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Spatial Variability of Soil Physiochemical Properties in Bahariya Oasis, Egypt

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MOST of the soil physiochemical properties are inherited from their parent materials. However, some of them are influenced by the management practices. These properties are of great importance for both land use and management activities in precision farming. Soils in Bahariya Oasis have a wide variability in their parent material, which is reflected on their physiochemical properties. The objectives of this work were to study soil physiochemical properties in Bahariya Oasis and their spatial distribution in light of soil pedology.

The obtained results indicated that the majority of soils in Bahariya Oasis are sandy, which had a very significant impact on their physical and chemical properties. The values of organic matter and soil porosity were low, whereas the values of bulk density, hydraulic conductivity, and mean pore diameter were relatively high. On the other hand, the CEC values were low in most of the studied soils and the ESP values were less than 15% in all soils. Most of soils in the oasis are highly saline. The availability of NPK in Bahariya Oasis varied from low to high and the C/N ratio was less than 25 in the studied soils. Also, highly significant correlations were observed among soil physical and chemical properties in the Oasis.

In conclusion, soil physiochemical properties in Bahariya Oasis were highly influenced by their pedology.

Keywords: Physiochemical properties, Weathering, Pedogensis, Soil classification, Spatial variability, GIS.

Introduction

Spatial variability of soil properties either over the horizontal or vertical directions generally result from the interaction between the soil forming factors; however some of them are due to tillage and management practices (Iqbal et al., 2005; Papadopoulos et al., 2006; Zebarth et al., 2009 and Muhaimeed & Saleh, 2013). Currently, information about the variability within soil properties is considered as one of the major fundamentals for local management in precision farming. Therefore, studying the spatial variability of both soil physical and chemical properties is very relevant for understanding the soil processes and for land management.

Soil physical properties include soil texture, structure, bulk density, porosity, hydraulic conductivity, and soil mean pore diameter. Soil texture is considered as the most important physical property, where it has major effects on the other soil properties (Medinski, 2007 and Zebarth et al., 1999). Soil texture is the proportions of sand, silt and clay fractions in a soil. It is generally affected by soil parent material and the predominant type of weathering either physical or chemical. Soil texture remains relatively unchangeable and is not affected by management activities, where soil weathering is a very slow process. Soil structure is the arrangement of soil particles into aggregates. Aggregation is important for increasing stability against erosion, maintaining porosity, aeration capacity and soil water movement. Fine-textured soils usually have a stronger and well defined structure than coarse-textured soils mainly due to shrink/swell processes and cohesion between particles. Soil porosity is one of the important physical properties. It is highly influenced by

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soil texture and structure (Lowery, et al., 1995). Coarse-textured soils have many of macro-pores because they are strucureless. Fine-textured soils generally have a greater total porosity than coarse-textured soils (Tester, 1990). Long term cultivation tends to lower total porosity because of a decrease in soil organic matter (SOM) and large peds (Brady and Weil, 2002). Calcareous and salt-affected soils can also alter soil porosity and structure (Kern, 1995). In general, increasing SOM levels, reducing the extent of soil disturbance, and minimizing compaction and erosion will increase soil porosity and improve soil structure.

Soil chemical properties starts with soil pH, which is a measure of hydrogen ions (H^+) in the soil. It refers to soil acidity or alkalinity, where the higher the concentration of H^+ is the lower the pH value and vice versa. Electrical Conductivity (EC) is used as a measure of soluble salts (ions) in the soil solution, where the higher the concentration of ions is the higher the EC of that. Salt-affected soils are very common under arid and semiarid environments, where the evaporation rate exceeds the precipitation. Salts can affect soil structure and porosity as well as plant growth. The cation exchange capacity (CEC) refers to the amount of cations being adsorbed by a 100 g of soil. The CEC is significantly affected by the soil texture, where fine-textured soils usually have higher CEC values than coarser soils. The CEC is also influenced by the amount of SOM, where its value increases as the amount of SOM increases in soil. $CaCO_3$ results from the weathering of carbonate-rich parent materials such as limestone. Calcareous soils refer to soils that have higher contents of secondary carbonates. They generally occur in arid regions characterized by low precipitation rates. Calcic and/ petrocalcic sub-surface horizons are common in these areas. The content of soil organic carbon (SOC) is a soil quality indicator with major influence on soil properties. The breakdown of organic biomas by microbes is dependent upon the carbon to nitrogen (C/N) ratio. C/N ratios less than 25 allow the organic materials to decompose very rapidly, whereas greater values than 25 mean a slower decomposition and a requirement for an additional N. The breakdown of SOM is also affected by soil physical and chemical properties, as well as by soil temperature, moisture, nutrition, and factors affecting biological activity (Esmaeilzadeh and Ahangar, 2014).

Soils in Bahariya Oasis are developed under arid and semi-arid environments. These soils are influenced by the scarcity of available water for soil formation (pedogenesis) and plant growth. Accordingly, physical weathering is the prominent type of weathering; however some chemical weathering and solution-precipitation processes slightly occur in these regions. Soils developed under these environments are often weakly developed, shallow in depth, coarse-textured and skeletal except in the lowlands where soils are deeper due to colluvial and alluvial deposits. The major soil forming factors in these areas are climate (precipitation, evaporation, and wind erosion) and vegetation growing on dew and groundwater, whereas the major forming processes are salinization, desalinization, calcification and decalcification (Salem, 1987 & Sabry, 1997 and Elnaggar et al., 2013).

The objectives of this work were to study soil physiochemical properties and their spatial distribution in Bahariya Oasis using GIS. This is in addition to studying the interrelationships among these soil properties.

Material and Methods

Description of the studied area

Bahariya Oasis is one of the greatest Oases in the western Desert of Egypt. It is located between latitudes 27° 48′ to 28° 30′ N and longitudes 28° 35′ to 29° 10′ E as represented in Fig. 1. Its area is about 2,200 km^2 and its elevation ranges between 73 to 358 m above sea level (ASL). Slope gradient varies from zero to 57.30% with an average value of 3.40%. According to its climatic conditions, Bahariya Oasis is considered as an extremely arid region. It has a mean annual precipitation (MAP) of about 4 mm. Maximum air temperature varies from 20.1 °C in winter to 36.9 °C in summer (about 29.6 °C in average). Minimum air temperature ranges between 4.9 °C in winter and 21.0 °C in summer (about 13.7 °C in average) (EMA, 1996).

Geology of Bahariya Oasis consists of seven types of formations. These formations are: 1. El-Heiz formation, 2. Bahariya sandstone and variegated Shale, 3. EI-Hufhuf formation, 4. Ain Giffara formation, 5. Khoman Chalk, 6. Plateau Limestone, and 7. Volcanic rocks (El-Sisi et al., 2002 and Khalifa et al., 2006).

