Journal of Algal Biomass Utilization
J. Algal Biomass Utln. - Copyright © PHYCOSPECTRUM
ISSN: 2229 – 6905

Cyanobacteria and algae in biological soil crust of East Khasi Hills, Meghalaya

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ABSTRACT

In the present study, algae inhabiting soil crust during the dry seasons (winter and Spring) and wet seasons (monsoon and post monsoon) were collected from selected landuse type in East Khasi Hills, Meghalaya. A total of 40 species belonging to 27 genera were recorded with Cyanobacteria (31 species) as the most dominant group followed by Chlorophyceae (4 species), Trebouxiophyceae (3 species) and Zygnematophyceae (2 species). Cyanobacteria (*Microcoleus*, *Scytonema*, *Stigonema* and *Schizothrix*) were the major group in these crusts during the dry seasons while filamentous green algae (*Microspora* and *Zygnema*) mostly prevalent during wet season. Soil parameters like moisture content, organic content, total nitrogen and available phosphorus differed significantly ($p<0.05$) in the crusted and uncrusted soil while no significant differences were observed in pH and potassium. Further, positive correlation between the algae in crust and soil characteristics revealed that the growth of algae on the soil surface positively influenced the moisture content, organic carbon, total nitrogen and phosphorus.

Key words: Soil crust, Cyanobacteria, Green algae, Moisture content, Potassium.

INTRODUCTION

Biological soil crusts (BSCs) are intimate association (in different proportions) between soil and organisms like Cyanobacteria, algae, fungi, lichens and sometimes bryophytes (Belnap et al., 2001). BSCs also referred to as cryptogamic, crytobiotic, microphytic, microbiotic, or microfloral soil crust by many others (West, 1990; Harper and Marbel, 1988). Since, biological soil crusts are in close association with the soil surface they play an important role in ecosystems processes and were able to withstand extreme environment conditions like temperature and scarcity of water where such conditions act as barrier for plant growth (Ullmann and Büdel, 2001).

BSC increase soil quality by soil stabilisation, cohesion and resistance to erosion (Rossi et al., 2017) and also increases soil surface temperature and modify water infiltration balance (Kidron and Yair, 1997). They also enhanced soil fertility by carbon (Beymer and Klopatek, 1992) and nitrogen fixation and make it available to plants in utilisable form (Pendleton et al., 2003).

Many investigators have studied and reported soil crust from arid and semi-arid regions (Belnap and Gillette, 1998; Belnap, 2002; Warren, 2001; Maestre et al., 2011) but such studies are very limited from Asia and Indian subcontinent. Soil crust from Indian subcontinent has been studied by many researchers (Venkatraman et al., 1974; Marathe and Kushaldas, 1997; Adhikary and Sahu., 2000; Tirkey and Adhikary, 2006; Sethi et al., 2012; Vinoth et al., 2017). Information on soil crust from this part of the region is limited, this study therefore aimed to survey the soil crust in East Khasi Hills, Meghalaya.

MATERIALS AND METHODS

Collection of algal samples

Crusted samples and soil samples were collected from selected landuse (agricultural farmlands, forests and plantation) of East Khasi Hills during dry seasons (winter and spring) and wet seasons (monsoon and post monsoon). The crust samples were kept in sterilised bottles and transported back to the laboratory. Some crust samples were wetted for immediate observation while some were incubated in BG 11 medium and Bold's basal medium at 25 ± 1^{0}C in light intensity of 40 µmol photons m^{-2} s^{-1} for 30 days. The organisms were morphometrically analysed under Olympus BX41 and Scanning electron microscope (SEM) was use to observed the delicate structure. Abundance was determined as individual/cm^2. All algae observed were identified using standard books and monograph like Fritsch (1935), Desikachary (1959), Philipose (1967), Prescott (1982), Gandhi (1998) and John et al. (2002) and (Guiry and Guiry, 2019).

Physico-chemical parameters of soil

Physico-chemical properties like pH, moisture content, soil temperature, organic carbon, nitrogen, phosphorus and potassium of both crusted and uncrusted soil were analysed. Soil pH was read using an electronic digital pH meter (pHtestr 20). Soil moisture content was determined by oven dry basis. Soil temperature was recorded using a soil thermometer. Soil organic carbon and total nitrogen were estimated following the method by Anderson and Ingram (1993). Available phosphorus was measured by following molybdenum blue method by Allen et al. (1974) while exchangeable potassium was estimated using flame photometer method by Jackson (1973).

Data analysis

Data were analysed by t-test in order to compare soil characteristics between crusted and uncrusted soils from all selected landuse. Pearson's correlation was performed between the algae species and physico-chemical parameter of soil.

Chlorophyll content

Chlorophyll content of crust was determined immediately while some are wetted and kept for 24 hours before chlorophyll analysis. Air dried samples of about 1 g was extracted with 5 ml of 90% methanol for 3 h followed by incubation for 2 min at 60ºC in a water bath. Absorption spectra was read at 663 nm measured in Cary 60 UV-Vis spectrophotometer. The amount of chlorophyll a was determined following Mackinney (1941).

