

Correlation between soil physico-chemical parameters and the diversity of their inhabiting algae

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Abstract

Five soil samples (S1-S5) collected from different locations in Egypt to investigate the effect of their physio-chemical parameters on the diversity of algae and their divisions. The results obtained showed that the physio-chemical parameters of the soil have its influence on the diversity of algae. The most varied parameters between the studied locations were soil pH and the nitrogen contents. The collected algae were 36 species representing 25 genera classified over four divisions. The dominant division was Cyanophyta, which represented by 18 species from 11 genera, followed by Chlorophyta, eleven species belonging to seven genera, then Bacillariophyta and Xanthophyta. The variation in the soil characters between the studied locations affects both the algae richness and diversity. Correlation analyses have been done to investigate the most effective parameters affecting the algae richness and diversity. This study showed that, the soil texture, moisture content, organic matter and nitrogen concentration are the most effective factors in controlling the diversity of soil algae at the studied locations.

Keywords: Cyanophytes, Diversity of soil algae, Edaphic algae, Microalgae, Physico-chemical of soil.

Introduction

Algae are diverse group of photosynthetic organisms representing the most abundant primary producers among all living organisms. They are usually inhabitants of aquatic biotopes either freshwater or marine habitats. Algae show a great variety of structure and their sizes range from microalgae to the giant seaweeds. They are widespread in wide range of ecological habitats including air, soil or even extreme habitats such as hot springs, deserts or cold regions (**Barsanti and Gualtieri, 2014**).

Algae occurs in terrestrial habitats are called edaphic algae where they occur as free living or as resting spores (**Metting, 1981**). Distribution and diversity of algae in soil are primarily affected by different environmental factors such as degree of exposure to sun light, temperature, water availability and soil properties as well as other biotic factors (**Roger and Reynaud, 1982**). The

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characterization of different terrestrial algal species is of important matter for exploring their diversity and revealing their biochemical composition. Soil algae have the ability of long survival over long times in the form of resting spores and are adapted to adverse conditions such as xeric habitats (**Trainor, 1985; Gupta and Agrawal, 2006; Nayaka *et al.*, 2017**).

Most of the studies on algae conducted on aquatic taxa whether freshwater, alkaline or marine species (**Shaaban, 1994; El-Sheekh *et al.*, 2010; Khairy and El-Shafay, 2013; Bharathiraja *et al.*, 2015; Dos Santos *et al.*, 2017**). The study of the aquatic algae is due to their abundance, easy to observe and propagate in liquid media.

However, purification of mixed soil algal cultures and obtaining of pure and axenic algal strains from the soil is a prerequisite for accurate identification of soil algae and so further any studies of soil algae. In addition, soil contains numerous and diverse potential contaminants such as bacteria, fungi, protozoa, etc., which are difficult to eliminate (**Temraleeva *et al.*, 2016**).

First publications on cultivation of algae from the soil include those by **Bold (1942), Provasoli (1960) and Smith and Wiedeman (1964)**. For successful cultivation of microalgae different growth factors are needed to be optimized such as light, temperature and nutrient media composition (**Andersen, 2005; Singh *et al.*, 2015**). Recently, different techniques are developed for isolation and purification of microalgae especially from soil (**Hodac, 2016; Alam *et al.*, 2019; Colsell, 2020**).

Nowadays, acceptance of algae as soil microorganisms is more widespread because the fact that algae influence soil structure and the activities of other soil inhabiting organisms (**Büdel *et al.*, 2016; van Elsas, 2019**). In general, algae have different ecological roles for the soil ecosystem, the most important is that they represent the only primary producers of oxygen in the soil and serve as sources of energy for the soil microorganisms (**Schinner *et al.*, 2012**). They also provide soil with organic matter and fixed nitrogen which is especially important in reclamation of soil. So that, algae considered as important factor in improving the physical and chemical properties of the soil (**Sylvia *et al.*, 2005**).

The isolation and identification of soil algae have been studied worldwide including all habitats previously (**Blank and Cameron, 1966; Curl and Becker,**

1970; Sullivan and Moncreiff, 1988) and recently (Vijayan and Ray, 2015; Gaysina *et al.*, 2018; Novakovskaya *et al.*, 2020). In Egypt, soil algal flora has been investigated also by different authors. Major studies concerned with algae inhabiting cultivated soils in different regions (El-Ayouty and Ayyad, 1972; Kobbia and Shabana, 1988; Atia, 1993; Ahmed, 1994; Osman, 2003; El-Gamal *et al.*, 2008). As well as, some studies were conducted on soil algal flora of the desert habitats (El-Sheekh *et al.*, 1998; Ibraheem, 2003; Mansour and Shaaban, 2010; Shaaban *et al.*, 2017; Mansour *et al.*, 2020).

The present study aims to investigate the relation of soil physico-chemical parameters to the diversity of their inhabiting algae.

Materials and Methods

1. Soil sample collection

According to soils textures, five different types of soil samples collected from uncultivated sites of Egypt, (Table 1 & 2). Loamy sand soils represented by: sample (1) of MitHelfa (30.149892, 31.235229) and sample (3) of Markaz Belbes (30.355104, 31.446727). Meanwhile, sandy soils were represented by: sample (2) of El Obour (30.249269, 31.480298) and sample (4) of El Khankah (30.233523, 31.379677). In addition to the silty loam soil of sample (5) which collected from Basous, El Kanater El Kheireya (30.131975, 31.218565). The sub-surface soil layers were removed and freed from gravels and debris. Each of the fine collected soil samples was air dried and stored in sterile clean air-tight plastic bags. Then, each soil sample was divided into two parts; the first part was used for algal cultivation, identification, and isolation and the second part was used to determine the physico-chemical properties.

