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STUDIES ON KINETICS OF PHOSPHATE UPTAKE BY BLUE-GREEN ALGAE

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Abstract

Cylindrospermum sp collected from Chennai and *Nostoc* sp collected from *Thandurai,* near Chennai, the two fresh water filamentous blue-green algae, were made unialgal and used for the present study. Investigations on the growth, kinetics of PO^4 uptake, effect of PO_4 on growth, uptake of PO_4, and photosynthesis were carried out. Uptake of PO_4 followed Michaelis-Menton Kinetics in both the algae. *Cylindrospermum sp* showed a biphasic kinetics by changing its uptake kinetics in higher PO_4 concentration and it is well suited as a phycoremediation organism for PO_4 removal from wastewaters and effluents. *Nostoc sp* showed only a simple kinetics and very low Ks (high affinity) for PO_4 and it is well suited for nutrient poor waters. PO_4 uptake was very low in dark. Higher uptake rates were observed in lower light intensities (0.05 k lux) in both the blue-green algae. Na^+ seems to enhance growth of blue-green algae along with PO_4. Na^+ is also required for the uptake of PO_4. In the absence of Na^+, PO_4 uptake was very low in blue-green algae studied

INTRODUCTION

The phytoplankton cells can survive and grow at concentrations below the detectable limit of phosphorus (about 0.03 µg at /L). This observation has stimulated studies relating the rate of supply of phosphorus

under natural conditions to its rate of utilization. There are several sources of phosphorus available to the phytoplankton other than inorganic orthophosphate. Phosphorus is found in natural waters also in the form of organic and inorganic polyphosphates of low molecular weight and bound to colloidal particles in suspension and in sediments (*Strick et al.,* 1972. Another possible major source of phosphorus is excretion by zooplankton. *Pomeroy et al.,* (1963) calculated the demand for phosphate from the rate of photosynthesis in several regions and compared it to the phosphate available from zooplankton.

The total phosphorus for a body of water is usually reasonably constant value fixed by geochemical factors (Chiou *et al.,* 1974). If "cultural eutrophication" is occurring, then sewage, industrial waste; or runoff from agricultural lands usually is associated with an increase in the total standing crop of algae. Papers by *Schindler* and colleagues (1972) show conclusively that in a group of small lakes of various types phosphorus was the nutrient which could often be called the "limiting nutrient" for the growth of phytoplankton and thus for eutrophication.

There is no evidence that algae can assimilate any form of phosphorus other than orthophosphate. Algal cells have phosphatases in or near the outer membrane which allow them hydrolyse organic phosphates.

"Luxury consumption" of phosphate by algae results in the storage of polyphosphate granules in the cell. These may contain sufficient PO_4 for many cell divisions and help to carry phytoplankton through short periods of phosphorus depletion. Phosphate, in contrast to nitrate, is readily adsorbed to soil particle and thus not move easily with ground water.

Phosphorus is not needed for growth in large quantities like Carbon, Oxygen, hydrogen and nitrogen, but it is one of the most common limiting elements on land and in fresh water. Devices for overcoming phosphorus deficits have been evolved by algae. These are (i) luxury consumption (2) an ability to use phosphate at low level (low Ks) and (3) alkaline phosphatase production.

In oligotrophic lakes the growth of cyanobacteria and higher algae is usually determined by the quantity of inflowing phosphate (Schindler, 1977). When this nutrient is limiting, phosphate uptake by the

algae is accompanied by a decrease of the external phosphate concentration to nanomolar levels (Rigler, 1968 ; Pettersson, 1979).

Under these conditions transport of phosphate into the cell has to proceed against a considerable concentrating gradient of several orders of magnitude (nanomolar concentration outside the cell compared to approximately 100 µM in the cytoplasm (Wagner and Falkner, 1992). This is only possible if transport is coupled to an energy source. Investigation by *Falkner et al.,* (1980) on the energy dependent accumulation of orthophosphate by the bluegreen alga *Anacystis nidulans* have established.