Chlorophyll a (μg g^{-1}) = O.D at 663 nm x 12.63

RESULTS

Morphology of the crust

Biological soil crusts observed were mostly of mat, crust and patch forms. Soil crust during monsoon and post monsoon were of greenish or blue green mat, crust or patches, while during the winter and spring crust form are mostly of brown or blackish mat and crust. The mat form of soil crust appeared thick blackish or greenish in colour and tightly bound with the soil surfaces **(Figure 1).** Observations after wetting for 24 h revealed the brownish or greenish coloured filaments of particular Cyanobacteria or filamentous green algae. The morphological features of these organisms were not sufficient for identification, however upon culture different Cyanobacterial species were observed as major components of soil crust **(Figure 2, a & b).**

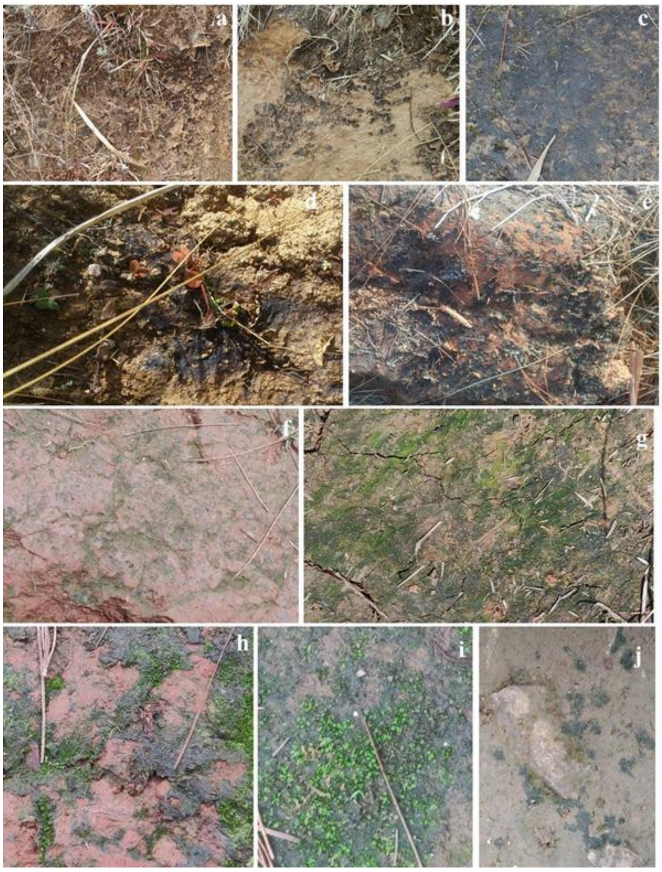


Figure 1: Photograph of soil crust (a) Light brown crust (b) Brownish crust (c) Blackish mat (d) Brownish black crust (e) Black crust (f) Light green patches (g) Dark green patches (h) Dark blue green patch (thick) (i) Dark blue green mat (j) Dark blue green patches (thin).

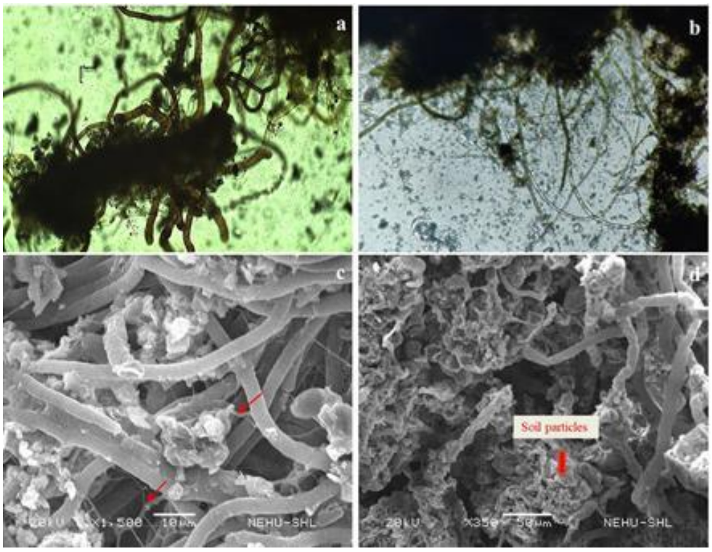


Figure 2: Microscope photographs - a. *Scytonema* dominated crust, b. *Microspora* dominated crust; SEM Photography - c. red arrows indicated the fibre sheath, d. sheath holding the soil particles.

Cyanobacteria and green algae binding to soil particles even after extensive cleaning of soil crust. Cyanobacteria like *Microcoleus*, *Scytonema*, *Stigonema* and *Schizothrix* found in crust are observed to consist of thick sheath material which can be seen winding through and among soil particles connecting the individual grains together. These sheath acts as fibres that seems to have great tensile strength and forms net like structures which holds the soil particles firmly in place, thus prevent soil loss **(Figure 2, c & d).** Filamentous green algae such as *Microspora* and *Zygnema* form thick multi layered mat like structure intertwined with the upper millimetres of soil were observed to be dominant during the wet seasons. Unicellular green algae like *Trebouxia*, *Chlorella*, *Myrmecia* present in the crust wre protected by the filamentous mat not only from the heat but also from vanishing during the cleaning process.

