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Correlation between physico-chemical attributes of Rhizospheric soils from agricultural fields of semi-arid Kachchh, Gujarat, Western India

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Abstract

Agriculture worldwide relies significantly on the quality of soil and water. This becomes particularly challenging in arid regions, given that salinity or sodicity poses additional issues. PGPR are common inhabitants that colonize plant roots and enhance yield by producing plant growth regulators. With this background, the present study was designed to assess the physico-chemical and microbiological attributes of soils from agricultural fields of different taluka of Kachchh, Gujarat, India. A total of 34 soil samples were collected during pre and post-monsoon seasons and characterized for various physico-chemical properties including nutrients. The study revealed that the mean values of N, P, and K during pre and post-monsoon season were 4.95%, 47.16 mg/kg, 119.62 mg/kg and 5.20%, 53.67 mg/kg, and 180.45 mg/kg respectively. The maximum chloride concentration in the soil was 2917.40 mg/kg during the pre-monsoon season was reflected in the salinity status (5.27 ppt). Pearson's correlation coefficient was calculated to understand the relationship between the physico-chemical properties.

Keywords: Aridity; Sodicity; Agriculture; Plant growth promotion; Bioinoculant; Pearson's co-efficient.

1. Introduction

Increasing in salinity and sodicity is an abiotic threat to agricultural lands and is now becoming one of the serious environmental problems that cause a risk to the food security of growing populations worldwide [1]. Among this, Salinity is mainly of two types, primary salinity and secondary salinity. Primary salinity is a natural occurrence found in salt lakes, salt marshes, tidal swamps, or natural salt scalds and is also known as inherent salinity. In contrast, secondary salinity is a result of human activities, such as excessive irrigation with saline water [2]. More than 800 million Ha of land (6%) all over the world is affected by salt which reduces crop production [3]. The main effects of salinity are due to the excessive accumulation of Na+ with deterioration of the hydraulic and structural properties of soil. In addition, high levels of Na+ in soil lead to an increase the soil pH and soil erosion. Furthermore, Na+ plays a key role in the destruction of other clay minerals by dispersion, and the process of dispersion occurs through the replacement of Ca^{2+} and Mg^{2+} in the inner layer of soil coagulates by interfering with Na^{+} [4]. Due to extreme climate change (low rainfall and higher temperatures), agricultural lands get converted to saline land sooner. This is still faster in arid regions favoring extra salt accumulation [1]. Moreover, the alkaline soil interrupts the physical, chemical, and biological properties of soil by decreasing the soil permeability and varying microbial diversity which leads to a decline in the yield and productivity of crops [5]. Furthermore, salt stress hinders plant growth by disturbing the metabolic, physiological, and biological processes [6]. Deterioration of the Physicochemical properties of the soil lead to soil fertility and soil productivity loss and improvement and adaptation in conventional agronomic practices are very much necessary for such soils [7].

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Considering the above scenario on soil conditions and microbial perspectives of arid regions like Kachchh, Gujarat, the present study was probed to characterize the soils of different agricultural fields for physical, chemical, and biological properties and their PGPR traits.

2. Material and Methods

2.1. Sampling site

A total of 34 soil samples were collected with the help of an auger from the rhizosphere region of the plants up to the depth of 12-15 cm from agricultural lands of different talukas in Kachchh district, Gujarat, India during pre-monsoon and post-monsoon seasons. The Rhizospheric soil sample was carefully collected and obtained by shaking method and subsequent brushing of remaining root system soil and was transferred in sterile polythene bags and labeled properly, and stored at 4^{0}C using ice bags [8].

2.2. Description of the Study Area

The largest district of India, Kachchh, is a unique ecological land of Western India that falls in the arid tract with harsh climatic conditions and a semi-arid climate not suitable for agricultural practices and abiotic stresses like erratic rainfall, salinity, seismic instability, and frequent droughts [2]. Owing to its unique ecological and geomorphological location, Kachchh is classified as a biogeographic zone "3A" experiencing tropical arid climate [9]. Kachchh is named because of its topography which is similar to a tortoise, (*kachbo* in Gujarati) with the Central portion (near Bhuj) elevated, and the land lightly sloping downwards in all four directions. Due to this sharp slope, all the rivers and streams of Kachchh are non-perennial and have a high run-off rate. Hence agriculture in this area is extremely dependent on rain with some exceptions in the usage of borewell water for irrigation in some pockets. Drought and high salinity are typical characteristics of this semi-arid region.