According to *Brownell* (1979) when Na^+ is present, Cyanobacteria have higher nutrient uptake efficiencies and lower loss rates of fixed organic matter. Seale *et al.,* (1987) evaluated the effects of NaCl and phosphorus enrichments on natural phytoplankton assemblages. Sodium chloride from anthropogenic sources, such as road run off and industrial wastes, may alter fresh water phytoplankton communities. Increased salinity should favour growth of cyanobacteria because these are the only phototrophic plankton taxa requiring Na^+ for growth (Allen and Arnon, 1955; Bostwick *et al.*, 1968). Phosphate uptake by cyanobacteria was enhanced most by Na^+ additions in the laboratory when PO_4-P levels exceeded 50 µg/L (Mohleji *and* Verhoff, 1980).

In the present investigation two fresh water blue-green algae, *Cylindrospermum sp* and *Nostoc sp* were selected for studying the kinetics of PO^4 uptake. The effect of Na^+ on the growth, uptake of phosphate and photosynthesis has also been investigated.

MATERIALS AND METHODS

Blue-green algae, culture medium and growth measurement

The blue-green algae, *Nostoc sp.* isolated from Chitheri Lake (Thandurai, Chennai.) and *Cylindrospermum sp.* isolated from R.K.M. Vivekananda College Campus (Mylapore, Chennai) were made unialgal and grown in Allen and Arnon medium (1955) without nitrate. Cultures were grown at 28 ± 1 °C in a growth chamber provided with continuous illumination by white fluorescent lamps (Philips, 40W). Growth was measured by fresh weight determination after centrifugation. Division rates were calculated using the fresh weight.

Pigment Analysis

i. Extraction and Estimation of chlorophyll a.

Algal culture was centrifuged at 8000 rpm for 5 minutes and pellet obtained was re-suspended in cold 90% acetone and left in the dark, inside the refrigerator for 10-12 hours. This was again centrifuged at 8000 rpm for 5 min and the clear supernatant was used for estimation of chlorophyll a. Optical density measurements were made using Spectronic 20. Chlorophyll a was estimated from extinction co-efficients given by Jeffrey *and* Humphrey, (1975).

ii. Extraction and estimation of phycobilin pigments

The pellet after acetone extraction was again resuspended in phosphate buffer (pH 7.5) and phycobilins were extracted by repeated freezing and thawing. After complete extraction, the clear supernatant was obtained by centrifugation and was subjected to spectrophotometric analysis of phycobilin pigments by employing the formula of Bennett and Bogorad,

Measurement of O_2 uptake and evolution

Photosynthesis measurements were made using PE 135 DO analyser, (Elico). Illumination was provided by a Philips 60W bulb. Light intensity was measured using a LUTRON LX-101 digital Luxmeter. Respiratory O_2 uptake measurement was taken after covering the reaction vessel with a black cloth. Photosynthesis rate were expressed as µg O_2 evolved/µg chl a/h.

Phosphate deficient cultures and uptake measurement (Murphy and Riley, 1962)

The culture was grown in Allen Arnon medium with 10 µM PO_4 for a week. After the phosphate in the medium was completely depleted the culture was centrifuged and the pellet was resuspended in PO_4 free medium and incubated under light for 30 min to ensure complete depletion of PO_4 and used for uptake studies. Aliquots enriched with PO_4 were incubated for 30 min at room temperature under 500 lux light intensity with occasional shaking and at the end of incubation period, the aliquots were centrifuged. Cell-free supernatants were analyzed for PO_4 and uptake was calculated as the difference between the concentration added and that remaining at the end of experiment.

RESULTS

Growth and pigment composition of *Cylindrospermum* sp and *Nostoc* sp in different PO_4 concentrations.

Actively growing PO_4 depleted cultures of *Cylindrospermum sp* and *Nostoc sp* were inoculated into conical flasks containing media amended with different concentration of PO_4 (5, 20 and 40 µM PO_4 (supplied as K_2HPO_4). Fresh weight determinations were made on the 7th day. The results are given in Table 1 and Fig.1. a,b. *Cylindrospermum sp* did not show any major increase in growth when the PO_4 concentration was increased. Whereas *Nostoc sp* showed a maximum growth only with lowest concentration supplied (5 µM PO_4). At 20 and 40 µM PO_4 levels the growth of *Nostoc sp* was retarded by 75% and 80% respectively.

Table 2 and Figs.2 a,b and 3 a,b show the results of pigment analysis of cultures grown in different concentrations of PO_4. In *Cylindrospermum* sp there was a slight increase in chla levels at higher PO_4 levels. Where as the phycobilins, especially, phycocyanin, showed a significant increase at higher PO_4 levels. In *Notosc* sp there was a significant increase in chla at higher PO_4 levels. Whereas the phycobilins did not increase except for phycoerythrin which showed a marginal increase at higher PO_4 levels.