Algal composition and abundance

A total of 40 species belonging to 27 genera was recorded. Out of 40 species, Cyanobacteria (31 species) was recorded as the most dominant followed by Chlorophyceae (4 species), Trebouxiophyceae (3 species) and Zygnematophyceae (2 species). Cyanobacteria (*Microcoleus*, *Scytonema*, *Stigonema* and *Schizothrix*) were the major group in these crusts during the dry seasons while filamentous green algae (*Microspora* and *Zygnema*) mostly prevalent during wet seasons. Unicellular green algae are mostly in the form of spores, cysts and vegetative cells **(Table 1).**

Abundance (Individuals/cm^2) during the dry seasons was mainly dominated by the genus *Scytonema* and *Stigonema*. *Scytonema papilicapitatum* and *Lyngbya aestuarii* dominated in light brown crust. The brownish crust on soil of citrus plantation harboured Cyanobacteria like *Scytonema hyalinuum* and *Microcoleus vaginatus* whereas the dominant species in blackish mat of soil of Mawphlang sacred grove were *Scytonema mirabile* and *Stigonema ocellatum*. On blackish crust soil of potato/maize field, *Nostoc muscorum* and *Gloeothece samoensis* were dominant, and in black crust in pine forest *Schizothrix tinctoria* and *Stigonema mammilosum* were abundant. The associated components in those crusts and mats were represented by Cyanobacteria genera like *Asterocapsa* and *Plectonema,* while green algal form *Trebouxia erici and Chlorella vulgaris* were observed **(Figure 3 a).**

During the wet seasons, green algal forms were also represented as dominant genera. Filamentous green algae *Microspora willeana* and *Oscillatoria rubescens* were observed in light green crust in soil of citrus plantation whereas *Leptolyngbya scotia* and *Oscillatoria curviceps* harboured the dark green patches of shifting cultivated land. *Schizothrix telephorioides* and *Phormidium retzii* were observed from blue green patches of forest floor of pine forest. In dark blue green mat of Mawphlang sacred grove, dominant species observed were *Microcoleus chthonoplastes and Oscillatoria limosa*. Filamentous green algae *Zygnema* sp was also observed in abundant in this field. From blue green patch of potato/rice field, *Leptolynbya vincentii* and *Chlorococcum acidum* were dominant. Associated species observed were *Anabaena spiroides*, *Chlorogloea* sp, *Gloeocapsa atrata*, *Nostoc linckia* and green algal genus observed were *Oedogonium*, *Myrmecia*, *Chlorella* **(Figure 3 b).**