2. Soil physico-chemical analysis

Soil samples were analyzed for determination of different mechanical, physical and chemical parameters at the Desert Research Center in Egypt. First, soil texture (the percentage of sand, silt and clay) were determined by the sedimentation cylinders using the pipette method according to (Page *et al.*, 1982).

Moisture content of the soil was estimated by oven drying of air-dried known weight of soil sample at 100 °C for 3 hours. For the soil extracts (1:5), both of electrical conductivity (mS/m), total dissolved solids (ppt), pH, soluble cations (Na⁺, K⁺, Ca²⁺, Mg²⁺), anions (Cl⁻, SO₄²⁻, HCO₃⁻), available phosphate-P, nitrate-N and micronutrients (Fe, Mn, Cu, Zn) were measured according to **Page *et al* (1982)**. Soil organic matter was determined using the procedure of **Walkely and Black (1934)**.

Table (1): Soil sampling locations.

Soil No.	Location	GPS
S1	MitHelfa, Qalyoub	30.149892, 31.235229
S2	El Obour	30.249269, 31.480298
S3	Markaz Belbes, El Sharqia	30.355104, 31.446727
S4	El Khankah	30.233523, 31.379677
S5	Basous, El Kanater El Kheireya	30.131975, 31.218565

3. Cultivation, isolation and identification of soil algae

Under aseptic conditions, soil samples were inoculated into liquid autoclaved nutritive media (Chu No.10) in triplicate manner (about 1g of soil in a 250-flask containing 100 ml of media). This medium was specifically selected as it considers the most favorable medium for a variety of algae including green algae, diatoms and cyanobacteria **Chu (1942)**. Then, flasks were incubated in continuous light with a temperature of 24 ± 1 °C with continuous shaking until appearance of algal growth.

During the period of propagation, some algal colonies were selected and isolated from the mixture culture again into liquid and solid media to obtain unialgal taxa. Isolation of uni-alga was carried out using the plating and serial dilution method recommended by **Jurgensen and Davey (1968)**. For solid media, about 20 gm of agar-agar were added to one liter of sterilized liquid media, then

constant volume was poured in Petri-dishes (9 cm diameter) and lifted to solidify. Finally, all flasks and plates incubated in the same previous conditions.

Identification of algal taxa were carried out according to **Desikachary (1959)**, **De Desenko-Schegolova and Gollerbach (1962)**, **Prescott (1978)** and **Foged (1980)**. The microscopically examined algal taxa were photographically recorded using the binocular BEL® photonics biological microscope fitted with a Canon Powershot G12 digital camera.

4. Statistical analysis

Data are reported as mean \pm standard deviation from triplicate determination. The physico-chemical analysis of soil samples were compared using one-way ANOVA (SPSS for Windows, version 20) to identify the significant difference between samples ($p < 0.05$). As well as, the relation between soil physico-chemical variables and algal divisions were evaluated using Pearson's correlation coefficient (r) at $p < 0.05$ and $p < 0.01$ and illustrated with the Biplot of Canonical Correspondence Analysis (Canoco for Windows, version 4.5) (**Snedecor and Waddel, 2008**).

Results

1. Soil analysis and algal diversity

1.1. Physico-chemical characteristics of the soil samples

Five soil samples (S1-S5) were collected from different regions in Egypt (see **table 1**). Then, the physico-chemical analysis of the studied soil parameters were recorded in **table (2)**. According to mechanical analysis, soil texture varied significantly among samples under investigation from sandy, sandy loam, silty loam to loamy soil. Large percentage of sand particles (90.48 and 88 % respectively) were the major constituents of soil S2 and S4 followed with the soil samples of S3 and S1 (83 and 79.07 % respectively). Meanwhile, moderate sand percentages were detected in S5 (40 % respectively). In contrast, clay percentages of the soil samples were very low in all studied soil samples. Maximum value of clay was recorded only for S5 (2 %) while lower ratios were detected in S5, S4, S1, S3 and S2 (2, 1.27, 0.45, 0.33 and 0.15 % respectively) (**See fig. 1**).

Table (2): Mechanical, physical and chemical analysis of the studied soil samples (S1: MitHelfa, Qalyoub, S2: El Obour, S3: Markaz Belbes, El Sharqia, S4: El Khankah, S5: Basous, El Kanater El Kheireya).