Effect of PO_4 and NO_3 on the heterocyst frequency

Actively growing cultures of *Cylindrospermum* sp and *Nostoc* sp were inoculated into the media amended with different concentrations of PO_4 and NO_3 separately and incubated for 7 days. On the 7th day the heterocyst frequency was determined and the results are given in Fig.4 a,b and 5. Increasing the PO_4 level increased the heterocyst frequency where as NO_3 showed the opposite effect. The results of *Cylindrospermum sp* were also showed the same trend and so the data are not given here.

Uptake of PO_4 by PO_4 - depleted and PO_4 - treated cultures of blue-green algae

Actively growing cultures (PO_4 - depleted) of *Cylindrospermum sp* and *Nostoc sp* were centrifuged and pellet was resuspended in 200 ml of PO_4 - free Allen Arnon medium. To 100 ml of the culture 20 µM PO_4 was added and incubated for 1 hr under light. This was taken as

PO_4 treated culture and the remaining 100 ml of sample was treated as PO_4 depleted culture. Uptake experiment was started by adding 6 µM PO_4 as the initial concentration and incubated under light. PO_4 analysis was done for every 5 minutes for 30 minutes. The results are shown in Table 5 and Fig.5, a,b. In *Cylindrospermum sp* PO_4 treated culture showed a faster rate of uptake than the PO_4 depleted. The saturation was reached within 15 min. Whereas in *Nostoc sp* both PO_4 depleted and treated cultures showed some rate of uptake.

Light and dark uptake of PO_4

Actively growing PO_4 depleted cultures were used for present study. 2µM PO_4 was added as initial concentration and samples were incubated for 30 min under dark and under different light intensities (0.5, 1.0, and 1.5 k lux) PO_4 uptake rates were calculated and the results are given in Table 6 and Fig. 6 a and b. *Cylindrospermum sp* showed a lower dark uptake (31% of light uptake) and under light (0.5 k lux) showed a maximum uptake and a slight decrease of uptake was noticed under higher light intensities (1.0 & 1.5 K lux). In *Nostoc sp* dark uptake was very low (only 5.3% of light uptake). Uptake was maximum in lower light intensities (0.5 K lux).

KINETICS OF PO_4 UPTAKE

Determination of V max and Ks

PO_4 –depleted cultures of *Cylindrospermum* sp and *Nostoc* sp were used for short- term (<30 min) uptake studies. Methods for preparing PO_4 depleted culture for uptake measurements are already given in Materials and Methods. The uptake experiments were carried out with different concentrations of PO_4. Velocity of PO_4 uptake (V) was plotted against substrate concentration (S) and from the hyperbola V max has obtained. The results are given in Figs 7 a,b and 8 a, b and Table 7. *Cylindrospermum sp* showed a biphasic kinetics. Whereas *Nostoc sp* showed only one V max (71.0). The Ks value of *Nostoc sp* was very low (2.0).

EFFECT OF Na^+ ON GROWTH AND PO_4 UPTAKE BY BLUE-GREEN ALGAE

Effect of Na^+ on growth

Actively growing PO_4 depleted cultures of *Cylindrospermum sp and Nostoc sp w*ere inoculated into Allen Arnon medium amended with different concentration of Na^+ (0.01, 0.05 and 0.01 mM). The cultures were incubated for 7 days and fresh weight

determination were done on 7th day. The results are shown in Table 8 and Fig 9 a,b. Increasing Na^+ increased growth in both the algae. Saturation of growth was reached at 0.1 mM Na^+ in *Cylindrospermum sp*, where as growth showed saturation at 0.05 mM Na^+ in *Nostoc sp*.

Effect of Na^+ and PO_4 combinations on growth and pigment composition

Actively grown PO_4 depleted cultures of *Cylindrospermum sp and Nostoc sp* were inoculated in Allen Arnon medium amended with different combination of Na^+ and PO_4 and incubated for 7 days. On the 7th day fresh weight determination was done. Division rates (divisions/day) were calculated and the results are shown in Table 9 and Fig 10 a,b. Chla and phycobilins were analyzed. The results are shown in Table 10 and 11 and Figs 11 a,b and 12 a,b. Chl a levels were higher in high PO_4 grown cultures of *Cylindrospermum sp and Nostoc sp*. Phycobilins were higher in higher PO_4 and high Na^+ combinations in both the cultures. Of the three phycobilins analysed, phycoeryhthrin was produced in higher concentrations in *Nostoc sp* where as *Cylindrospermum sp* produced higher amount of phycocyanin and lesser amounts of phycoerythrin. Na^+ alone did not enhance the pigments.