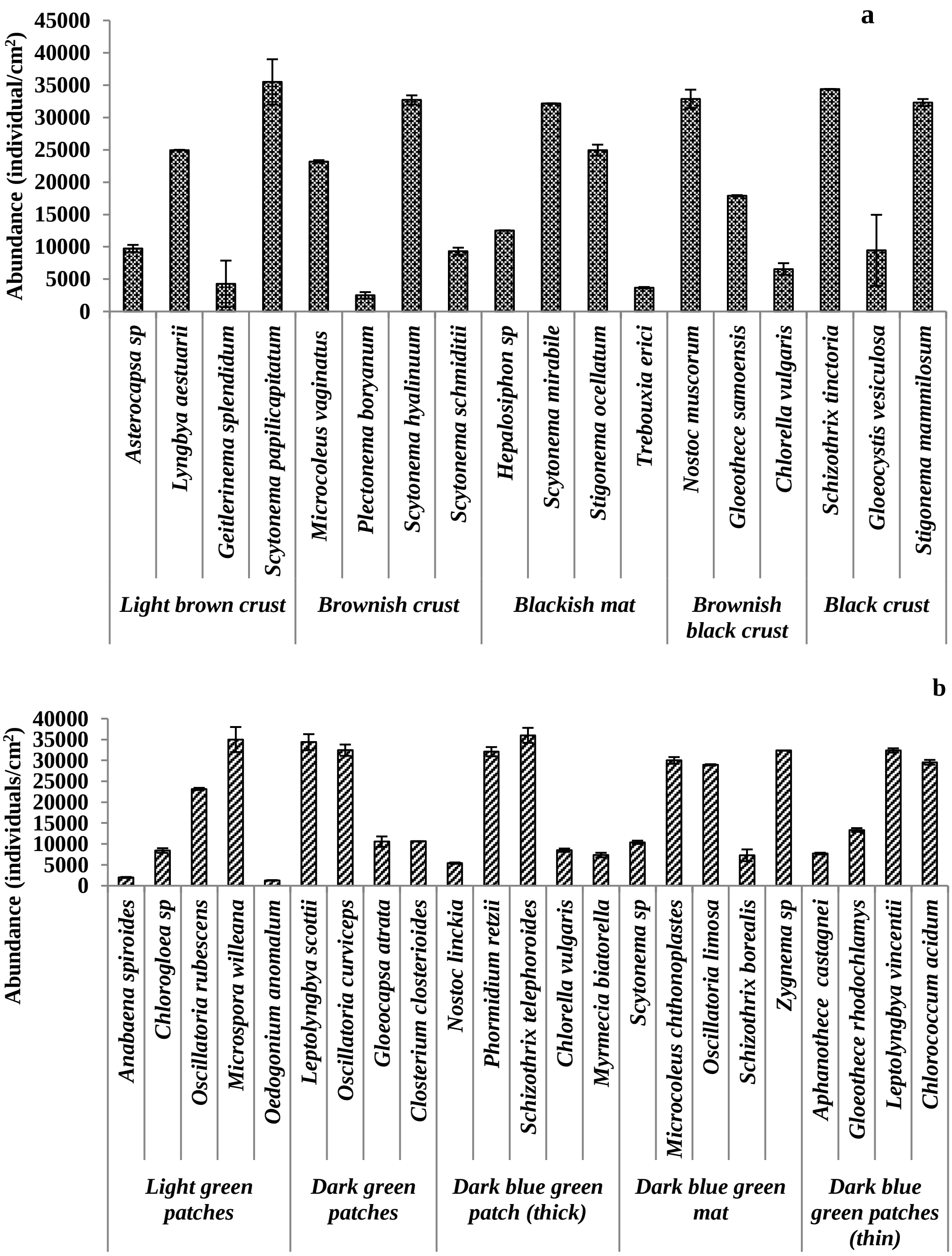


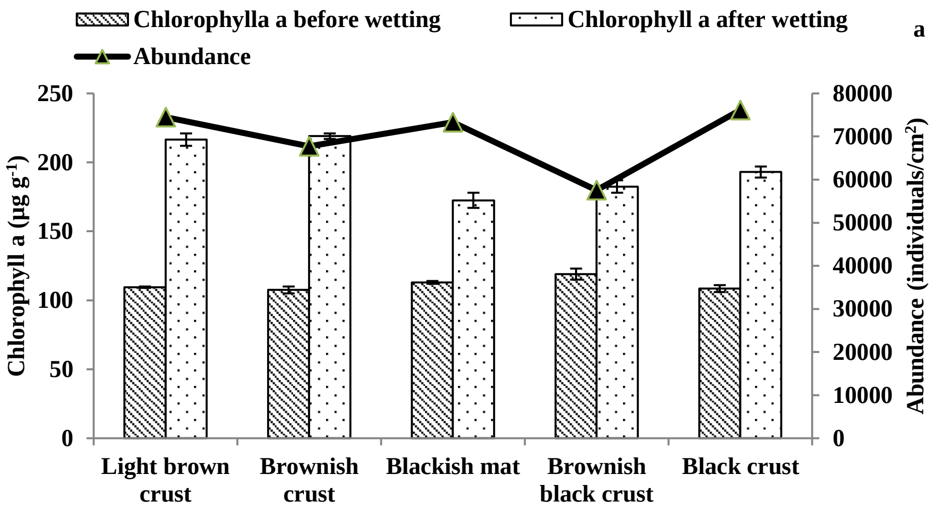
Figure 3: Abundance of algae in soil crust (Individual/cm²) during a) winter and spring b) monsoon and post monsoon.

Table 1: Nature of the soil substratum of the sampled sites and the species composition from different landuse.

Crust appearance	Location	Seasons	Class	Species Composition
Light brown crust	Potato/Rice field (Mawlai)	Winter & Spring	Cyanobacteria Cyanobacteria Cyanobacteria Cyanobacteria	*Asterocapsa* sp *Lyngbya aestuarii* *Geitlerinema splendidum* *Scytonema papilicapitatum*
Brownish crust	Citrus plantation (Mawlai)	Winter & Spring	Cyanobacteria Cyanobacteria Cyanobacteria Cyanobacteria	*Microcoleus vaginatus* *Plectonema boryanum* *Scytonema hyalinuum* *Scytonema schmiditii*
Blackish mat	Sacred grove (Mawphlang)	Winter & Spring	Cyanobacteria Cyanobacteria Cyanobacteria Trebouxiophyceae	*Hepalosiphon* sp *Scytonema mirabile* *Stigonema ocellatum* *Trebouxia erici*
Blackish crust	Potato/Maize field (Mylliem)	Winter & Spring	Cyanobacteria Cyanobacteria Trebouxiophyceae	*Nostoc muscorum* *Gloeothece samoensis* *Chlorella vulgaris*
Brownish black crust	Pine forest (NEHU campus)	Winter & Spring	Cyanobacteria Cyanobacteria	*Schizothrix tinctoria* *Stigonema mammilosum*
Light green patches	Citrus Plantation (Mawlai)	Monsoon & Post Monsoon	Chlorophyceae Cyanobacteria Cyanobacteria Cyanobacteria Chlorophyceae Chlorophyceae	*Gloeocystis vesiculosa* *Anabaena spiroides* *Chlorogloea sp* *Oscillatoria rubescens* *Microspora willeana* *Oedogonium anomalum*
Dark green patches	Shifting cultivation land (Mylliem)	Monsoon & Post Monsoon	Cyanobacteria Cyanobacteria Cyanobacteria Zygnematophyceae	*Leptolyngbya scottii* *Oscillatoria curviceps* *Gloeocapsa atrata* *Closterium closterioides*
Dark blue green patch (thick)	Pine forest (NEHU campus)	Monsoon & Post Monsoon	Cyanobacteria Cyanobacteria Cyanobacteria Trebouxiophyceae Trebouxiophyceae	*Nostoc linckia* *Phormidium retzii* *Schizothrix telephoroides* *Chlorella vulgaris* *Myrmecia biatorella*
Dark blue green mat	Sacred grove (Mawphlang)	Monsoon & Post Monsoon	Cyanobacteria Cyanobacteria Cyanobacteria Cyanobacteria Zygnematophyceae	*Scytonema sp* *Microcoleus chthonoplastes* *Oscillatoria limosa* *Schizothrix borealis* *Zygnema* sp
Dark blue green patches (thin)	Potato/Rice field (Shillong)	Monsoon & Post Monsoon	Cyanobacteria Cyanobacteria Cyanobacteria Chlorophyceae	*Aphanothece castagnei* *Gloeothece rhodochlamys* *Leptolyngbya vincentii* *Chlorococcum acidum*