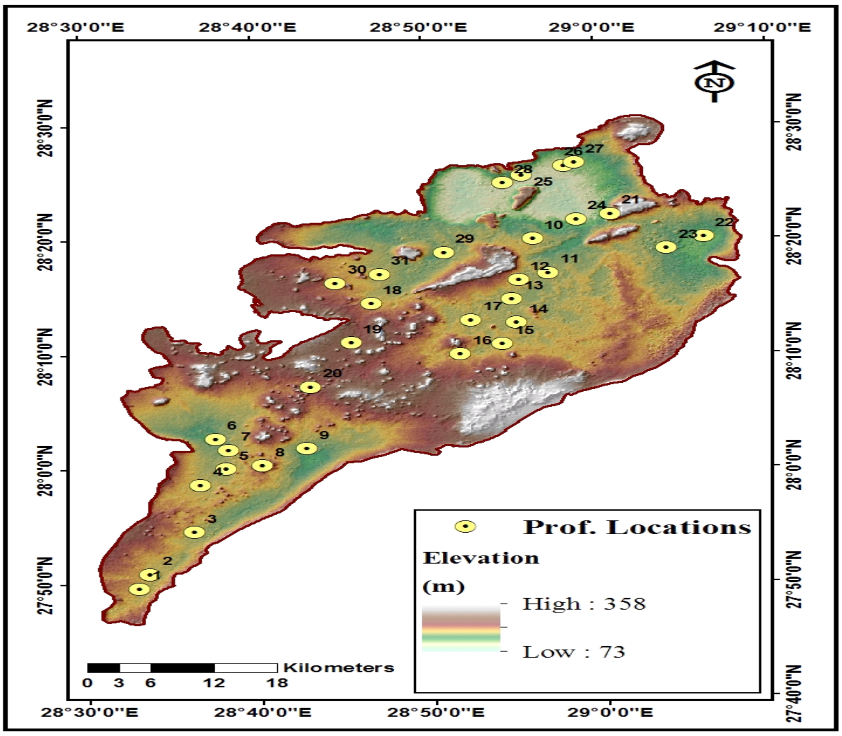

Fig.1. Location map of Bahariya Oasis and soil profile locations

Soil samples and analysis

Thirty one geo-referenced soil profiles were dug and studied in Bahariya Oasis. The spatial distribution of these soil profiles is illustrated in Fig. 1. These profiles were described in the field according to the USDA-NRCS (2002). They were also classified according to U.S. soil taxonomy (Soil Survey Staff, 2010). Sixty eight samples were collected to represent the different soil horizons of the studied profiles. These samples were air-dried, crushed to pass through 2 mm sieve, and stored for physical and chemical analyses. Soil physical and chemical analyses were carried out according to the procedures described by the Soil Survey Staff (2014).

The data represented in this work include the results of physical and chemical analyses for only 11 reprehensive soil profiles.

Results and Discussions

Soil classification in Bahariya Oasis

Soils in Bahariya Oasis were located in two soil orders, which are aridisols and entisols. Sub-orders under aridisols include gypsids, salids and argids. Sub-orders under entisols include psamments, fluvents, and orthents. The great groups under aridisols were haplogypsids, calcigypsids, gypsiargids, aquisalids, and haplosalids. Great groups under eridisols were torripsamments, torrifluvents, and torriorthents. These soils were fit in 11 soil sub-great groups as represented in Table 1 and Fig. 2. The dominant sub-group was Lithic Haplogypsids (34.45% of the Oasis). This was followed by Lithic Calcigypsids (19.19%), Typic Haplogypsids (14.90%), Typic Torripsamments (7.98%) and Typic Quartzipsamments (5.79%). The other sub-groups represented less than 10% of the studied area. It is important to mention that about 9.99% of Oasis was excluded in this work. These excluded areas include areas that have rock outcrops, sabkhas and water bodies.

Physical soil properties

Representative physical properties of soils in Bahariya Oasis are shown in Table 2.

Soil depth

Soils in Bahariya Oasis vary significantly in their soil depth depending on the parent materials as illustrated in Fig. 3a. Soils developed on Aeolian deposits (sand dunes) have higher soil depth (> 150 cm). These soils represent about 14% of the studied area. Shallow soils (< 50 cm) represent soils developed in situ (residuum) on sandstone, limestone or shale. These soils represent about 58% of the studied area. Soils having medium soil depth (50 – 100 cm) are developed on either Aeolian deposits or residuum and these represent about 18% of the Oasis. Less than 1% of the soils have soil depth between 100 and 150 cm. According to these results, great concern should be given the management practices of these soils regarding the type of crops to be grown and the necessity to establish a drainage system.

Soil texture
Table 2 and Fig. 3b show wide variations in soil textures within Bahariya Oasis. Soil texture was also associated with the parent material. The majority of soils in the oasis were sandy (68% of the oasis) and most of these soils are developed on sand dunes and sandstone. Sandy loam soils represented about 15% of the oasis. Loamy soils and sandy clay loam soils represented about 0.78 and 0.38%, respectively. Clay loam soils represented about 6.5% of the oasis and these soils were developed on fluvial deposits.

Saturation percentage (SP)
Variations in saturation percentage (SP) within Bahariya Oasis are represented in Fig. 4a. The SP values varied from 22 to 47% with an average of 33%. These values were directly affected by soil texture. The lower values (20 – 30%) were associated with sandy and sandy loam soils and these represent about 68% of the oasis. On the contrary, the higher values were contributed to loamy, sandy clay loam and clay loam soils and these represent about 22% of the oasis.

Bulk density (BD)
Bulk density in the oasis varied from 1200 to 1700 kg m^{-3} , with an average of 1450 kg m^{-3} as represented in Table 2 and illustrated in Fig. 4b. The lower values (< 1250 kg m^{-3}) were found in about 2.75% of the oasis and these values were associated with fine-textured soils. The moderate values (1250 – 1500 kg m^{-3}) were found in about 20% of the oasis and most of them were associated with sandy loam and loamy soils. The higher values (1500 – 1750 kg m^{-3}) were associated with the coarse textured soils and they represent about 68% of the oasis.

TABLE 1. Sub-great groups in Bahariya Oasis and their areas and percentages.

SMU	Soil Sub-Group	Area (km^2)	(%)
1	Lithic Calcigypsids	402.85	19.19
2	Lithic Haplogypsids	723.22	34.45
3	Typic Haplogypsids	312.85	14.90
4	Typic Aquisalids	57.78	2.75
5	Typic Haplosalids	77.98	3.71
6	Typic Gypsiargids	1.04	0.05
7	Typic Quartzipsamments	121.56	5.79
8	Lithic Torripsamments	3.05	0.15
9	Typic Torripsamments	167.56	7.98
10	Typic Torrifluvents	7.01	0.33
11	Typic Torriorthents	16.42	0.78
Total		1891	90.10*

*About 9.99% of Oasis was excluded (Rock outcrops, Sabkhas and Water bodies).