Geologically, the saline flats *i.e.,* Great Rann and Little Rann centuries ago were under the Arabian Sea and are made up of fluvio-marine sediments of Banas, Indus, Luni, and other rivers [2]. Kachchh experiences extremes of weather condition. The winter season lasts usually from the middle of November to the end of February with January being the coldest month having an average minimum temperature of 4.6°C and a maximum temperature ranging between 39 - 45°C. The monsoon commences with the onset of the Southwest monsoon and continues between July and September. The district is characterized by scanty rainfall with a mean annual rainfall of 353 mm and about 60% area of Kachchh contains saline water.

Various researches highlight the effect of salinity coupled with water shortage. Salinity ingression has spread for about 1125 km long Kachchh-Saurashtra coastal belt engulfing 779 villages with a population of 13.3 lakh making the life of the people miserable [2]. In Gujarat saline impacted lands are 1680570 Ha and Sodic affected area is 541430 ha [10]. Kachchh is a major producer of salt in India and its production is also significant globally. According to agro-climatic zonation, the major crops fit for Kachchh are rice, wheat, gram, pearl millets, maize, pigeon pea, groundnut, sorghum, castor, cotton, sesame, rapeseed, barley, and mustard.

2.3. Sample Collection and sample handling

Soil samples were collected from the rhizosphere region of the crop up to the depth of 12-15 cm from agricultural land which is near the sea from the selected location of all ten talukas of Kachchh district (Figure 1). A total of 34 samples were collected in pre-monsoon and post-monsoon seasons from different agricultural fields of Kachchh, Gujarat (Table 1). Geographical information of all the sampling locations was recorded using GPS. In two sets samples were collected one set in poly-ethylene bags for physicochemical analysis and the other in a sterilized plastic container for microbial analysis then these samples were stored at 4°C for microbiological analysis and physicochemical samples were air dried in shade and sieved through a 2 mm sieve for physicochemical characteristics.

2.4. Physico-chemical characteristics

A total of fifteen Physicochemical characteristics were studied by standard methods [11,12]. The bulk density of the soil was determined by measuring after drying the sample at 105°C until a constant weight was attained transferring the sample of known volume to a measuring cylinder and noting the volume. Final results are calculated based on recording the weight. The water-holding capacity of the soil was also determined [11]. Soil pH and Electrical Conductivity of the samples were measured by preparing the 1:2 soil water suspensions (w/v) and the measurement was taken using a microprocessor-based Digital pH meter (Systronics make) which was pre-calibrated using Certified Reference Material.

The Soil Organic Carbon (SOC) was determined by using the Titrimetric method [13]. The method is also known as the "Wet-digestion method" and involves a rapid titration procedure for the determination of organic carbon in soil. The available Nitrogen also known as Mineralizable Nitrogen in the soil was determined using the Alkaline Permanganate method using (Pelican Kjeloplus Kjelodist SPS VA) instrument [14]. In major nutrients, phosphorus was performed by Olsen's method for alkaline soil [15]. The exchangeable potassium was determined using a standard neutral ammonium acetate ($CH3COONH4$) extract from the soil. Sodium and Calcium levels were also assessed using the same method with appropriate filters [16].

The sulphur concentration in the soil samples was estimated turbidimetrically using Shimadzu 1900 UV-Vis spectrophotometer at 340 nm [12]. The exchangeable magnesium concentration in the samples was determined using the water extracts of soil by titration with EDTA (Ethylene Diamine Tetra Acetic acid) [12]. The chloride concentration in the samples was estimated using Mohr's titration/Argentometric titration method [12] and the salinity values were calculated based on the chloride concentration as per the 23rd edition of [17]. The sodicity parameter of the soil is an index value for evaluating the sodium hazard associated with the irrigation water and it was calculated by Sodium Absorption Ratio (SAR), which is determined from the relative concentrations of Sodium, Magnesium, and Calcium from cation concentrations in a saturated paste extract [18].