Chlorophyll a content

Chlorophyll a content from soil crusts during the dry season ranged from 107 to 119 µg g^{-1} before wetting and 172 to 219 µg g^{-1} after wetting for 24 hours. During the wet seasons, chlorophyll a ranged from 203 to 292 µg g^{-1} before wetting to 215 to 312 µg g^{-1} after wetting. During dry season, Chlorophyll a was significantly lower than that on the wet season. It was also observed that chlorophyll a content present in the crusts rapidly recovered not only during the wet seasons but also after 24 hours of wetting. Significant difference was observed for dry crust between before wetting and after, however no significant difference was observed during the wet season. On comparing with abundance, higher number of individuals was observed during the wet season **(Figure 4, a & b).**



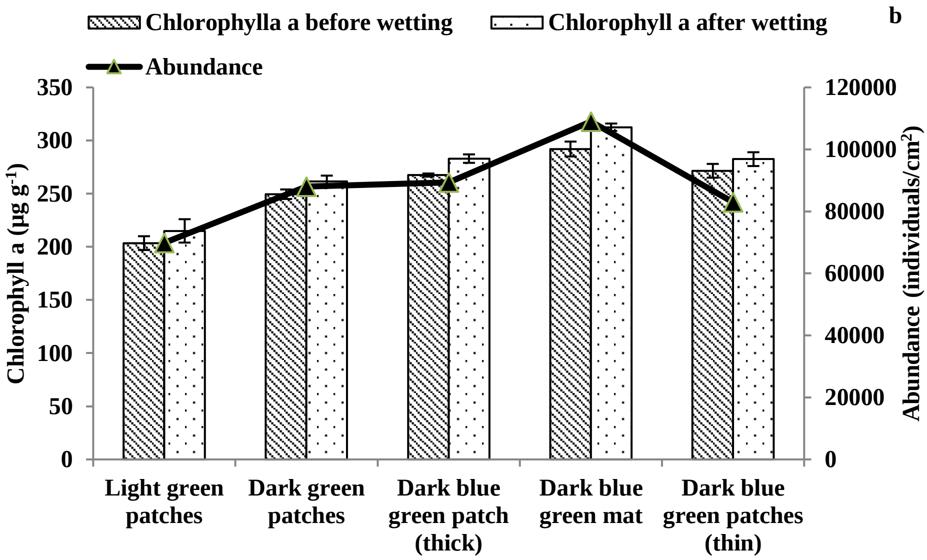


Figure 4: Seasonal variation of Chlorophyll a of soil crust in different landuse type a) winter and spring b) monsoon and post monsoon

Figure 5 : a) *Anabaena spiroides* Klebahn, b) *Aphanothece castagnei* (Kützing) Rabenhorst, c) *Asterocapsa* sp, d) *Chlorogloea* sp, e) *Geitlerinema splendidum* (Greville ex Gomont) Anagnostidis, f) *Gloeocapsa atrata* Kützing, g) *Gloeothece rhodochlamys* Skuja, h) *Gloeothece samoensis* Wille, i) *Hepalosiphon* sp, j) *Leptolyngbya scottii* (Fritsch) Anagnostidis & Komárek, k) *Leptolyngbya vincentii* Komárek, l) *Lyngbya aestuarii* Liebman ex Gomont, m) *Microcoleus chthonoplastes* (Thuret) Gomont, n) *Microcoleus vaginatus* (Vaucher) Gomont, o). *Nostoc linckia* Bornet ex Bornet & Flahault, p) *Nostoc muscorum* C. Agardh