TABLE 2. Soil physical analysis for some representative profiles of soil map units (SMUs) in Bahariya Oasis

SMU	Prof. No	Soil Depth (cm)	Total Sand (%)	Silt (%)	Clay (%)	Soil Texture	$CaCO_3$ (%)	OM (%)	SP (%)	BD kg/m³	Porosity (%)	Ks m/ day	d* (µm)
1	P11	< 50	89.86	5.93	4.21	S	17.86	0.3	23.8	1530	42.26	3.60	11.72
2	P18	< 50	90.12	5.83	4.05	S	5.09	0.28	24.3	1600	39.62	2.64	10.04
3	P28	60	66.42	17.33	16.25	SL	4.2	0.78	34.5	1400	47.17	1.68	8.01
4	P22	60	42.77	29.33	27.9	CL	2.29	1.46	46.1	1200	54.72	0.05	1.35
5	P2	< 50	43.73	28.95	27.32	CL	2.47	1.36	46.5	1270	52.08	0.12	2.14
6	P27	75	56.49	21.98	21.53	SCL	10.49	0.62	27.5	1400	47.17	0.72	5.24
7	P17	200	91.79	5.16	3.05	S	5.32	0.14	21.9	1700	35.85	3.72	11.91
8	P30	< 50	91.39	4.86	3.75	S	5.32	0.23	23.6	1660	37.36	3.17	11.00
9	P24	200	85.98	7.91	6.11	S	5.95	0.55	27.6	1540	41.98	2.64	10.04
10	P12	150	54.33	23.16	22.51	SCL	18.41	1.13	42.7	1350	49.06	0.96	6.05
11	P21	< 50	46	28.03	25.97	L	2.55	1.32	45.1	1300	50.94	0.17	2.53
Minimum			42.77	4.86	3.05	--	2.29	0.14	21.9	1200	35.85	0.05	1.35
Maximum			91.79	29.33	27.9	--	18.41	1.46	46.5	1700	54.72	3.72	11.91
Average			68.99	16.22	14.79	--	7.27	0.74	33.05	1450	45.29	1.77	7.28

*d= Soil Mean Pore Diameter.

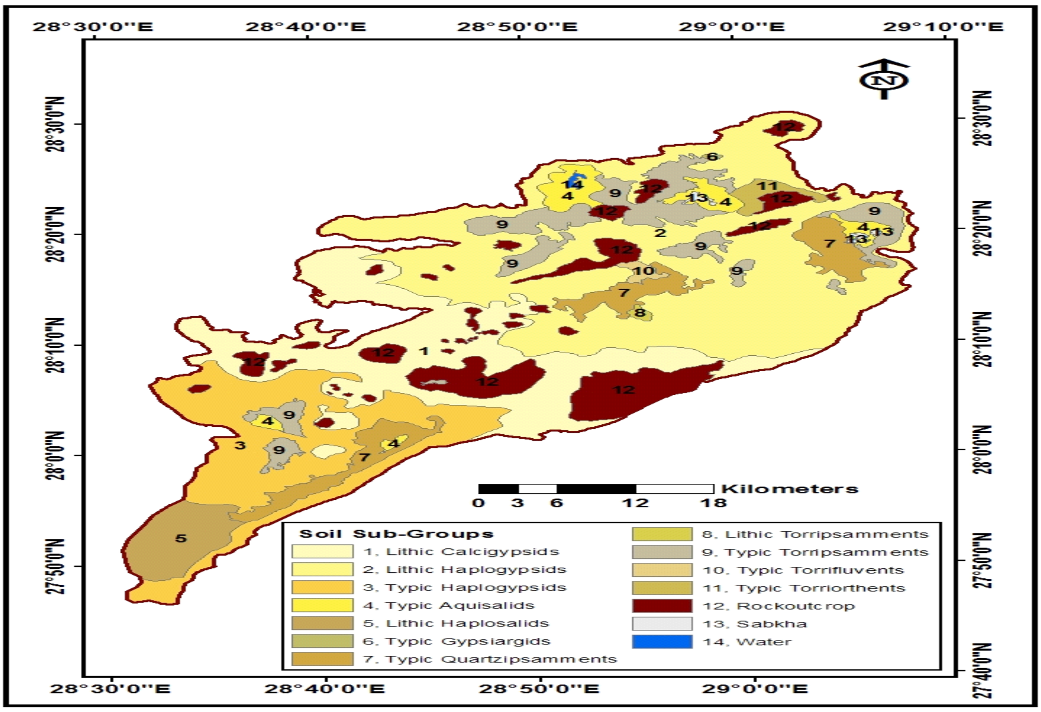

Fig. 2. Spatial distribution of soil map units and sub-groups in Bahariya Oasis

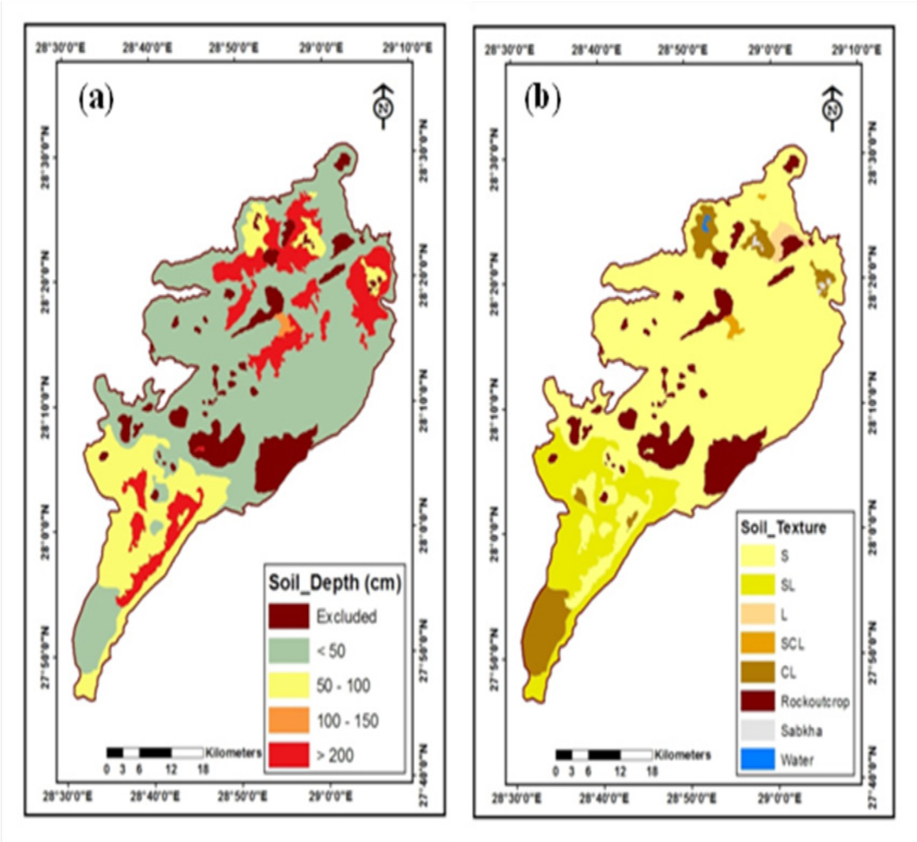

Fig. 3. Spatial distribution of a) soil depth and b) soil texture in Bahariya Oasis.

