.08	206.10
Site 10	216.79	222.21	240.88	247.11	192.70	197.69
Average	**214.33**	**219.89**	**237.78**	**243.61**	**190.02**	**194.87**

Fig 5: Sodium (mg/kg) level in soil samples of Bhadra block



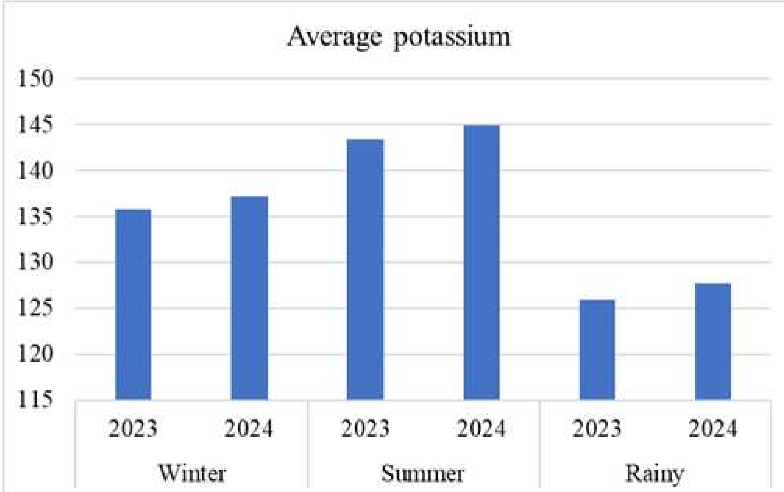
Potassium:

The potassium content in the soils of Bhadra block exhibited distinct seasonal variations across both study years (2023 and 2024), reflecting the influence of climatic conditions, soil processes and possible agricultural practices on nutrient dynamics. In general, the highest potassium levels were recorded during the summer season, followed by winter, while the lowest values occurred during the rainy season. This trend was consistent across all sample sites in both years. For example, in 2023, potassium ranged from 134.87 mg/kg (Site 1 and Site 9) to 152.82 mg/kg (Site 2) in summer, compared to 128.00 mg/kg (Sites 1 and 9) to 145.00 mg/kg (Site 2) in winter and only 118.50 mg/kg (Sites 1 and 9) to 134.50 mg/kg (Site 2) during the rainy season. A similar pattern was observed in 2024, with values slightly higher than the previous year, indicating minor year-to-year variation likely due to changes in weather patterns or nutrient management practices. The elevated potassium levels in summer can be attributed to evaporative concentration of soluble salts under high temperatures and low soil moisture, which restricts leaching losses. In contrast, the rainy season showed a marked reduction in potassium content due to intensive leaching and runoff, especially in the sandy and aeolian soils common in Bhadra, which have low cation exchange capacity. Winter values were intermediate, benefiting from residual moisture and reduced leaching compared to the monsoon period, but without the high concentration effect of summer.

Table 5: Potassium (mg/Kg) level in soil samples of Bhadra block

Sample site	Winter		Summer		Rainy	
	2023	2024	2023	2024	2023	2024
Site 1	128.00	129.50	134.87	136.50	118.50	120.00
Site 2	145.00	146.80	152.82	154.60	134.50	136.00
Site 3	138.00	139.50	145.64	147.10	128.50	130.00
Site 4	132.00	133.40	140.00	141.50	123.00	124.50
Site 5	137.00	138.40	145.13	146.60	127.50	129.00
Site 6	139.00	140.50	147.69	149.20	129.50	131.00
Site 7	132.50	134.00	140.51	142.00	123.50	125.00
Site 8	136.00	137.50	144.10	145.60	126.50	128.00
Site 9	128.00	129.50	134.87	136.40	118.50	120.00
Site 10	140.00	141.50	148.21	149.80	130.50	132.00
Average	**135.75**	**137.16**	**143.38**	**144.93**	**126.00**	**127.65**

Fig 6: Potassium (mg/Kg) level in soil samples of Bhadra block



Calcium:

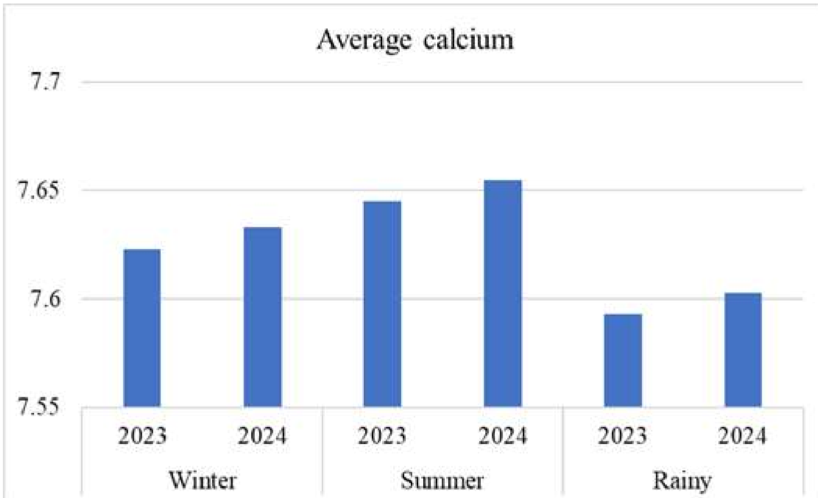
The calcium content of soils in the Bhadra block showed only minor seasonal variation and remained relatively stable across both years. Calcium levels were highest during summer (7.645–7.655 mg/kg), followed by winter (7.623–7.633 mg/kg), and lowest during the rainy season (7.593–7.603 mg/kg). Higher summer values may be attributed to evaporation-induced concentration, whereas slightly lower rainy-season values likely resulted from leaching. The narrow range of variation and minimal differences among sites indicate a largely uniform calcium distribution, suggesting that seasonal factors exert a greater influence than site-specific characteristics. The consistently moderate calcium content provides a favourable nutrient environment for plant growth and may contribute to the mineral composition of ethnobotanically important plant species in the region.

Table 6: Calcium (mg/kg) level in soil samples of Bhadra block

Sample site	Winter		Summer		Rainy	
	2023	2024	2023	2024	2023	2024
Site 1	7.63	7.64	7.65	7.66	7.60	7.61
Site 2	7.61	7.62	7.63	7.64	7.58	7.59
Site 3	7.64	7.65	7.66	7.67	7.61	7.62
Site 4	7.66	7.67	7.68	7.69	7.63	7.64
Site 5	7.66	7.67	7.68	7.69	7.63	7.64
Site 6	7.67	7.68	7.69	7.70	7.64	7.65
Site 7	7.58	7.59	7.60	7.61	7.55	7.56

Site 8	7.56	7.57	7.58	7.59	7.53	7.54
Site 9	7.55	7.56	7.57	7.58	7.52	7.53
Site 10	7.57	7.58	7.59	7.60	7.54	7.55
Average	**7.623**	**7.633**	**7.645**	**7.655**	**7.593**	**7.603**

Fig 7: Calcium (mg/kg) level in soil samples of Bhadra block



Phosphorus:

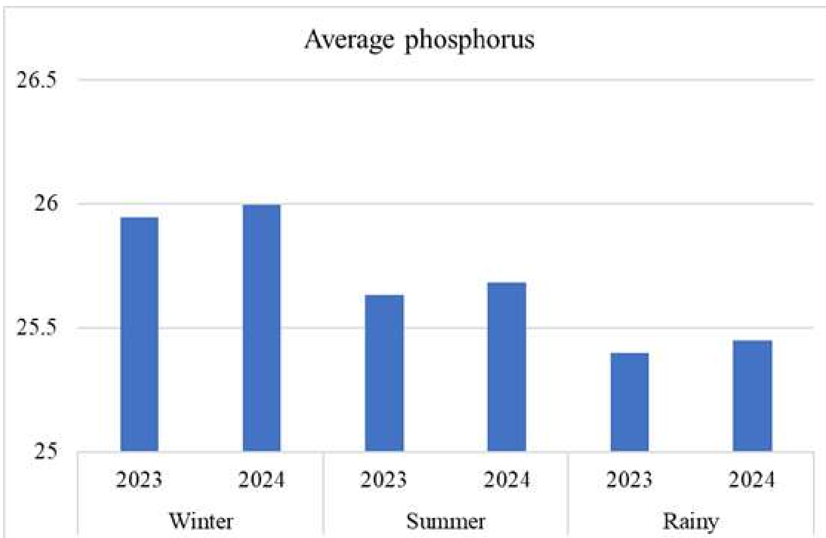
The analysis of phosphorus levels in the soil samples of Bhadra block revealed clear seasonal variations. The highest phosphorus concentrations were recorded during winter, followed by summer, while the lowest values occurred in the rainy season. Average phosphorus content ranged from 25.947 mg/kg (winter 2023) to 25.997 mg/kg (winter 2024), whereas rainy season values were comparatively lower at 25.398 mg/kg and 25.448 mg/kg, respectively. The reduction during the rainy season may be attributed to leaching, runoff, and reduced phosphorus availability under high soil moisture conditions. A slight increase in phosphorus content from 2023 to 2024 indicates stable soil fertility and nutrient status. Overall, the trend of Winter > Summer > Rainy highlights the influence of seasonal climatic conditions and soil moisture on phosphorus availability in the soils of Bhadra block.