	S1	S2	S3	S4	S5
Sand (%)	79.07 ^d ±3.55	90.48 ^a ±4.51	83.00 ^c ±2.98	88.00 ^b ±3.67	40.00 ^f ±1.28
Silt (%)	20.48 ^c ±0.23	9.37 ^f ±0.17	16.67 ^d ±0.54	10.73 ^e ±0.23	58.00 ^a ±1.34
Clay (%)	0.45 ^d ±0.08	0.15 ^f ±0.01	0.33 ^c ±0.07	1.27 ^e ±0.03	2.00 ^b ±0.21
Texture	Loamy sand	Sand	Loamy sand	Sand	Silty loam
pH	7.86 ^c ±0.14	8.30 ^b ±0.32	8.36 ^a ±0.26	7.06 ^e ±0.15	7.84 ^c ±0.18
E.C (mS/m)	15.8 ^a ±0.67	0.56 ^c ±0.04	0.24 ^e ±0.01	0.44 ^d ±0.03	0.92 ^b ±0.08
T.D.S (ppt)	7.92 ^a ±0.34	0.28 ^c ±0.03	0.12 ^e ±0.01	0.22 ^c ±0.02	0.46 ^b ±0.05
O.M.(%)	2.76 ^d ±0.32	0.12 ^f ±0.01	0.87 ^e ±0.04	3.49 ^b ±0.42	4.86 ^a ±0.51
M.C. (%)	18.64 ^b ±0.77	0.23 ^f ±0.02	7.46 ^d ±0.61	12.13 ^c ±0.29	23.12 ^a ±0.82
Na⁺	2713.25 ^a ±6.50	60.23 ^b ±0.98	13.10 ^e ±0.14	44.60 ^c ±0.43	57.48 ^b ±0.23
K⁺	69.21 ^a ±0.71	2.35 ^f ±0.13	3.13 ^c ±0.32	16.03 ^c ±0.33	17.99 ^b ±0.45
Ca⁺⁺	872.54 ^a ±4.10	41.68 ^d ±1.26	30.06 ^f ±1.73	107.82 ^b ±3.22	104.41 ^c ±2.82
Mg⁺⁺	440.13 ^a ±3.97	10.09 ^c ±0.35	3.04 ^d ±0.29	11.91 ^c ±0.42	12.52 ^c ±0.57
Cl⁻	4837.86 ^a ±8.10	73.74 ^e ±0.75	58.14 ^f ±2.70	128.33 ^b ±3.78	112.73 ^c ±3.48
SO₄⁻	2809.76 ^a ±5.82	42.75 ^d ±1.70	33.62 ^e ±1.18	163.30 ^c ±3.89	238.23 ^b ±4.90
HCO₃⁻	282.52 ^a ±4.32	161.09 ^b ±3.93	3.66 ^f ±0.28	102.51 ^d ±3.50	65.29 ^e ±0.59
N	44 ^d ±0.19	26 ^f ±0.09	55 ^b ±0.44	42 ^e ±0.10	52 ^c ±0.34
P	12.2 ^c ±0.22	2.3 ^e ±0.08	8.2 ^d ±0.12	24.2 ^a ±0.20	1.38 ^f ±0.07
Fe	28 ^c ±0.33	19 ^d ±0.17	18 ^e ±0.19	32 ^b ±0.26	36 ^a ±0.41
Mn	22 ^c ±0.30	11 ^e ±0.13	14 ^d ±0.15	24 ^b ±0.23	28 ^a ±0.40
Zn	18 ^a ±0.16	8 ^e ±0.09	10 ^d ±0.18	14 ^c ±0.27	16 ^b ±0.28
Cu	10 ^b ±0.99	4 ^e ±0.04	6 ^d ±0.07	10 ^b ±0.10	9 ^c ±0.09

*Values are expressed as average ± standard error. Different letters indicate a significant difference at the level of $p \leq 0.05$.

On the other hand, pH values showed non-significant variations in the investigated soil samples where it was slightly to moderately alkaline (7.06 to 8.36). In relevant to organic matter and moisture contents, there was a significant positive relation between them (**See fig. 1**). Higher value of organic matter was observed in S5 (4.86 %) location followed by nearable values of S4, and S1 (3.49 and 2.76 % respectively) whereas, minimum value (0.87 and 0.12 %) were recorded in both S3 and S2. In the same manner, moisture content was the highest in S5 (23.12%) followed by soil samples of S1, S4 and S3 (18.64, 12.13 and 7.46 % respectively) and lowest percentage was recorded only for S2 soil sample (0.23 %).

Regarding to the chemical analysis of soil samples, values of cations (Na^+ , K^+ , Ca^{2+} and Mg^{2+}) (2713.25, 69.21, 872.54 and 440.13 ppm respectively) and anions (Cl^- , SO_4^{2-} and HCO_3^-) (4837.86, 2809.76 and 282.52 ppm respectively) were the maximum in soil of S1 among all locations. Moreover, data of **fig (1)** showed maximum records for EC and TDS values (15.84 mS/m and 7.92 ppt respectively). However, lower contents of the same ions were recorded in S3; cations (13.10, 3.13, 30.06, 3.04 ppm respectively) and anions (58.14, 33.62 and 3.66 ppm respectively). So that, lower EC and TDS values also were recognized (0.24 mS/m and 0.12 ppt respectively). In addition to, relatively higher concentrations of Ca^{2+} , Cl^- and SO_4^{2-} were recorded in the soil samples of S4 (107.82, 128.33 and 163.30 ppm respectively) and S5 (104.41, 112.73 and 238.23 ppm respectively). Also, HCO_3^- values were higher in S2, S6 and S4 locations (161.09, 118.38 and 102.51 ppm respectively). While other locations showed non-significant differences in the previous parameters (**See table 2**).

Moreover, location S2 has minimum values of nitrogen whereas for phosphorous lower values were found in S5 (1.38 ppm). On the other side, maximum value for nitrogen was recorded in S3 and S5 (55 and 52 ppm) whereas other localities recorded nearable values (**See Fig. 1**) as well as maximum value of phosphorous was detected in S4 (24.2 ppm). Additionally, lower micronutrients contents (Mn, Fe, Zn and Cu) were also observed in Soil No.2 (19, 11, 8 and 4 ppm respectively).