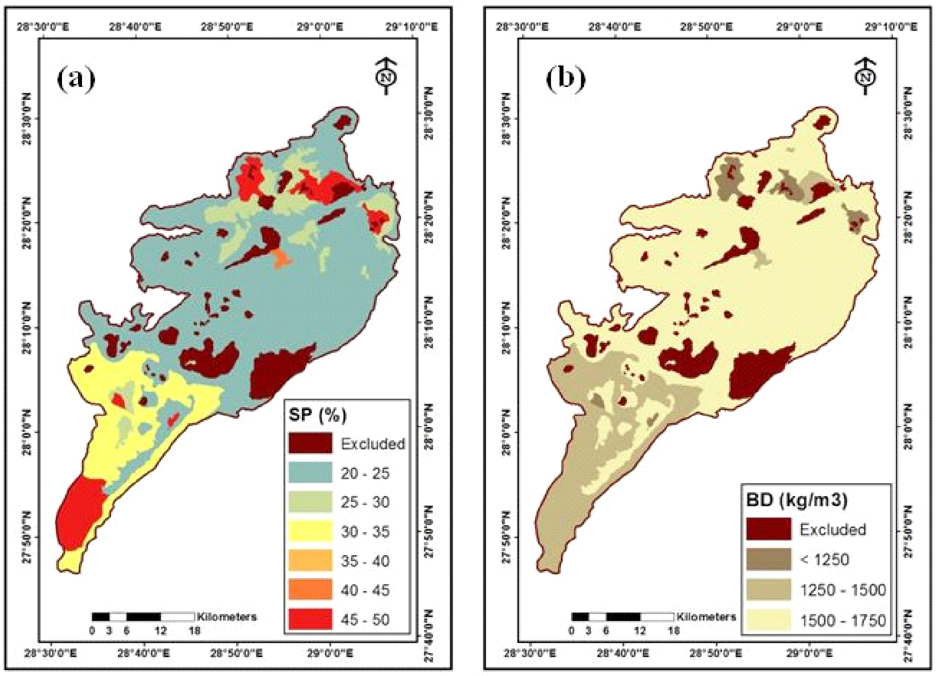

Fig. 4. Spatial distribution of a) saturation percentage (SP) and b) soil bulk density (BD) in Bahariya Oasis.

Soil porosity

Soil porosity in Bahariya Oasis ranged between 36 and 55% with an average of 45% as illustrated in Fig. 5a. These values were affected by soil texture and structure. The higher values were associated with fine-textured soils that have moderate to a strong structure. They were associated with soils that have high contents of gypsum and calcium carbonates. Also, higher values were found in highly saline soils, which could be attributed to the false aggregation developed by soil salinity. On the other hand, the lower values were associated with coarse-textured soils and other soils that have a weak structure or structureless (single grained or massive). Based on the obtained soil porosity values, about 40% of soils in the Oasis had soil porosity between 35 and 40%; 27% of soils had porosity between 40 and 45%; 15% of soils had porosity between 45 and 50%, and only about 7% of the soils had porosity between 50 and 55%.

Hydraulic conductivity (Ks)

The values of saturated Hydraulic Conductivity (Ks) in Bahariya Oasis varied from 0.05 to 3.72 m day^{-1} with an average of 1.77 m day^{-1}. The higher values were associated with coarse-textured soils, whereas the lower values were associated with the fine-textured soils in the oasis. Figure 5b illustrates the spatial variability of Ks in Bahariya Oasis.The lower values (< 0.24 m day^{-1}) represented about 7% of soils in the oasis and the values between 0.24 and 1.2 m day^{-1} represented less than 1% of soils in the Oasis. On the other hand, the values between 1.2 and 2.4 m day^{-1} represented about 15% of the soils, the values between 2.4 and 3.6 m day^{-1} represented about 62% of the soils, and the values between 3.6 and 4.8 m day^{-1} represented about 6% of the soils in the Oasis. Depending on these results great concern should be given to the type of irrigation systems used in these areas, where the majority of soils are sandy and have higher Ks values.

Soil mean pore diameter (d)

The soil mean pore diameter (d) was calculated from the Ks values using the following equation (Dielman and De Ridder, 1972):

$$d = 6.1776 \text{ ks}$$

where, d is the soil mean pore diameter in μm and Ks is the saturated hydraulic conductivity (Ks) in m^3 day^{-1} at 20^oC.

The d in soils of Bahariya Oasis varied from 1.35 to 11.91 μm with an average value of 7.28 μm. The higher values (macro-pores) were associated with the coarse textured soils, whereas the lower values (micro-pores) were associated with the fine textured soils in the Oasis.

Chemical soil properties

Chemical soil properties of some representative soil profile for soil map units (SMUs) in Bahariya Oasis are represented in Table 3.

Soil pH

Soils in Bahariya Oasis are developed under arid and semi-arid conditions. These soils are rich in alkali cations, calcium carbonates, and gypsum; therefore, their pH values tend to increase toward alkalinity (pH > 7). These values ranged between 7.23 and 8.73 with an average of 7.82 as represented in Table 3 and illustrated in Fig. 6a. The majority of soils (87%) have pH values less than 8.5; however about 3% of the soils have pH values between 8.5 and 9.0. The higher values were associated with the typic aquisalids soils.

Electrical Conductivity (EC)

The EC values in the oasis varied from 3.2 to 42.60 dS m^{-1} with an average value of 20.06 dS m^{-1}. This indicates that the majority of soils in the oasis are highly saline as illustrated in Fig. 6b. Only about 0.34% of the soils had EC values < 4 dS m^{-1}. About 9% of the soils had values between 4 and 8 dS m^{-1} and about 6% of the soils had values between 8 and 16 dS m^{-1}. The majority of the soils (75%) had EC values greater than 16 dS m^{-1}. These higher values could be attributed to the prevalence of surface irrigation and poor drainage under the extreme weather conditions in the oasis.

Cation Exchange Capacity (CEC)

The CEC values are generally correlated with the amount and type of clay minerals and organic matter content. These components are very limited in soils of Bahariya Oasis; therefore, the CEC values in these soils are relatively low (Fig. 7a). Accordingly, about 40% of the soils in the oasis have CEC values less than 5, about 27% of the soils have CEC values between 5 and 10, and about 15% of the soils have values between 10 and 15 meq/ 100 g of soil. Only about 7% of the soils have values between 15 and 20 meq/ 100 g of soil.

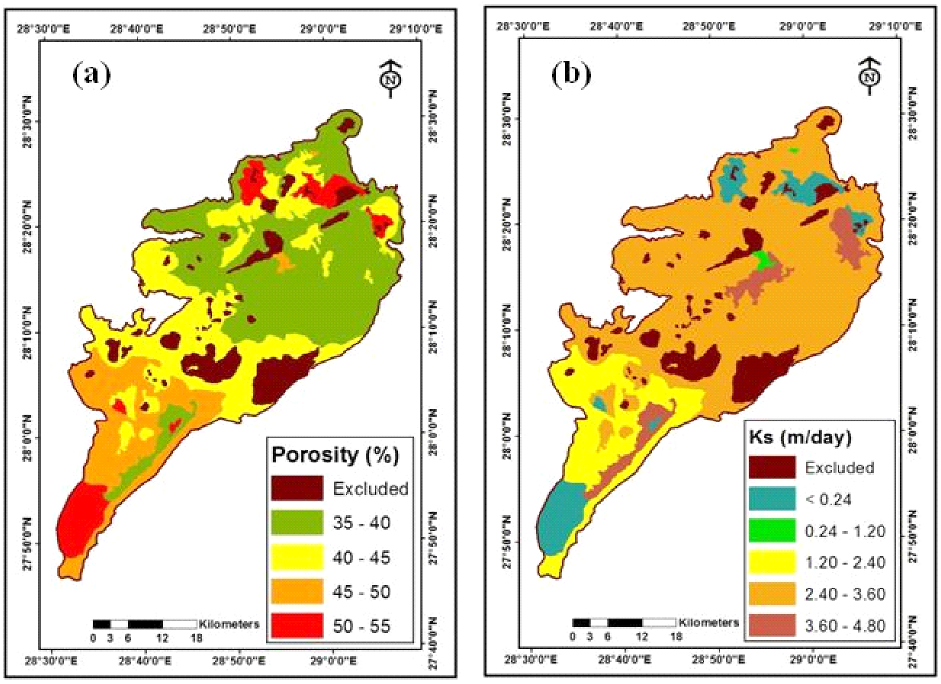

Fig. 5. Spatial distribution of a) soil porosity and b) hydraulic conductivity (Ks) in Bahariya Oasis.