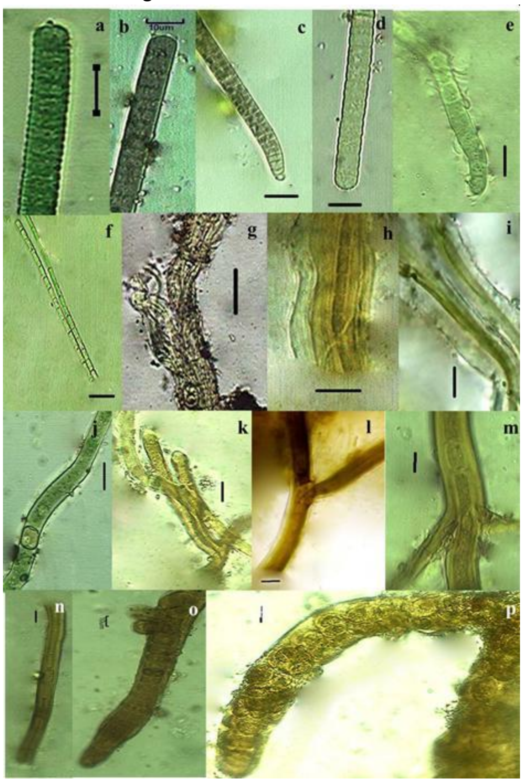


Figure 6: a) *Oscillatoria curviceps* Agardh ex Gomont, b) *Oscillatoria limosa* Agardh ex Gomont, c) *Oscillatoria rubescens* De Candolle ex Gomont, d) *Phormidium retzii* Kützing ex Gomont, e) *Plectonema boryanum* Gomont, f) *Pseudoanabaena galeata* Böcher, g) *Schizothrix borealis* Komárek & Kovacik, h) *Schizothrix telephorioides* Gomont, i) *Schizothrix tinctoria* Gomont ex Gomont, j) *Scytonema hyalinuum* Gardner, k) *Scytonema* sp, l) *Scytonema mirabile* Bornet, m) *Scytonema papillicapitatum* Sant'Anna & J. Komárek, n) *Scytonema schmiditii* Gomont, o) *Stigonema ocellatum* Lyngbye ex Bornet & Flahault, p) *Stigonema mamillosum* C. Agarh ex Bornet & Flahault.

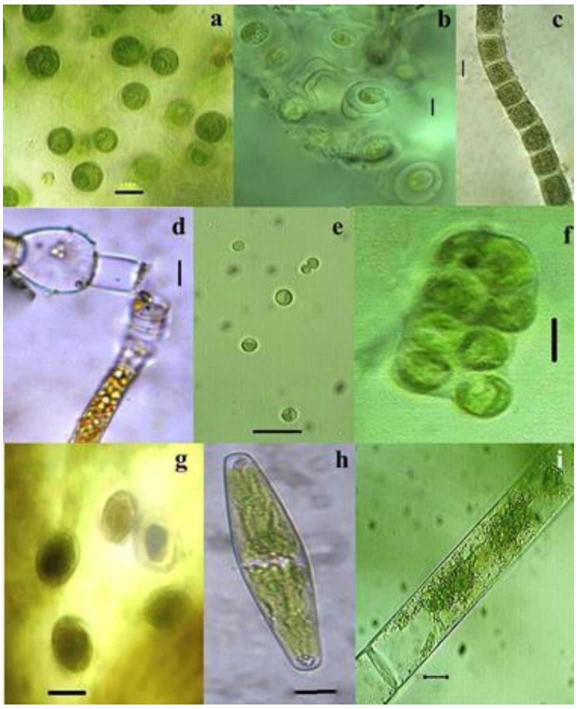


Figure 7: CHLOROPHYCEAE - a) *Chlorococcum acidum* (Schrank) Meneghini, *b) Gloeocystis vesiculosa* Nägeli, *c) Microspora willeana* Lagerheim *d) Oedogonium anomalum* Hirn, TEBOUXIOPHYCEAE - *e) Chlorella vulgaris* Beyerinck (Beijerinck), *f) Myrmecia biatorellae* Peterson, *g) Trebouxia erici* Ahmadjian ZYGNEMATOPHYCEAE - *h) Closterium closterioides* (Ralfs) Louis & Peeters, *i) Zygnema* sp.

Physico-chemical parameters of soil

On comparing the different soil parameters between the crusted and uncrusted soil, characters like moisture content, organic content, total nitrogen and available phosphorus differed significantly while no significant differences were observed in pH and potassium (**Table 2).**

Table 2: Soil temperature, moisture content and pH in crusted and uncrusted soil collected from selected land use type.

Location	Soil temperature (ºC)		Moisture content (%)		pH	
	uncrust	crust	uncrust	crust	uncrust	crust
Winter & Spring						
Potato/Rice field (Mawlai)	21.31±3.90	21.47±3.73	21.64±3.75	23.13±3.69	5.44±0.60	5.74±0.20
Citrus plantation (Mawlai)	21.31±3.90	23.16±1.94	19.43±3.36	20.86±3.14	5.64±0.11	5.68±0.14
Sacred grove (Mawphlang)	12.50±4.63	11.83±3.81	26.23±3.29	27.58±3.08	5.03±0.07	5.09±0.04
Potato/Maize (Mylliem)	17.98±0.52	16.94±0.83	14.66±1.69	16.86±1.22	5.63±0.13	5.62±0.18
Pine forest (NEHU campus)	16.83±6.14	15.66±5.92	18.41±2.37	20.39±3.13	5.88±0.37	5.88±0.19
Monsoon & Post Monsoon						
Citrus plantation (Mawlai)	25.83±3.81	25.16±3.54	23.59±1.34	26.43±1.35	6.53±0.17	6.71±0.16
Shifting cultivation land (Mawlai)	28.83±3.14	28.50±3.20	23.77±2.23	27.18±1.02	5.94±0.39	6.11±0.49
Pine forest (NEHU campus)	24±4.47	23±4.24	26.35±1.82	33.47±2.42	5.48±0.60	5.41±0.35
Sacred grove (Mawphlang)	20.50±3.39	19.83±3.54	34.80±2.09	41.46±2.55	5.12±0.22	5.23±0.12
Potato/Rice field (Shillong)	25.91±3.58	25.16±2.48	26.33±2.41	33.61±2.01	5.86±0.18	5.97±0.19
Significance	NS		**		NS	