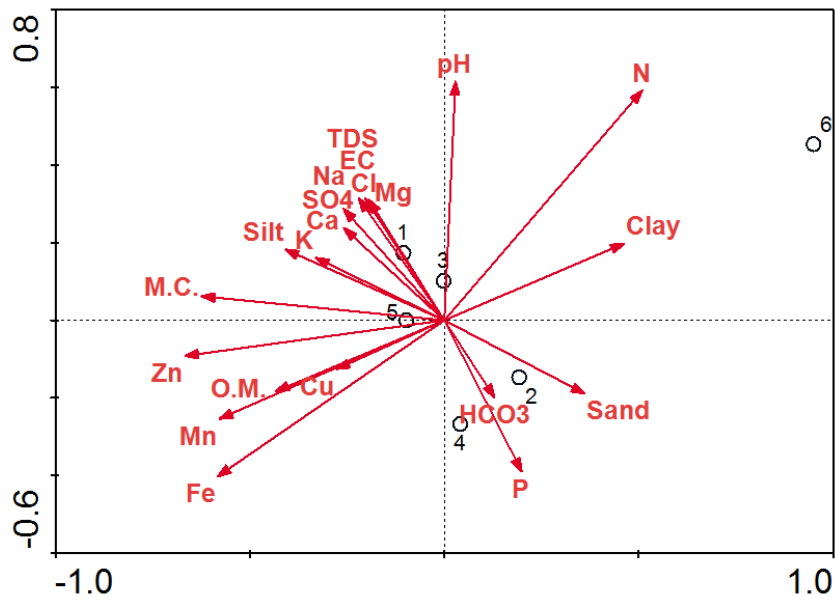


Figure (1): Biplot of Canonical Correspondence Analysis showing the relationships between the different localities under investigation and physico-chemical parameters of the soil.

1.2. Algal diversity of the collected soil samples

Data in **table (3)** revealed the presence of total 36 algal taxa (25 genera) in the algal mixtures of all soil samples belonging to four algal divisions. These were dominated with Cyanophyta about 18 blue green algal taxa (11 genera) followed by Chlorophyta 11 green algal taxa (7 genera), while Bacillariophyta (Diatoms) and Xanthophyta (Yellow-green) were represented only by 4 and 3 algal taxa respectively.

Table (3): Total number of algal taxa (genera) recorded per each algal division within the different locations understudy.

Algal divisions	S1	S2	S3	S4	S5
Cyanophyta	1	2	10 (6)	3	8 (6)
Chlorophyta	2	2	4 (3)	2	8 (5)
Xanthophyta	-	2	2	1	-
Bacillariophyta	1	-	4	-	3
Total	4	6	20 (15)	6	19 (14)

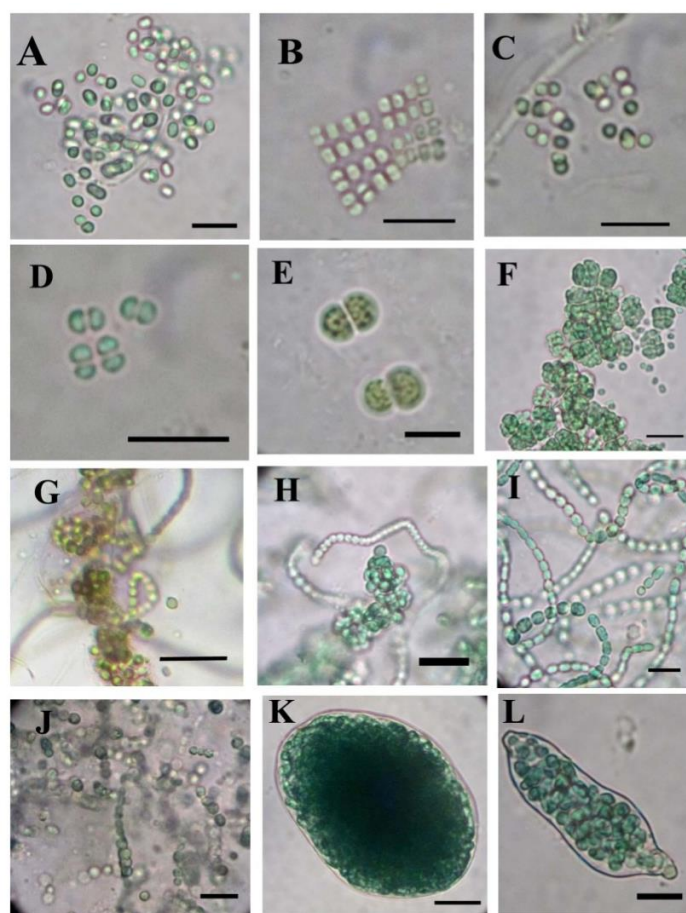
Among the highly recorded blue-green algal taxa were *Stratonostoc linckia* (Roth) Elenk and *Anabaena constricta* (Szaf.) Geitl. On the other side, the most dominant species of Chlorophyta among different locations were *Chlamydomonas globosa* Snow and *Scenedesmus bijugatus* var. *graevenitzii* (Bernard) comb. nov. Concerning Xanthophyta, only three taxa were revealed namely *Chloridella simplex* Pasch., *Pleurochloris pyrenoidosa* Pasch. and *Botrydiopsis eriensis* Snow. Meanwhile, rarely frequency of Bacillariophyta was recorded at all soil samples (Table 4).

Regarding the number of recorded algal taxa within each site (Table 3), the soil No (3) was found to be the richest one (20 taxa) and S5 (19 taxa) followed by S4 and S2 (6 taxa each one). However, the least number of taxa was noted in S1 (4 taxa). It was shown also that, the largest number of blue-green algae was recorded in S3 followed by S5 (10 and 8 algal taxa respectively), while the lowest number was found at S4, S2 and S1 (3, 2 and 1 algal taxa respectively). In addition, S5 showed rich flora of Chlorophyta followed by S3 (8, 4 algal taxa respectively), meanwhile other locations were poor in Chlorophyta. Concerning Xanthophyta, only 3 algal taxa were found at S2, S3 and S4. However, Bacillariophyta were represented only in the soils of S1, S3 and S5.

Table (4): Recorded soil algal flora of the locations under investigation.