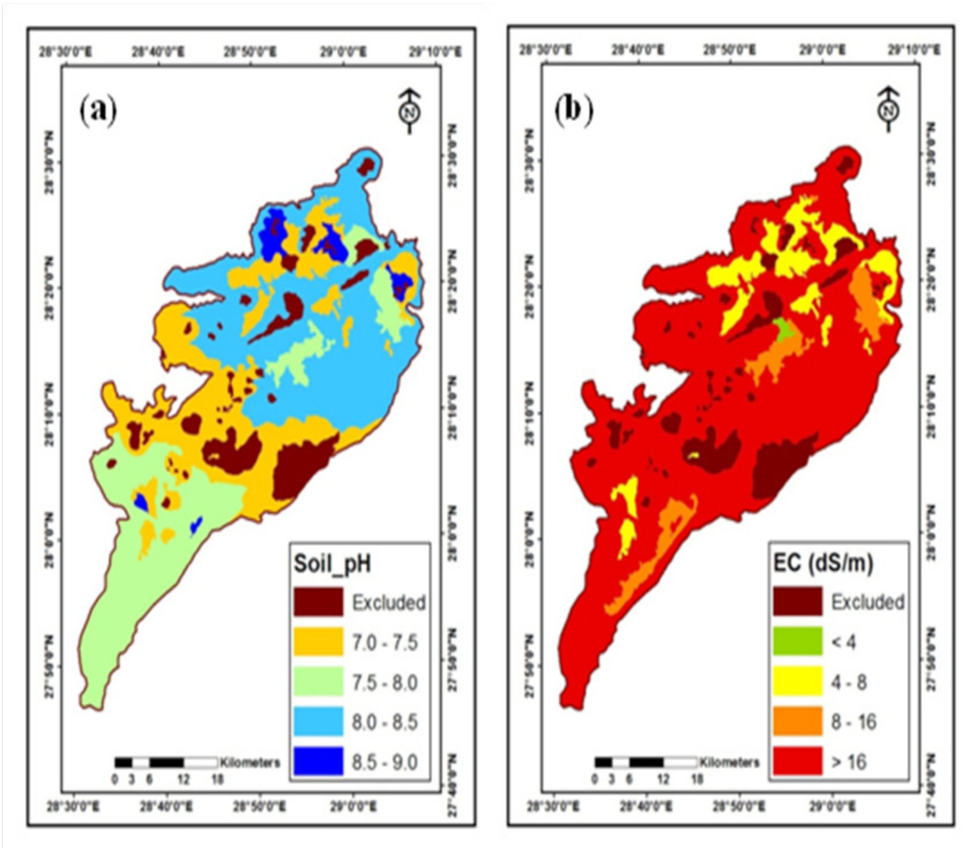

Fig. 6. Spatial distribution of a) soil pH and b) EC of soils in Bahariya.

Exchangeable sodium percentage (ESP)

The ESP values in Bahariya Oasis varied from 11.84 to 14.65% with an average of 12.9%. All soils in Bahariya Oasis had ESP values less than 15 (between 10 and 15%), which is the critical limit for sodic soils. This could be contributed to the higher concentration of calcium cations on the exchange complex.

Available nitrogen

Available nitrogen in Bahariya Oasis varied from 15.30 to 63.60 ppm with an average of 38.27 ppm. About 60% of the soils in the oasis had values from 15 to 30 ppm and 23% of the soils had values from 30 to 45 ppm. On the other hand, only less 1% of the soils had values from 45 to 60 ppm and about 7% of the soils had values between 60 and 75 ppm. The spatial variability of available N in the oasis is illustrated in Fig. 7b.

Available phosphorous

Available phosphorus in Bahariya Oasis ranged between 2.94 and 18.17 ppm with an average of 10.53 ppm. The spatial variability in available P in Bahariya Oasis is shown in Fig. 8a. On the contrary of nitrogen, about 60% of the soils in the Oasis had values from 15 to 20 ppm, which is considered as a high rate. About 23% of the soils had values from 10 to 15 ppm, which is a moderate rate. Less than 1% of the soils had values from 5 to 10 ppm, which is a low rate and about 7% of the soils had values less than 5 ppm, which is a very low rate.

Available potassium

Available potassium in Bahariya Oasis varied from 78 to 245 ppm with an average of 163 ppm. About 6% of the soils in the oasis had values from 50 to 100 ppm; which is considered as a low concentration. About 62% of the soils had values from 100 to 150 ppm, 15% of the soils had values from 150 to 200 ppm; which is a moderate concentration. About 8% of the soils had values between 200 and 250 ppm; which is a relatively high concentration. The spatial variability in available K in the oasis is demonstrated in Fig. 8b.

TABLE 3. Soil chemical analyses for some representative profiles of soil map units (SMUs) in Bahariya Oasis

SMU	Prof. No	Soluble Cations (meq/100 g soil)				Soluble Anions (meq/100 g soil)			pH	EC dS/m	CEC meq/ 100 g	ESP	Available NPK (ppm)			C/N Ratio
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}					N	P	K	
1	P11	2.35	0.98	4.63	0.004	0.38	3.40	4.19	7.44	31.40	5.03	14.65	22.20	15.39	107.5	10.26
2	P18	1.36	1.29	4.94	0.004	0.14	5.16	2.28	8.16	29.80	4.77	14.10	21.40	15.45	104.0	9.58
3	P28	0.94	0.46	2.35	0.006	0.06	1.79	1.91	7.51	17.10	11.18	12.10	40.50	10.17	175.0	16.80
4	P22	4.02	2.78	13.94	0.010	0.20	14.72	5.83	8.73	42.60	18.95	12.00	63.60	2.94	245.0	21.22
5	P2	3.53	1.75	12.34	0.007	0.71	13.68	3.23	7.84	35.90	18.20	13.77	61.20	3.53	237.5	21.37
6	P27	1.30	0.71	2.69	0.004	0.05	2.19	2.46	7.23	15.90	8.72	11.84	33.10	12.19	150.0	12.02
7	P17	0.65	0.64	2.23	0.002	0.08	2.49	0.96	7.94	14.90	2.71	13.65	15.30	18.17	78.0	13.57
8	P30	0.85	0.55	2.07	0.005	0.07	1.64	1.76	7.88	17.10	4.05	11.90	18.90	16.16	94.0	11.14
9	P24	0.72	0.42	1.37	0.002	0.05	1.14	1.32	7.42	7.90	8.05	12.13	31.30	12.68	145.0	15.23
10	P12	0.31	0.19	1.20	0.000	0.12	1.31	0.28	8.22	3.20	16.12	13.75	53.10	5.32	225.4	21.90
11	P21	0.67	0.37	1.36	0.002	0.10	1.00	1.29	7.66	4.90	17.84	12.00	60.40	3.87	236.0	19.68
Minimum		0.31	0.19	1.20	0.000	0.05	1.00	0.28	7.23	3.20	2.71	11.84	15.30	2.94	78.0	9.58
Maximum		4.02	2.78	13.94	0.010	0.71	14.72	5.83	8.73	42.60	18.95	14.65	63.60	18.17	245.0	21.90
Average		1.52	0.92	4.47	0.004	0.18	4.41	2.32	7.82	20.06	10.51	12.90	38.27	10.53	163.4	15.71