2.5. Data Analysis

The Correlation analysis of the data done for Physico-chemical characteristics was performed using SPSS Software 16 and Pearson's coefficient was calculated.

3. Results and Discussion

The reason behind this study is to investigate the variations of soil characteristics during both seasons to compare the change in soil quality due to changes in precipitation in the semi-arid district of Gujarat. The descriptive statistics values are mentioned in Table 2 and the suggested range of the properties are consolidated in Table 3.

In Bulk density, the values were on the higher side (1.41±0.12 gm/cm^3) during pre-monsoon and were slightly decreased during post-monsoon (1.35±0.11 gm/cm^3), and in general, the bulk density values are found to be higher than soils of other regions which might be due to the sandy texture of the soil. As expected, the water holding capacity of the soil samples was higher during post-monsoon than the pre-monsoon season which was 46% which could be due to the higher evaporation rate which has caused a decrease in WHC values during pre-monsoon. In pH, the mean values during pre-monsoon was 8.79±0.81, and during post-monsoon was 8.94±0.65 with a slight increase in pH value obtained during post-monsoon season. Similar elevated values of pH between 6.6- 9.8 have been reported in the soils of Kachchh, Gujarat [19]. The electrical conductivity of the samples was higher in the pre-monsoon season compared to the post-monsoon season which was 7.5 mS/cm and 1.41 mS/cm respectively which could be attributed to the high soluble salt content of groundwater used in irrigation in the study area [20]. The soil pH value of 6.56, a salinity of 4.33%, and an Electrical conductivity of 3.7 mS/cm was also recorded. [21].

The maximum sodium concentration of 13630.8 mg/kg and 36139.33 mg/kg was recorded during pre-monsoon and post-monsoon seasons respectively which is typical of inherent saline soil and such increased sodium content in soil affects the fertility of the soil and productivity of crops. Similarly, the post-monsoon season recorded higher potassium concentration which was of 433.85mg/kg than the pre-monsoon season which was 250.16mg/kg. The mean Calcium concentrations during pre-monsoon and post-monsoon season was 1661.07±751.03 and 2425.75±1065.73 in post-monsoon recorded a higher value. One of the major nutrients Phosphorus recorded a maximum pre-monsoon value of 165.32 mg/kg and during the post-monsoon, it was 233.32 mg/kg. All the major nutrients, including Sodium, Potassium, Calcium, and Phosphorus, were discovered in higher concentrations during the post-monsoon season compared to the pre-monsoon season. In contrast, Magnesium, Chloride, and Sulphur exhibited higher levels in the pre-monsoon season as opposed to the post-monsoon season. Chloride and Salinity are major indicating parameters for soil salinity and in the present study, Chloride concentration was recorded between 46.80 to 2917.40 mg/kg in both seasons. In line with Chloride, Salinity concentration was also on the higher side during the pre-monsoon season than the post-monsoon season which ranges between 0.08 to 5.27 ppt and 0.08 to 1.08 ppt respectively. Arid regions with higher temperatures generally lead to higher soil salinization due to capillary action. The Total organic carbon (1.64%) and Available nitrogen (9.89%) were higher during the pre-monsoon season compared to the post-monsoon season. Another significant parameter is the SAR result ranged between 4.75 to 56.77 meq/l during pre-monsoon and during post-monsoon season it was 35.21 - 86.35 meq/l. Many research studies have shown such values in the soil as per [19].