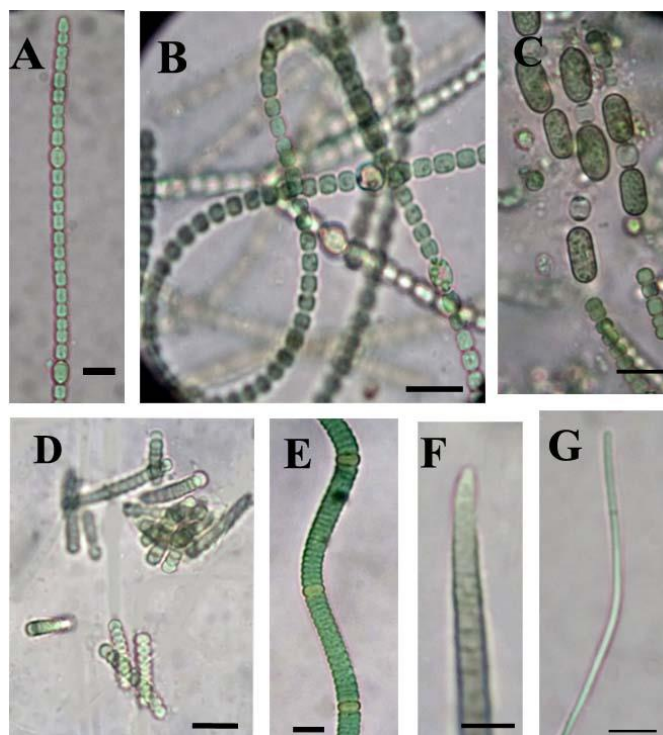
	Plate	Fig.	S1	S2	S3	S4	S5
Cyanophyta							
<i>Aphanothece microscopica</i> Näg.	1	A	-	-	-	-	+
<i>Merismopedia punctate</i> Meyen	1	B	-	-	-	-	+
<i>Gloeocapsa minor</i> (Kütz.) Hollerb.	1	C	-	-	-	-	+
<i>Gloeocapsa minuta</i> (Kütz.) Hollerb.	1	D	-	-	-	-	+
<i>Gloeocapsa turgida</i> (Kütz.) Hollerb.	1	E	-	-	-	-	+
<i>Myxosarcina chroococcoides</i>	1	F	-	+	-	-	-
<i>Amorphonostoc paludosum</i> (Kütz.) Elenk	1	G	-	-	+	-	-
<i>Amorphonostoc punctiform</i> f. <i>populorum</i> (Kütz.) Elenk.	1	H	-	-	+	+	-
<i>Stratonostoc linckia</i> f. <i>linckia</i> (Roth) Elenk.	1	I	-	+	+	-	+
<i>Stratonostoc linckia</i> f. <i>calcicola</i> (Bréb.) Elenk	1	J	-	-	-	+	-
<i>Sphaeronostoc corulum</i> (Lyngb.) Elenk	1	K	-	-	+	-	-
<i>Sphaeronostoc microscopicum</i> (Carm.) Elenk	1	L	-	-	+	-	-
<i>Anabaena constricta</i> (Szaf.) Geitl	2	A	+	-	+	-	+
<i>Anabaena contorta</i> Bachm	2	B	-	-	-	+	-
<i>Anabaena oscillarioides</i> Bory	2	C	-	-	+	-	-
<i>Nodularia harveyana</i> f. <i>sphaerocarpa</i> (Born. et. Flah.) Elenk	2	D	-	-	-	+	-
<i>Calothrix brevissima</i> G. S. West	2	E	-	-	+	-	-
<i>Oscillatoria jatorvensis</i> Vouk	2	F	-	-	+	-	-
<i>Oscillatoria princeps</i> Vaucher	2	G	-	-	+	-	+
Total					18 (11)		
Chlorophyta							
<i>Chlamydomonas globosa</i> Snow	3	A	-	+	+	+	-
<i>Tetraedron minimum</i> (A. Braun) Hansg.	3	B	+	-	-	-	-
<i>Chlorococcum humicola</i> (Naegeli) Rabenhorst	3	C	-	-	-	-	+
<i>Chlorella vulgaris</i> Beijerinck	3	D	-	-	+	-	+

<i>Scenedesmus bijugatus</i> Kütz	3	E	-	+	+	+	-
<i>Scenedesmus bijugatus</i> var. <i>graevenitzii</i> (Bernard) comb. nov.	3	F	-	-	-	-	+
<i>Scenedesmus obliquus</i> (Turpin) Kütz	3	G	+	-	+	-	+
<i>Scenedesmus quadricauda</i> (Turpin) Brébisson	3	H	-	-	-	-	+
<i>Pediastrum simplex</i> var. <i>duodenarium</i> (Bailey) Rabenh	3	I	-	-	-	-	+
<i>Pediastrum duplex</i> var. <i>reticulatum</i> (Meyen) Lagerheim	3	J	-	-	-	-	+
<i>Coelastrum microporum</i> Nägeli	3	K	-	-	-	-	+
Total						11 (7)	
Xanthophyta							
<i>Chloridella simplex</i> Pasch.	3	L	-	+	+	-	-
<i>Pleurochloris pyrenoidosa</i> Pasch.	3	M	-	+	-	-	-
<i>Botrydiopsis eriensis</i> Snow	3	N	-	-	+	+	-
Total						3	
Bacillariophyta							
<i>Cyclotella</i>			-	-	+	-	+
<i>Achnanthus</i>			+	-	+	-	-
<i>Nitzschia</i>			-	-	+	-	+
<i>Synedra</i>			-	-	+	-	+
Total						4	