Effect of Na^+ on the uptake of PO_4 by blue-green algae

PO_4 uptake (short term) experiments were conducted using PO_4 and Na^+ depleted cultures of *Cylindrospermum sp* and *Nostoc sp* amended with different Na^+ concentrations (0.01, 0.05 and 0.1mM) with 5 µM PO_4 as the initial concentration. Cultures without Na^+ served as control. The results are given in Table 12 and Fig 13 a,b. The uptake of PO_4 was very low when Na^+ was not included in both the organisms (3.6 & 18%). Even with a little Na^+ (0.01 mM) the uptake reached the maximum.

DISCUSSION

Effect of PO_4 on growth and pigment composition of blue-green algae

Attempts to model algal succession under nutrient limitation are often based on the assumption that the uptake of the limiting nutrient is in equilibrium with the use of the nutrient for cellular growth and development (Tilman, 1977, 1981., Tilman *et al.*, 1982; Cembella *et al* . , 1984 a). The growth rate of the algae may then be described by the Monod model or the Droop

model as a function of the ambient or the cellular concentration of the limiting nutrient, respectively (Cembella *et al.,* 1984 b). The two models are both applicable for steady state situations (Tilman *and* Kilham, 1976, Goldman, 1977). Other workers have decoupled the processes of uptake and growth to study the effect of transients in the supply of the limiting nutrient and its consequences for growth (Grenney *et al.,* 1973 ; Lehman, *et al.,* 1975 ; Nyholm 1976 & 1978).

Of the two blue-green algae tested in the present study Nostoc sp., behaved like a low nutrient species. The growth was maximum under very low PO4 levels. Where as Cylindrospermum sp. showed similar growth rates in all the concentrations tested (Table 1 and Fig.1 a,b). This was also reflected in the levels of pigments in both the blue-green algae.

Olsen *et al.,* (1989) showed that the ability of the species to compete for PO_4 depended on the Pi uptake characteristics and their capability to retain the accumulated Pi. High affinity (low Ks) in uptake at low Pi concentrations contributed considerably to the growth efficiency. Kuenzler and Ketchum (1962) showed that algal growth rates plotted against PO_4 concentrations from batch culture show a linear relationship at very low concentrations and virtual independence at concentrations above 10 µg P/L.

Kinetics of PO_4 uptake by blue-green algae

Falkner *et al.,* (1995) working with the blue-green alga *Anacystis nidulans* observed that the PO_4 uptake did not obey Michaelis - Menton equation due to existence of a threshold value. (Olson, 1989). The simplest explanation for the existence of a threshold concentration is that transport of phosphate is catalyzed by a carrier until the external PO_4 concentration has attained an equilibrium value (Pe)A, the threshold value. In such a case, the uptake process can be depicted by the following simplified model:

$$Pe + C = CPe = CPi = C + Pi$$

Which is composed of reversible reaction steps that allow for some kind of product control (Rhee 1973). Accordingly, the external PO_4, (Pe), reacts with a carrier C to give a phosphocarrier complex that releases PO_4 at the inner side of the membrane (Droop, 1974).

Studies by Falkner *et al.,* (1980) in *Anacystis nidulans* has shown that the rate limiting step for the incorporation of phosphate is the transport through the membrane, which appears to be strictly regulated by bivalent cations. They have proposed that the activation of the transport by illumination may be mediated by changes in the cytoplasmic levels of Mg^{2+} via an activation of the carrier from the inner side of the membrane.

In the present investigation when the PO_4 depleted cultures of blue-green algae were given a short period of PO_4 treatment for 20 min. *Cylindrospermum* sp. could change its uptake capability and show an enhanced PO_4 rates when compared to control. Whereas *Nostoc sp.* could not change its uptake mechanism and both the PO_4 -depleted and PO_4 - treated cultures showed the same trend.