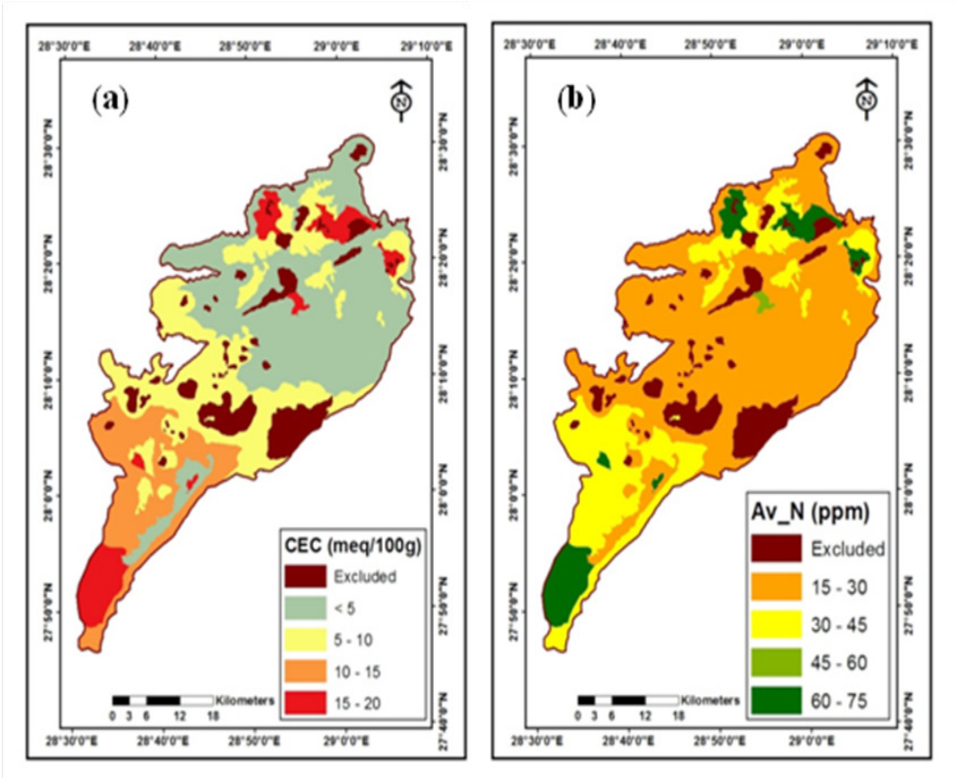

Fig. 7. Spatial distribution of a) cation exchange capacity (CEC) and b) available N in Bahariya Oasis.

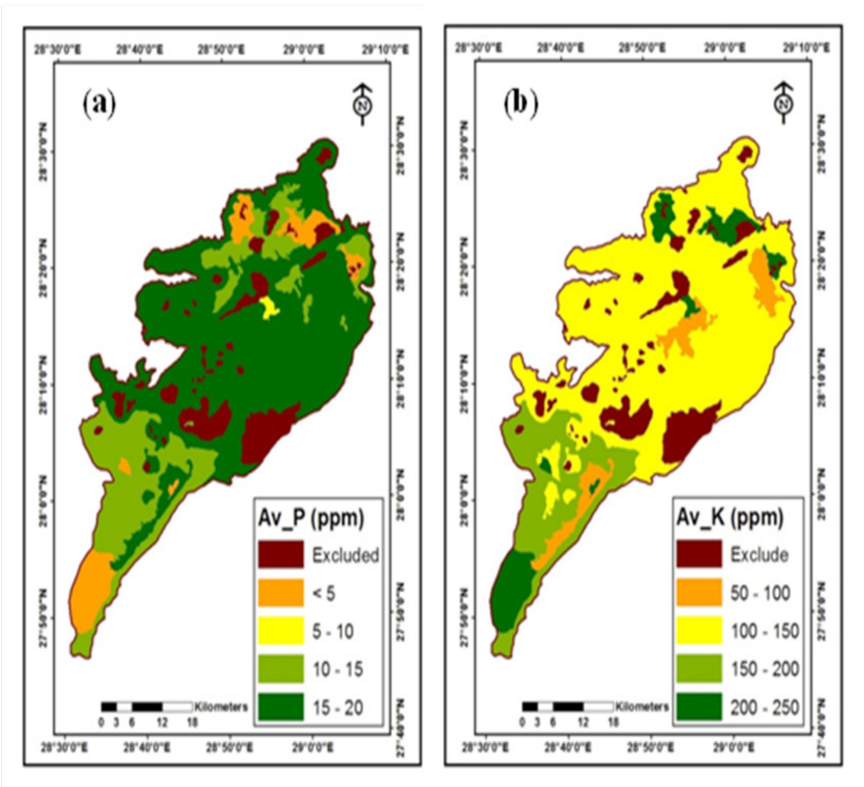

Fig. 8. Spatial distribution of a) available P, and b) available K in Bahariya Oasis.

C/N Ratio

The C/N ratio in Bahariya Oasis was less than 25% as illustrated in Fig. 9. It ranged between 9.58 and 21.90% with an average of 15.71%. About 34% of the soils in the Oasis had values less than 10%, about 25% of the soils had values from 10 to 15 %, 24% of the soils had values from 15 to 20 % and about 7% of the soils had values between 20 and 25%. This indicates that decomposition of organic materials may proceed at the maximum rate possible under these environmental conditions.

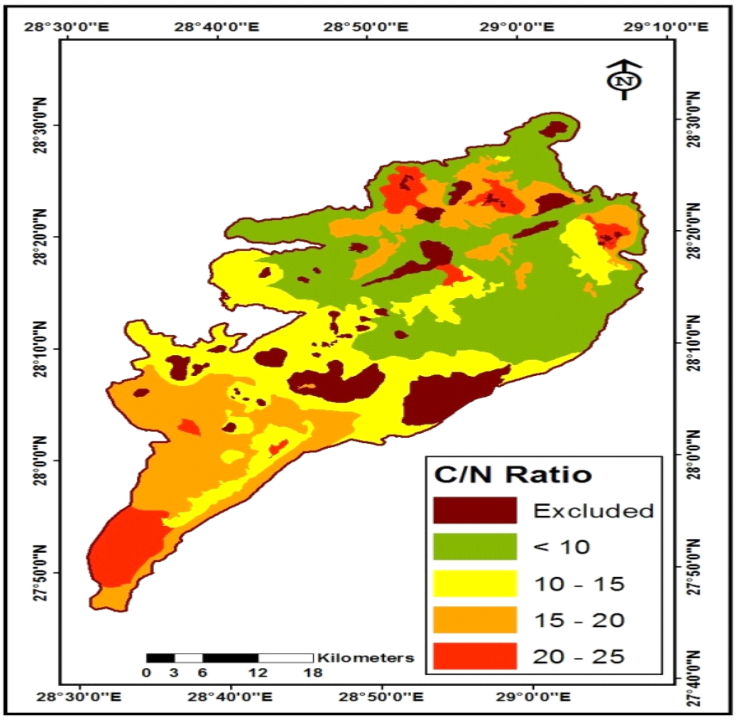

Fig. 9. Spatial distribution of C/N ratio in Bahariya Oasis.