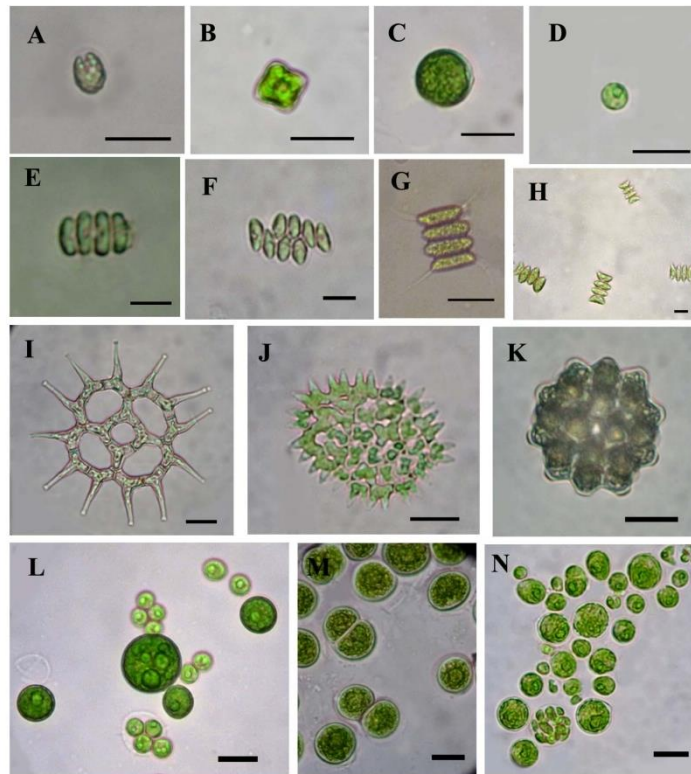
*Scale bar = 10 μ m.

Plate 1 (A-L): Figs. A) *Aphanothece microscopica* Näg. B) *Merismopedia punctate* Meyen, C) *Gloeocapsa minor* (Kütz.) Hollerb. D) *Gloeocapsa minuta* (Kütz.) Hollerb. E) *Gloeocapsa turgida* (Kütz.) Hollerb. F) *Myxosarcina chroococcoides* Geitler. G) *Amorphonostoc paludosum* (Kütz.) Elenk. H) *Amorphonostoc punctiform* f. *populorum* (Kütz.) Elenk. I) *Stratonostoc linckia* f. *linckia* (Roth) Elenk. J) *Stratonostoc linckia* f. *calcicola* (Bréb.) Elenk, K) *Sphaeronostoc corulum* (Lyngb.) Elenk, L) *Sphaeronostoc microscopicum* (Carm.) Elenk.



*Scale bar = 10 μ m.

Plate 2 (A-G) Figs. A) *Anabaena constricta* (Szaf.) Geitl. B) *Anabaena contorta* Bachm. C) *Anabaena oscillarioides* Bory. D) *Nodularia harveyana* f. *sphaerocarpa* (Born. et. Flah.) Elenk. E) *Calothrix brevissima* G. S. West. F) *Oscillatoria jasorvensis* Vouk. G) *Oscillatoria princeps* Vaucher.



*Scale bar = 10 μ m.

Plate 3 (A-N): Figs. A) *Chlamydomonas globosa* Snow. B) *Tetraedron minimum* (A. Braun) Hansg. C) *Chlorococcum humicola* (Nageli) Rabenhorst. D) *Chlorella vulgaris* Beijerinck. E) *Scenedesmus bijugatus* Kütz. F) *Scenedesmus bijugatus* var. *graevenitzii* (Bernard) comb. nov. G) *Scenedesmus obliquus* (Turpin) Kütz. H) *Scenedesmus quadricauda* (Turpin) Brébisson. I) *Pediastrum simplex* var. *duodenarium* (Bailey) Rabenh. J) *Pediastrum duplex* var. *reticulatum* (Meyen) Lagerheim. k) *Coelastrum microporum* Nägeli. L) *Chloridella simplex* Pasch. M) *Pleurochloris pyrenoidosa* Pasch. N) *Botrydiopsis eriensis* Snow.

1.3. Correlation between the soil physico-chemical parameters and the identified algal taxa

The relation between the soil physicochemical parameters and the inhabiting algal divisions was assessed using Pearson's correlation coefficient in **table (5)** and illustrated using Biplot of Canonical Correspondence Analysis in **fig (2)**. Concerning Chlorophyta, there was a markedly negative correlation ($r = -0.901$ at $p < 0.01$) with total sand and significant positive relationships with silt ($r = 0.900$ at $p < 0.01$) and clay content ($r = 0.741$ at $p < 0.05$) of the soil. On the other hand, members of Xanthophyta showed significant positive relation ($r = 0.658$ at $p < 0.05$) with total sand and significant negative relation with silt ($r = -0.654$ at $p < 0.05$) and clay content ($r = -0.633$ at $p < 0.05$) of their soil.

As regard to Xanthophyta, there was markedly significant negative relationship ($r = -0.943$ and -0.858 at $p < 0.01$) between moisture content and organic matter of the soil and its inhabiting yellow-green algae (**See table 5**). In contrary, other algal divisions showed moderate significant positive effect especially members of Chlorophyta (**Fig.2**). Moreover, the results indicated the strong significant negative correlation ($r = -0.852$, -0.882 , -0.964 and -0.838 respectively at $p < 0.01$) between Xanthophyta and all available micronutrients Fe, Mn, Cu and Zn. In general, there were also weak significant negative correlation between yellow-green algae and variable parameters including EC, TDS, cation (Na^+ , K^+ , Ca^{2+} , Mg^{2+}), anions (Cl^- , SO_4^{2-} , HCO_3^-) and nitrogen content.

On the other hand, Cyanophyta revealed strong significant negative correlation with all ionic contents of the soil particularly Na^+ , Ca^{2+} and Mg^{2+} ($r = -0.634$, -0.637 and -0.635 respectively at $p < 0.05$) as well as EC and TDS (**Fig. 2**). **Table (5)** showed also that, HCO_3^- content of the soil is negatively affecting all algal divisions under the study with markedly significant relation with Cyanophyta ($r = -0.940$ at $p < 0.01$) followed by Bacillariophyta algal taxa ($r = -0.638$ at $p < 0.05$). Results showed also strong significant positive correlation between nitrogen ($r = 0.846$ at $p < 0.01$) for Bacillariophyta and moderate in Cyanophyta ($r = 0.721$ at $p < 0.05$) and Chlorophyta ($r = 0.673$ at $p < 0.05$).