Table 1 Details of sampling locations from different agricultural fields in Kachchh district, Gujarat

S. No	Taluka	Village	Crops		Latitude	Longitude
			Pre-monsoon	Post-monsoon		
1.	Lakhpat	Gaduli	Castor	Black eyed pea	23° 41' 51.78" N	68° 52' 57.66" E
2.		Nara	Lucerne (Rajka)	Mustard, Rajka and Oats	23° 39' 7.68" N	69° 7' 40.08" E
3.	Abdasa	Vanku	Cotton	Wheat	23° 7' 3.18" N	68° 50' 11.82" E
4.		Arikhana	Nil	Nil	23° 4' 27.9" N	68° 52' 3.24" E
5.		Dhanavada	Cotton	Wheat	23° 9' 10.92" N	69° 1' 26.52" E
6.	Rapar	Khengarpar	Napier grass	Castor	23° 35' 22.26" N	70° 29' 0.66" E
7.		Adesar	Sorghum	Lucerne (Rajka)	23° 34' 3.9" N	70° 58' 31.08" E
8.		Gagodar	Lucerne (Rajka)	Wheat	23° 24' 44.1" N	70° 48' 34.86" E
9.	Bhuj	Khavda	Guar	Napier grass	23° 51' 30.06" N	69° 43' 42.3" E
10.		Andhau	Lucerne (Rajka)	Castor	23° 45' 43.78" N	69° 50' 32.52" E
11.	Mandvi	Halapar	Cotton	Wheat	23° 1' 27.54" N	69° 6' 12.72" E
12.	Nakhatrana	Nirona	Sorghum	Wheat	23° 27' 52.68" N	69° 31' 5.4" E
13.	Mundra	Samagoga	Sorghum	Lucerne (Rajka)	22° 53' 13.98" N	69° 40' 35.76" E
14.	Anjar	Anjar	Maize	Sorghum	23° 6' 29.28" N	70° 1' 8.58" E
15.	Gandhidham	Kidana	Sorghum	Wheat	23° 1' 57.24" N	70° 6' 18.96" E
16.	Bhachau	Bhachau	Sorghum	Tomato	23° 17' 56.46" N	70° 21' 18.78" E
17.	Control	Bhuj	Garden	Garden	23° 13' 4.38" N	69° 39' 17.7" E

Table 2 Soil characteristics during Pre-monsoon and Post-monsoon season collected from Kachchh, Gujarat, India

Physico-chemical characteristics	Pre-monsoon			Post -monsoon		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
pH	6.6	9.8	8.79	6.9	9.7	8.94

Electrical Conductivity (mS/cm)	0.28	7.5	1.97	0.21	1.41	0.62
Bulk Density (gm/cm^3)	1.25	1.61	1.41	1.19	1.54	1.35
Water Holding Capacity (%)	23.6	45.6	34.28	28.8	46	36.56
Chloride (mg/kg)	46.80	2917.40	707.55	46.09	599.22	269.33
Salinity (ppt)	0.08	5.27	1.28	0.08	1.08	0.49
Sodium (mg/kg)	1184.33	13630.8	5860.09	13946.16	36139.33	23745.94
Calcium (mg/kg)	516.9	2789.31	1661.07	838.98	4385.88	2425.75
Magnesium (mg/kg)	24.30	340.20	94.34	40.50	170.10	76.24
Sulphur (mg/kg)	11.62	508.50	175.32	15.88	177.20	59.46
Available Nitrogen (%)	1.87	9.89	4.95	2.80	8.59	5.20
Phosphorus (mg/kg)	6.15	165.32	47.16	12.29	233.32	53.67
Potassium (mg/kg)	41.91	250.16	119.62	65.11	433.85	180.45
Sodium Absorption Ratio (meq/100 gm)	4.75	56.77	26.41	35.21	86.35	48.20
Total Organic Carbon (%)	0.12	1.64	0.54	0.01	1.02	0.36

Table 3 Suggested range of soil quality parameters for agricultural purpose

Category	**Parameters**							
	pH*	**Elec. Conductivity* (µS/cm)**	**Calcium* (mg/kg)**	**Magnesium* (mg/kg)**	**Potassium* (mg/kg)**	**Nitrogen* (mg/kg)**	**Phosphorus** (mg/kg)**	**Total Organic Carbon** (%)**
Low	<6	<1000	<150	<60	<48.2	<125	<4.5	<0.2
Medium	6.0-7.5	15000	300	120	48.2–125	125-250	4.5-11	0.2-1.0
High	>7.5	>15000	>300	>120	>125	>250	>11	>1