Organic Matter (OM)

Organic matter and $CaCO_3$ contents can be used as physical or chemical soil properties. They are used as physical soil properties, when we refer to them as soil components and their effect on physical properties. Also, they are used as chemical soil properties due to their great effects on chemical properties. In this work they were studied under chemical properties.

Soils in Bahariya Oasis were poor in their organic matter content. It varied from 0.14 to 1.46% with an average of 0.74%. The spatial distribution of OM in the oasis is illustrated in Fig. 10a. About 60% of soils in the Oasis had values less than 0.5%, about 23% had values between 0.5 and 1.0%, and about 8% had values between 1.0 and 1.5%. The lower values were generally associated with coarse-textured soils, whereas the higher values were linked with medium to fine textured soils. It was found that the higher values were also associated with highly saline soils (aquisalids and haplosalids), which could be due to the preservative effect of high soil salinity.

Total carbonates ($CaCO_3$)

Total carbonates in Bahariya Oasis were calculated as $CaCO_3$. The percentage of $CaCO_3$ varied from 2.29 to 18.41% with an average of 7.27%. Fig. 10b shows the spatial distribution of $CaCO_3$ in the oasis. About 22% of the soils in the oasis had values < 5%, about 48% of the soils had values from 5 to 10 %, and about 20% of the soils had values between 15 and 20%. The higher values were associated with the calcigypsids soils in the middle of the oasis. As a result,a great concern should be given to the fertilization management program that will be used in these soils. This is particularly important in case of fertilization with micronutrients.

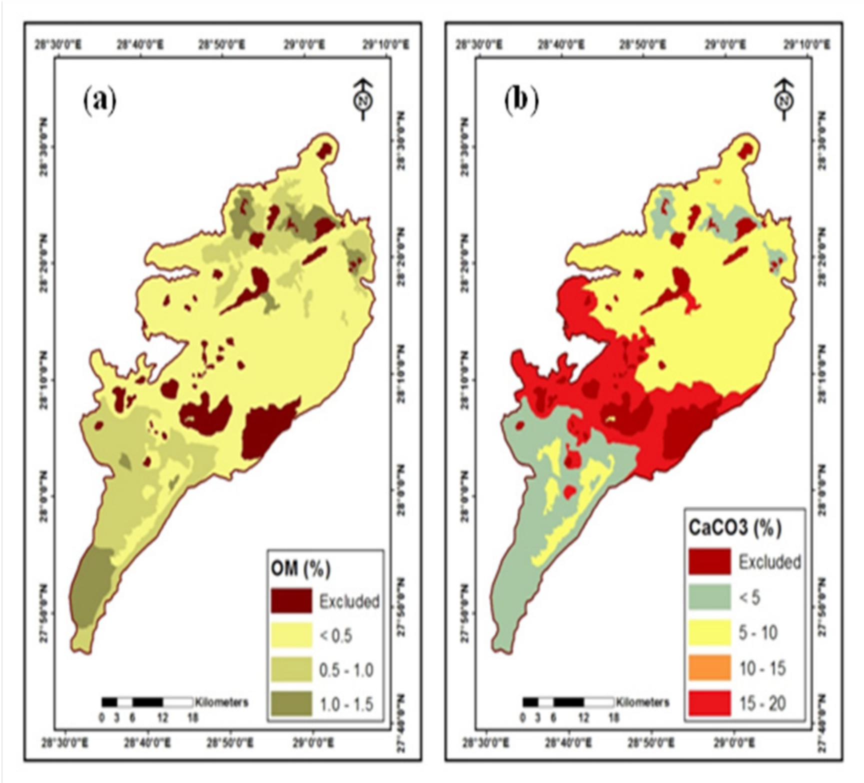

Fig. 10. Spatial distribution of a) organic matter (OM) and b) calcium carbonates contents in Bahariya Oasis

Interrelationships between soil properties
Highly significant correlations were observed among soil physical and chemical properties in Bahariya Oasis and these relationships can be expressed in linear models as represented in Table 4. Highly positive and significant correlations were observed between clay content and saturation percentage (SP), soil porosity, CEC, available N, available K, and C/N ratio (r=0.92, 0.96, 0.94, 0.94, 0.94, and 0.83, respectively). On the other hand, negative but highly significant correlations were observed between clay content and bulk density (BD), hydraulic conductivity (Ks), and available phosphorus (r= 0.96, 0.98, and 0.94, and respectively).

Similarly, highly significant correlations were observed between total sand and BD and Ks (r= 0.96 and 0.98, respectively), whereas negative but significant correlations were observed between total sand and SP and soil porosity (r= 0.92 and 0.96, respectively). Highly significant correlations were observed between electrical conductivity (EC) and soluble sodium (Na^+) and chloride (Cl) (r= 0.88 and 0.85, respectively). Also, positive correlations were obtained between OM and CEC, C/N ratio and available N and K (r= 1.0, 0.92, 1.0 and 0.99, respectively). Similar to clay content, the OM had a highly significant but negative correlation with the available P. Figure 11 illustrates some of the linear relationships between some soil physical and chemical properties in Bahariya Oasis.

It is worthy to mention that there was negative but non-significant correlation between $CaCO_3$ and available K and N. However, there was no obvious relationship between available P and $CaCO_3$ in the studied soils.

Conclusion
It could be concluded that soils in Bahariya Oasis have great variations in their physiochemical properties. Most of these properties were influenced by their soil pedology. The majority of soils in the Oasis are sandy and highly saline soils, which had a very significant impact on their physical and chemical properties. Consequently, the values of saturation percentages (SP) and soil porosity were low, whereas the values of bulk density (BD) and hydraulic conductivity (Ks) were relatively high. On the other hand, the

CEC values were low in most of the studied soils and the ESP values were less than 15 in all soils. Although the lower contents of organic matter and clay in the oasis soils, they had a great influence on their soil properties. Also, the availability of NPK in Bahariya Oasis varied from low to high and the C/N ratio was less than 25. Highly significant correlations were also observed among the studied soil physical and chemical properties in the Oasis.

TABLE 4. Correlation coefficients and linear relationships between soil properties in Bahariya Oasis.