Table (5): Pearson's Correlation Coefficients (*r*) between soil analysis of the selected sites and inhabiting algal divisions.

** Correlation is significant at the 0.01 level (1-tailed)

* Correlation is significant at the 0.05 level (1- tailed).

	Cyanophyta	Chlorophyta	Xanthophyta	Bacillariophyta
Total sand	-0.370	-0.901**	0.658*	-0.518
Silt	0.370	0.900**	-0.654*	0.527
Clay	0.289	0.741*	-0.633*	0.187
pH	0.258	0.084	0.463	0.460
EC	-0.630	-0.388	-0.583	-0.186
TDS	-0.630	-0.388	-0.583	-0.186
O.M.	0.062	0.568	-0.858**	0.103
M.C.	0.050	0.560	-0.943**	0.294
Na	-0.634*	-0.408	-0.565	-0.194
K	-0.603	-0.270	-0.743*	-0.191
Ca	-0.637*	-0.375	-0.628	-0.208
Mg	-0.635*	-0.406	-0.570	-0.196
Cl	-0.628	-0.406	-0.568	-0.190
SO4	-0.622	-0.366	-0.616	-0.183
HCO3	-0.940**	-0.626	-0.432	-0.638*
N	0.721*	0.673*	-0.331	0.846**
P	-0.234	-0.463	-0.083	-0.418
Fe	-0.092	0.457	-0.852**	-0.083
Mn	0.010	0.505	-0.882**	0.072
Zn	-0.270	0.208	-0.964**	0.013
Cu	-0.187	0.141	-0.839**	-0.072

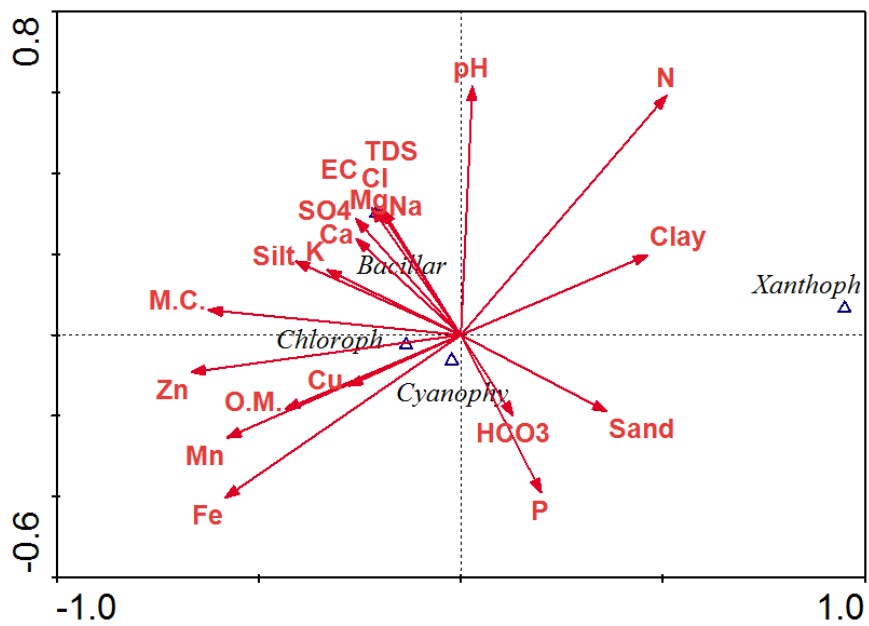


Figure (2): Biplot of Canonical Correspondence Analysis showing the relationships between the soil physicochemical parameters of localities under investigation and its inhabiting algal divisions.

Discussion

Despite of the generally known aquatic habitats of algae, they are also occupying different terrestrial habitats range from cold to hot environments as well as arid deserts. They occur either on the surface or down to several centimeters in the soil. Soil algae can survive a habitat with very low light intensities and low nutrients (**Hoffmann, 1989**). According to **Bold and Wynne**

(1978), the algal flora of the soil includes mostly members of Cyanophyta, Chlorophyta, Euglenophyta, Bacillariophyta and Xanthophyta.

The current results clearly indicated that many of the studied soil physico-chemical parameters varied between the studied soil localities. Previous studies of **Shields and Durrell (1964)**, **Macentee *et al* (1972)** and **Ibraheem and Al-Sherif (2009)** reported also the association between the soil properties and their inhabiting algae.

One of the most parameters affecting algal distribution in the soil is the proportion of sand, silt and clay particles (soil texture) according to **Starks *et al* (1981)**. In the present study, soil samples varied in their texture from site to another. The high percentage of sand particles confined to the soil of S2 and S4, while maximum ratio of silt and clay was associated with S3 and S5 soil. Our results showed a significant positive correlation between silt and clay soil structure and green algal members; however sandy soil exhibited a significant negative correlation. On the other hand, members of Xanthophyta showed significant positive relation with sand particles. In this respect, the present result indicates the role of silt and clay in selecting and distribution of green algae. According to **de Cano *et al* (1997)**, fine particles such as silt and clay lead to more exposed surface in contrast to sandy soil which may result in the availability of more algae. However, results obtained by **Fathi and Zaki (2003)** indicated that the response of algal biomass at the different investigated sites to soil texture is not reflected in retarded or activated algal growth.