NS-Not Significant p<0.001**

Most notable differences were high level of organic carbon, nitrogen and phosphorus in crusted soil. Significantly high level of organic carbon, nitrogen and phosphorus ($p<0.001$) were recorded in crusted soil. Potassium content was also observed with a weak differences between crusted and uncrusted soil, however the difference was not significant **(Table 3).**

Table 3: Nutrients in crusted and uncrusted soil collected from selected land use type

Type of landuse	Organic carbon (%)		Total Nitrogen (%)		Available Phosphorus (µg g^{-1})		Exchangeable Potassium (µg g^{-1})	
	uncrust	crust	uncrust	crust	uncrust	crust	uncrust	crust
Winter & Spring								
Potato/Rice field (Shillong)	0.95±0.04	1.32±0.07	0.14±0.02	0.35±0.04	21.34±0.90	42.34±0.87	180±1.41	190±4.56
Citrus plantation (Mawlai)	1.12±003	1.38±0.04	0.16±0.02	0.25±0.01	18.21±1.14	38.21±1.12	130±18.12	130±10.12
Sacred grove (Mawphlang)	1.50±0.07	1.69±0.10	0.04±0.20	0.07±0.41	23.54±0.88	28.34±1.11	160±2.54	160±0.78
Potato/Maize (Mylliem)	1.21±0.04	1.90±0.09	0.11±0.02	0.19±0.00	13.12±0.95	31.12±0.87	200±4.76	210±12.23
Pine forest (NEHU campus)	0.19±0.02	0.35±003	0.03±0.10	0.05±0.30	15.32±1.11	18.32±0.84	150±11.21	160±8.76
Monsoon & Post Monsoon								
Citrus plantation (Mawlai)	1.24±0.0	1.32±0.01	0.30±0.01	0.49±0.03	22.32±0.87	23.34±0.87	240±0.98	260±1.41
Shifting cultivation land (Mawlai)	1.30±0.04	1.60±0.10	0.38±0.10	0.64±0.06	15.43±1.17	54.43±0.92	150±1.65	160±1.41
Pine forest (NEHU campus)	1.63±0.07	1.83±0.06	0.19±0.01	0.40±0.01	23.47±0.97	35.42±1.12	220±1.98	260±12.12
Sacred grove (Mawphlang)	2.19±0.05	2.40±0.04	0.30±0.01	0.49±0.03	34.32±1.06	43.32±1.06	210±10.76	210±9.87
Potato/Rice field (Shillong)	1.18±0.01	1.41±0.06	0.33±0.05	0.63±0.05	18.23±0.65	65.32±0.87	170±6.36	180±7.45
Significance	**		**		**		NS	

NS- Not Significant $p<0.001$*

Pearson's correlation coefficient

Positive correlation between the algae in crust and soil characteristics revealed that the growth of algae on the soil surface was positively influence by moisture content, organic carbon, total nitrogen and phosphorus. pH was negatively correlated with algae species which revealed that difference in pH did not affect the distribution of Cyanobacteria **(Table 4).**

Table 4: Pearson's correlation coefficient between soil parameters and algae in crusted soil. (pH-pH, MC-Moisture Content, ST-Soil Temperature, OC- Organic Carbon, TN-Total Nitrogen, PHOS-Phosphorus, POT-Potassium, ALGAE-Algae in crust)

	pH	MC	ST	OC	TN	PHOS	POT
pH	-	-	-	-	-	-	-
MC	-0.263*	-	-	-	-	-	-
ST	0.624*	NS	-	-	-	-	-
OC	-0.472*	0.558*	NS	-	-	-	-
TN	NS	0.579*	0.872*	0.540*	-	-	-
PHOS	NS	0.649*	0.600*	0.640*	0.758*	-	-
POT	0.302*	NS	NS	NS	NS	-0.202*	-
ALGAE	-0.395*	0.654*	NS	0.564*	0.879*	0.542*	NS

$^*p<0.05$; NS Not Significant

DISCUSSION

In the present study, Cyanobacterial genera of *Scytonema* and *Stigonema* were most dominant during the winter while those of *Chlorococcum*, *Microspora, Zygnema*, *Schizothrix* and *Leptolyngbya* were prevalent during the monsoon. These were associated with many other genera of *Anabaena*, *Asterocapsa Chlorogloea* sp, *Gloeocapsa*, *Nostoc and Plectonema* and green algal genus observed were *Chlorella, Oedogonium*, *Myrmecia* and *Trebouxia.* Study on soil crust from different parts of India recorded the occurrence of same forms like *Scytonema*, *Plectonema* or *Lyngbya* as the dominant components along with other species like *Oscillatoria*, *Phormidium*, *Microcoleus*, *Aulosira*, *Fishcherella*, *Nostoc*, *Westiellopsis* and *Hepalosiphon* (Tirkey and Adhikary, 2005).