*Soil Testing in India (2011); **Tandon (2013)

Table 4 Correlation analysis of Physico-chemical characteristics of soil samples during Pre-monsoon season

Parameters	**pH**	**Electrical Conductivity**	**Sodium**	**Potassium**	**Calcium**	**Phosphorus**	**Magnesium**	**Chloride**	**Sulphur**	**Total Organic Carbon**	**Available Nitrogen**	**Salinity**	**Sodium Absorption Ratio**
pH	1.00												
Electrical Conductivity	-0.21	1.00											
Sodium	0.39	0.64**	1.00										
Potassium	0.11	0.47	0.72**	1.00									
Calcium	0.66**	0.15	0.66**	0.69**	1.00								
Phosphorus	-0.32	0.78**	0.37	0.60**	0.10	1.00							
Magnesium	-0.45	0.85**	0.24	0.15	-0.18	0.75**	1.00						
Chloride	-0.08	0.96**	0.70**	0.48	0.24	0.71**	0.80**	1.00					
Sulphur	-0.42	0.90**	0.47	0.37	-0.10	0.73**	0.82**	0.86**	1.00				
Total Organic Carbon	-0.34	0.44	0.21	0.62**	0.23	0.72**	0.45	0.33	0.41	1.00			
Available nitrogen	-0.25	0.38	0.29	0.61**	0.28	0.58**	0.29	0.27	0.32	0.93**	1.00		
Salinity	-0.08	0.96**	0.70**	0.48	0.24	0.71**	0.80**	1.00**	0.86**	0.33	0.27	1.00	
Sodium Absorption Ratio	0.26	0.71**	0.98**	0.66**	0.51**	0.42	0.34	0.75	0.59**	0.20	0.28	0.75	1.00

**Pearson's Correlation is significant at the 0.01 level (2-tailed); *Pearson's Correlation is significant at the 0.05 level (2-tailed).