Also, soil pH is an important factor in determining the composition of algal communities. Our data revealed that, pH values of all soil samples under investigation were neutral to slightly alkaline. This may explain the greatest number of identified algal taxa from Cyanophyta over algal members of Chlorophyta and other groups. According to previous studies of **Brock (1973)**, blue-green algae was completely absent at low pH, whereas Chlorophyta and other eukaryotic algae flourish. It was confirmed later also by many studies (**Salama and Kobbia, 1982; El-Gamal, 1995; El-Attar, 1999**). Moreover, the high percentage of the cyanobacterial taxa in all investigated locations can be explained by the mechanisms employed by cyanobacterial cells to tolerate diverse conditions (**Metting, 1981**). Such assumption is in accordance with that of

Kobbia and Shabana (1988), Ibraheem (2003) and Shaaban *et al* (2016) who explained the ability of blue-green algae to survive under variable conditions.

Although, it was no significant relation between pH and Cyanophyta, but this may be a result of non-significant differences indicated by the statistical analysis among the studied soil regions in pH values. In consistent, results observed by **Zancan *et al* (2006)** revealed that neutral conditions support the growth of most algal groups.

Results showed also higher algal populations of both S3 and S5 localities, especially cyanobacteria which may be attributed to the soil structure (high % of silt and clay) of those sites. Another explanation, may be the relatively high nitrogen content of both sites which reflect their significant positive effect on the growth and multiplication of the soil algal flora as recorded before by **Lund (1947)** and **Salama and Kobbia (1982)**.

Additionally, the presence of higher algal taxa in location S3 may be attributed to the nature of soil sample which located near cultivated land and so the possibility of the enrichment of the soil with N and P is present. Whereas, the reason for higher algal populations in site 5 could be due to relatively higher moisture content and organic matter of the soil. Both of them considered as a prime factor in abundance of algae in soils as described before by **Al-Fredan and Fathi (2007)** and **El-Hameed *et al* (2007)**. Water availability is of primary importance in controlling life in terrestrial habitats in which water is present in the minute spaces between soil particles (**Kennedy, 1993**).

On the other hand, lower number of algal taxa in location S1 may be a result of the high salinity in this site even in the presence of high ratio of silt and clay. According to **Handley (2003)**, one of the most factors that also affect algal diversity, the presence of Sodium chloride in relatively high concentrations in the soil. Our results revealed also, there was a significant negative correlation between sodium ion ratio and the number of algal taxa especially of blue green algae as observed before also by **Alghanmi and Jawad (2019)**.

The green soil algal taxa of this study showed moderate positive relation with organic matter and moisture content. This was confirmed by the presence of *Chlorella vulgaris*, *Chlorococcum humicola* and *Coelastrum microporum* (green algae) in the location of S5 (Maximum values for O.M and M.C). Both algal

species have predilection for organic matter and moisture content as essential factors for their growth. On the other hand, previous studies speculated that the organic nutrients might have a great effect on algae in terms of fertilization than inorganic nutrients (Ketchum, 1951).

It is also evident from results the presence of non-heterocytous cyanophytes *Oscillatoria jatorvensis* Vouk, *O. princeps* Vaucher and *O. terebriformis* (Ag.) Elenk (bio-indicators of eutrophication) in site S3 and S5 might be linked to relative high content of available nitrogen (Nowicka-Krawczyk and Zelazna-Wieczorek, 2013; Mateo *et al.*, 2015; Shaaban *et al.*, 2015). In this connection, diatoms of certain soils grow only where appreciable amount of phosphorous and nitrates are available (Lund and John, 1945) which may explain the low percentage of this algal groups throughout the study. Finally, the presence of many heterocytous cyanophytes within the studied area particularly *Nodularia harveyana* f. *sphaerocarpa* (Born. et Flah.) Elenk can be recommended for the evaluation of atmospheric N₂-fixation efficiency as mentioned before by Shaaban *et al* (2017).

Based on overall comparison of locations for many soil variables and algal populations revealed that, the soil texture, moisture content, bicarbonate, nitrogen and micronutrients are the most highly significant factors in controlling the diversity of soil algae at different locations. Finally, significant variation in soil properties throughout the studied locations as well as the correlations between edaphic algae and specific soil parameters was detected at this study.

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صفات التربة الفيزيائية والكيميائية وعلاقتها بالمحتوى الطحلي لها

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تم تجميع خمس عينات من التربة (1-5) من مناطق مختلفة في مصر لدراسة تأثير العوامل الفيزيوكيميائية للتربة على تنوع الطحالب بها. وأشارت الدراسة الحالية لوجود العديد من الاختلافات الفيزيائية والكيميائية بين عينات التربة المدروسة والتي بدورها أدت لوجود اختلاف في المكون الطحلي لهم. حيث أوضحت النتائج أن درجة القاعدية للعينات متعادلة وتميل قليلا الى القلوية. وسجل أيضا ارتفاع في المحتوى النيتروجيني في عينات رقم 3 و5. أما دراسة التنوع الطحلي في جميع المواقع تحت الدراسة قد أسفرت عن وجود 36 نوع من الطحالب تنتمي الى 25 جنس والتي تتمثل في 4 أقسام طحلبية. هذا وقد سادت فيها مجموعة الطحالب الخضراء المزرقة حوالي 18 نوع (11 جنس)، يليها مجموعة الطحالب الخضراء حوالي 11 نوع (7 جنس) وأخيرا مجموعة الطحالب العسوية والخضراء المصفرة. وبعد لاختلافات صفات التربة تأثيرا على تنوع وكمية الطحالب فيها. و في النهاية أستنتج من هذه الدراسة أن أكثر صفات التربة تأثيرا في وجود طحالب التربة وتنوعها هي تركيب التربة والمحتوى المائي، العضوي والنيتروجيني للعينات تحت الدراسة.