Cyanobacteria were prominent components during the dry seasons while green algal forms occurred during the wet season, such observation was also observed by Sethi et al. (2012) in which green algae forms occurred in crust only during the rainy seasons. Dominant genera of Cyanobacteria like *Microcoleus*, *Scytonema*, *Stigonema* and *Schizothrix* found in crust occur as intertwined mat of filaments. Sheath materials from these are observed to be winding through and across all types of soil surfaces by attaching and binding soil particles together. Observation by Belnap and Gardner (1993) and Zheng et al. (2011) on the role of *Microcoleus vaginatus* lead to conclusion that presence of cyanobacterium significantly influence soil stability, retention of moisture and fertility of soil in desert region.

Significance difference was observed between the crusted and uncrusted soil for moisture content which revealed that moisture retention significantly increased in crusted soil. Furthermore a positive correlation (r=0.654) was observed between algae and moisture content which shows enhancement of soil properties in crust. According to Garibotti et al. (2017) matured soil crust associated with lichens greatly improve soil stability by regulating soil moisture content increasing nitrogen and phosphorus content in soil.

Filamentous green algae such as *Microspora* and *Zygnema* forming thick mat like structure intertwined with the upper millimetres of soil were observed to be dominant during the wet seasons. Such aggregation of filaments contributed to self-shading of individual filaments as well as other green algae (Karsten and Holzinger, 2014). Unicellular green algae like *Trebouxia*, *Chlorella*, *Myrmecia* present in the crust are protected by the filamentous mat and are greatly tolerant to dehydration. They seems to survived the dehydration and recovered immediately after wetting. According to Gray et al. (2007) algae found in crust associations were different to aquatic relatives and differed greatly in recovery of photosynthesis after wetting.

Chlorophyll a content from soil crusts during the dry season ranged from 107 to 119 µg g^{-1} before wetting and 172 to 219 µg g^{-1} after wetting for 24 hours. During the wet seasons, chlorophyll a ranged from 203 to 292 µg g^{-1} before wetting to 215 to 312 µg g^{-1} after wetting. Studies by Tirkey and Adhikary (2005) on chlorophyll a content of soil from four different regions of India was recorded within ranged of 121 to 284 µg g^{-1}. Abed et al. (2014) also observed an increase of chlorophyll a and phycocyanin after wetting and subsequently increased if kept wetted for several days. Hence higher amount of chlorophyll content during wet seasons in greenish patches in our study suggested enhancement of growth of crust organisms in the presence of water.

The present study clearly indicated that pH, temperature and potassium were not influenced by crust development on the soil. Chamizo et al. (2012) also reported that crust formation did not play any role on soil pH but greatly enhanced soil moisture and nitrogen content (Garibotti et al., 2018). In all the different land use type, an increased level of nitrogen has been recorded in soil covered with crust. Heterocystous Cyanobacteria observed in these crust have the ability to bind free atmospheric nitrogen which leads to nitrogen accumulations and increased the biomass. There are several reports where nitrogen is strongly enhanced by biological soil crust in arid and semi-arid environment, mainly due to presence of Cyanobacterial organisms responsible for fixing atmospheric nitrogen (Jafari et al., 2004). Vinoth et al. (2017) reported presence of high number of Cyanobacterial species and increased nitrogen content in soil of sacred grove forest of Tamil Nadu. Cyanobacterium *Microcoleus vaginatus* was observed to consist of differentiated cyanosphere that concentrates on nitrogen-fixing function and also contributed as the main source of leaked organic carbon while *Stigonema* and *Scytonema* are important source of nitrogen (Patova et al., 2016; Couradeau, 2019). The presence of such Cyanobacteria like *Scytonema*, *Stigonema*, *Schizothrix* and *Microcoleus* as dominant organisms in our crust had played a role in nitrogen fixation as observed from the values in crusted soil. Not only nitrogen, higher levels of organic content and phosphorus were observed in crusted soil.. According to Belnap and Harper (1995) accumulation of plants litter, mosses, lichens and activity of the microbiota on litter lead to higher amount of organic matter in soil crust.

No significant difference was observed for potassium. According to Brown and Brown (1991) potassium got washed downward by percolating water. Greater concentrations of phosphorus have been reported in crusted soil as compared to non-crusted soil (Jafari et al., 2004). Higher concentration of phosphorus in soil crust could be due to its binding to soil particles (Harper and Marble, 1988). Development of soil crust creates an edaphic environment with enhanced moisture and nutrients properties which contributed to plant growth. Such observations have been reported by many authors indicating the role of soil crust to a variety of functions like soil stabilization, nitrogen availability and establishments of vascular plants (Belnap and Gardner, 1993; Pendleton et al., 2003).

ACKNOWLEDGEMENT
The authors are thankful to North-Eastern Hill University for providing financial assistance. Authors also acknowledge the Head of Botany Department for providing all the laboratory facilities.

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