Table 7: Phosphorus (mg/kg) level in soil samples of Bhadra block

Sample site	**Winter**		**Summer**		**Rainy**	
	2023	**2024**	**2023**	**2024**	**2023**	**2024**
Site 1	25.97	26.02	25.65	25.70	25.42	25.47
Site 2	25.94	25.99	25.63	25.68	25.39	25.44

Site 3	25.95	26.00	25.64	25.69	25.40	25.45
Site 4	25.94	25.99	25.63	25.68	25.39	25.44
Site 5	25.98	26.03	25.66	25.71	25.43	25.48
Site 6	25.99	26.04	25.67	25.72	25.44	25.49
Site 7	25.91	25.96	25.60	25.65	25.36	25.41
Site 8	25.90	25.95	25.59	25.64	25.35	25.40
Site 9	25.96	26.01	25.65	25.70	25.42	25.47
Site 10	25.93	25.98	25.62	25.67	25.38	25.43
Average	**25.947**	**25.997**	**25.634**	**25.684**	**25.398**	**25.448**

Fig 8: Phosphorus (mg/kg) level in soil samples of Bhadra block



The present study conducted in Bhadra block of Hanumangarh district revealed that the soils were slightly alkaline in nature (pH 7.72–8.17) and non-saline, with EC values consistently below 1 dS/m. Seasonal variations were prominent in water holding capacity, sodium, and potassium levels, whereas calcium and phosphorus remained relatively stable. These findings differ from those of Bhati (2017), who reported higher pH and EC values and widespread salinity problems in parts of Hanumangarh and Sri Ganganagar due to waterlogging and saline irrigation water. Similarly, Singh et al. (2016) documented saline soils in Hanumangarh (pH 8.2; EC 5.41 dS/m), requiring soil amendments for fertility improvement. The lower EC values observed in the present study suggest comparatively better soil conditions in the sampled areas of Bhadra block.

The nutrient status of the soils showed stable phosphorus concentrations (25.39–25.99

mg/kg) and moderate potassium levels (126–145 mg/kg), which broadly agree with the observations of Bhati (2017), who reported low to medium phosphorus and medium to high potassium availability in the region. However, the phosphorus levels recorded in the present study were comparatively higher, possibly reflecting improved nutrient management or less degraded soil conditions. Raina et al. (2009) reported substantial nutrient depletion due to erosion, waterlogging, and salinity in Hanumangarh district, whereas the relative stability of phosphorus and potassium in the present investigation indicates lower degradation pressure.

The study also highlighted distinct seasonal dynamics in soil properties. Water holding capacity increased during the rainy season, while EC, sodium, and potassium were higher during summer, likely due to evapotranspiration and salt concentration effects. Such seasonal variations were not emphasized in earlier studies by Bhati (2017) and Raina et al. (2009). Overall, the findings support previous observations regarding the alkaline nature and moderate fertility of soils in the region while providing additional insights into their seasonal variability and nutrient dynamics in the Bhadra block of Hanumangarh district.

Conclusion: -

The present study revealed that the soils of the Bhadra block, Hanumangarh district, are generally slightly alkaline and possess moderate fertility status. Significant seasonal variations were observed in water holding capacity, electrical conductivity, sodium, and potassium content, whereas calcium and phosphorus remained relatively stable throughout the study period. The rainy season was characterized by higher moisture retention and lower salt concentration, while summer conditions promoted increased salinity and nutrient concentration due to evaporation. Inter-annual variations between 2023 and 2024 were minimal, indicating overall stability of soil characteristics. The findings provide valuable baseline information on soil quality and nutrient dynamics in the region and may assist in developing appropriate soil management and fertilization practices for sustainable agricultural productivity in the Bhadra block.

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