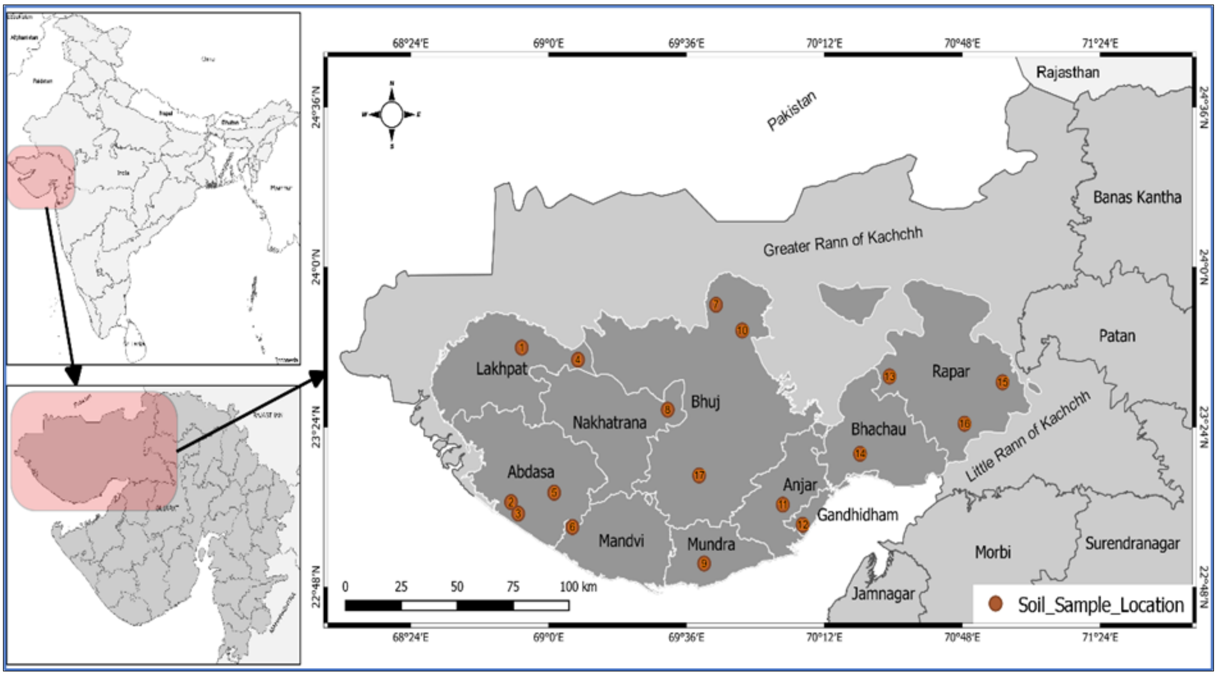

Figure 1 Sampling locations in the study area, Kachchh district, Gujarat, India

The physico-chemical characteristics revealed that the change in precipitation and temperature leads to a change in the soil properties significantly. Further, heavy rainfall patterns observed during the year might be attributed to increasing nutrient concentrations.

Pearson's co-efficient values during pre-monsoon are concerned, pH shows the strongest relationship with Ca+ (r-0.66). Similarly, Na+, K+, SAR studies have also reported similar values [22]. EC shows the strongest positive relation with chloride (r-0.96), salinity (r-0.96), sulphur (r-0.90) except pH which observed a negative correlation. Sodium shows a positive correlation with all the other parameters with the strongest significant relationship with SAR (r-0.98). Calcium shows the strongest positive relationship with potassium (r-0.69), but magnesium and sulphur exhibited a negative correlation. Phosphorus exhibited a strong positive correlation with EC (r = 0.78) and Potassium (r = 0.60), while it displayed a negative relationship with pH. Interestingly, Chloride demonstrated a robust positive correlation with salinity (r = 1.0) and EC (r = 0.96), whereas it exhibited a negative correlation with pH (r = -0.08). TOC exhibited a strong positive correlation with available nitrogen (r-0.93) and a negative correlation with pH (r = -0.34). WHC and bulk density are negatively correlated with each other (Table 4).

During post-monsoon season, the Co-efficient values (Table 5) of pH showed a positive correlation with calcium (r - 0.69), Na+, K+ and negatively correlated with other parameters similar to pre-monsoon season. Furthermore, the Electrical Conductivity (EC) data revealed a pattern resembling the pre-monsoon period, with a strong positive correlation with chloride levels (r = 0.94), salinity (r = 0.94), and various other parameters. In contrast, it displayed a negative correlation with pH (r = -0.25). Calcium exhibits a strong positive correlation with potassium (r = 0.74), but it demonstrates negative correlations with EC, Phosphorus, Magnesium, Sulphur, and SAR. In contrast, Chloride shows a robust positive relationship with EC (r-0.94) and salinity (r-1) and except pH all showed a positive correlation. Like during the pre-monsoon season, Total Organic Carbon (TOC) displayed a significant positive correlation with available nitrogen (r = 0.86), while pH and SAR exhibited negative correlations. Sodium Absorption Ratio (SAR) showed a positive correlation with Sodium (r = 0.49), while it displayed negative correlations with pH, Calcium, Phosphorus, Total Organic Carbon (TOC), and Available Nitrogen. Such correlation analysis was conducted for the soil studies conducted [23].

4. Conclusion

In the present study, the preliminary work done to isolate PGPR from soils having higher sodium and chloride concentrations, and rhizobacteria isolated from such soils, can be useful for plant growth enhancement, especially in soils threatened by high sodium and chloride concentrations that challenge soil fertility. Considering the merits of the PGPR, region-specific strategies should be developed such as to make the organisms work in extreme conditions such as aridity, salinity, etc. and such technologies developed should be implemented for regions facing similar issues across the globe. Our future research focuses on the application of these strains for plant growth enhancement in field conditions.

Compliance with ethical standard

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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