Soil properties	**Correlation Coefficient (r)**	**Linear Relationship**
Clay * Ks	0.98**	Ks (cm/hr) = -0.5534 Clay (%) + 15.556
Clay * Porosity	0.96**	Porosity (%) = 0.5664 Clay (%) + 36.916
Clay * SP	0.92**	SP (%) = 0.8794 Clay (%) + 20.051
Clay * BD	0.96**	BD (g/cm^3) = -0.015 Clay (%) + 1.6717
Sand * BD	0.96**	BD (g/cm^3) = 0.0076 Sand (%) + 0.9274
Sand * Ks	0.98**	Ks (cm/hr) = 0.2788 Sand (%) - 11.861
Sand * SP	0.92**	SP = -0.4456 Sand (%) + 63.793
Sand * Porosity	0.96**	Porosity (%) = -0.2857 Sand (%) + 65.004
Clay * CEC	0.94**	CEC (meq/100 g soil) = 0.5564 Clay (%) + 2.2837
OM * CEC	1.00**	CEC (meq/100 g soil) = 12.565 OM (%)+ 1.1783
EC * Na^+ (Soluble)	0.88**	Na^+ (meq/100 g soil) = 0.3028 EC (dS/m) - 1.6109
EC * Cl^-	0.85**	Cl^- (meq/100 g soil) = 0.3249 EC (dS/m) - 2.1075
OM * P	1.00**	P (ppm)= -11.415 OM (%) + 19.012
OM * K	0.99**	K (ppm)= 127.64 OM (%) + 68.595
OM * N	1.00**	N (ppm)= 37.105 OM (%) + 10.714
OM * C/N Ratio	0.92**	C/N Ratio= 8.7512 OM (%) + 9.2066
Clay * N	0.94**	N (ppm)= 1.6423 Clay (%) + 13.989
Clay * P	0.94**	P (ppm)= -0.5038 Clay (%) + 17.984
Clay * K	0.94**	K (ppm)= 5.6732 Clay (%) + 79.514
Clay * C/N Ratio	0.83**	C/N Ratio= 0.3697 Clay (%) + 10.24

**Highly significant correlation at a confidence level of 0.01.

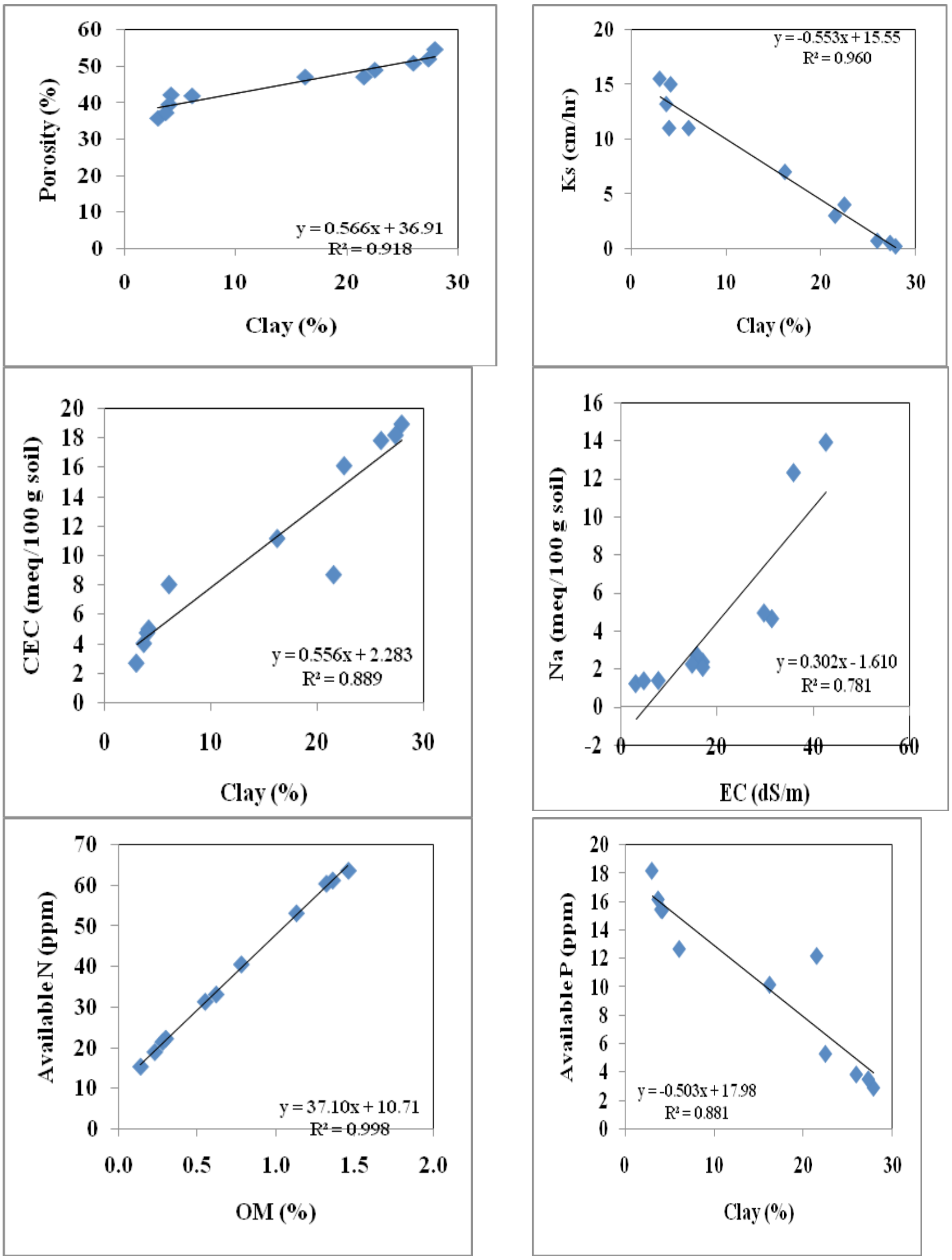

Fig. 11. Linear relationships between some soil physical and chemical properties in Bahariya Oasis.

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التباين المكانى فى الخواص الفيزيوكيميائية للتربة بالواحات البحرية ـ مصر

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معظم الخصائص الفيزيوكيميائية للتربة موروثة من مادة الأصل ولكن بعضها يتأثر بعمليات آدراة التربة. وهذه الخصائص ذات أهمية كبيرة لكل من استخدام الأراضي والأنشطة الآدارية في الزراعة الدقيقة. والأراضى في الواحات البحرية ذات تباينات كبيرة في مواد الأصل والذى ينعكس بدورة على خصائصها الفيزيوكيميائية. وكان أهداف هذا العمل هى دراسة التباينات فى الخصائص الفيزيوكيميائية للتربة في الواحات البحرية الواحات ودراسة توزيعها المكاني في ضوء علم بيدولوجيا الأراضى ygolodeP lioS .

وأوضحت النتائج أن الغالبية العظمى من الأراضى في الواحات البحرية رملية القوام والذى كان له تأثيرا كبيرا على خصائصها الفيزيائية والكيميائية. وكانت قيم كل من المادة العضوية ومسامية التربة منخفضة بينما كانت قيم الكثافة الظاهرية والتوصيل الهيدروليكي ومتوسط قطر المسافات البينية عالية نسبيا. ومن ناحية أخرى كانت قيم السعة التبادلية الكاتونية CEC للتربة منخفضة في معظم الأراضى التى تم دراستها وكانت قيم الـ PSE أقل من 51 في جميع أنواع الأراضى. وكانت الأراضى فى الواحة عالية الملوحة. وأختلفت درجة تيسر عناصر الـ KPN في الواحات البحرية من منخفضة الى عالية وكانت نسبة الكربون الى النيتروجين N/C أقل من 52 في الأراضى التى تم دراستها. كما لوحظ أيضا وجود ارتباطات عالية المعنوية بين خواص التربة الفيزيائية والكيميائية في الواحة.

والأستنتاج العام هو ان الخصائص الفيزيوكيميائية للتربة في الواحات البحرية كانت متأثرة بدرجة كبيرة بتكوينها البيدولوجى