In *Clyindrospermum sp.* and *Nostoc sp.* PO_4 uptake was almost 80 to 90% light dependent and *Nostoc sp.* showed a very low dark uptake. PO_4 dependent velocity of PO_4 uptake by these two blue-green algae followed the Michaelis - Menton Kinetics on *Nostoc sp.* showed (low Ks) high affinity for PO_4 than *Cylindrospermum* sp. *Cylinsdrospermum* sp. showed a biphasic kinetics (Fig.7 a,b and 8 a,b). This is considered to be an efficient method of adaption to higher ambient PO_4 levels and will help the organism to withstand eutrophication. This also makes *Cylindrospermum* sp as a suitable organism for removal of nutrients from wastewaters and effluents.

Effect of Na^+ on growth and PO_4 uptake

Seale *et al.,* (1987) have studied the effect of Na^+ and phosphate on growth of cyanobacteria. They have observed that as single factor NaCl enrichments had no significant effect on growth rates of cyanobacteria. But Na^+ in combination with high PO_4 could enhance the growth of cyanobacteria. *Anabaena* growth rates *(*Allen *and* Arnon, 1955 ; Ward *and* Wetzel, 1975) and biomass yields (Brownell *and* Nicholas, 1967) were maximized at 5 - 40 ppm NaCl. Phosphate uptake by cyanobacteria was enhanced most by Na^+ additions when PO_4 - P levels exceeded 50 µg/L (Mohleji and Verhoff, 1980). These laboratory studies imply that cyanobacteria may be stimulated when Na^+ concentration exceed 5 µg/L, particularly if phosphate is also increased. Increased salinity appears to be correlated with filamentous cyanobacteria

(Stoermer and Ladewski, 1976 ; Baybutt and Makarewicz, 1981).

In both the organisms tested, in the present investigation, Na^+ alone could not enhance the growth and pigment composition. Enhanced growth rates and higher pigment compositions were observed in PO_4 and Na^+ combinations.

In *Cylindrospermum sp* and *Nostoc sp* the PO_4 uptake was completely reduced in the absence of Na^+. This shows that the uptake and transport systems for PO_4 is Na^+ dependent. Even with a very low Na^+ (0.01 mM) the uptake reached the maximum.

To sum up, of the two organisms tested *Nostoc sp* is well suited to grow in low phosphate environments and it cannot adapt to higher levels of phosphate due to eutrophication. Whereas *Cylindrospermum sp* could adapt to increasing PO_4 levels by changing its uptake kinetics. Na^+ ions are necessary for the uptake of PO_4 in these organisms. The PO_4 uptake mechanism seems to be Na^+ dependent. Further studies by employing metabolic inhibitors, and other divalent cations like Mg_{2+} and alkaline phosphatase will throw more light on the kinetics of PO_4 uptake and mechanism involved in transport of PO_4 across the membrane and also the actual role played by Na^+ in enhancing uptake of PO_4 by these blue-green algae.

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Tables

Table 1 Growth of *Cylindrospermum sp* and *Nostoc sp* in different PO_4 concentrations

PO_4 µM	Fresh weight on 7th day (g/L)	
	Cylindrospermum sp	*Nostoc* sp
5	14	103
20	10	26
40	14	21

Table 2. Effect of PO_4 on chl a level in *Cylindrospermum sp* and *Nostoc sp*

PO_4 µM	Pigments µg/g fresh wt	
	Cylindrospermum sp Chl a	Nostoc sp Chl a
5	43.0	25
20	60.0	107
40	62.5	213

Table 3. Effect of PO_4 on phycobilins in *Cylindrospermum sp* and *Nostoc sp*

PO_4 µM	Pigments µg/g fresh weight					
	Cylindrospermum sp			*Nostoc* sp		
	PC	APC	PE	PC	APC	PE
5	0.150	0.06	0.09	0.009	0.0350	0.876
20	0.480	0.25	0.12	0.0374	1.354	3.518
40	0.530	0.27	0.15	0.469	0.740	4.76

Table 4(a) Effect of Phosphate on heterocyst frequency in *Nostoc sp*

PO_4 µM	Heterocyst frequency %
12.5	9.87
25.0	18.18
50.0	21.80
100.0	27.40
200.0	152.27

Table 4(b) Effect of nitrate on heterocyst frequency in *Nostoc sp*

NO_3µM	Heterocyst frequency (%)
0	25.2
0.14	17.5
0.20	16.58
0.50	11.63
1.0	7.38
2	3.5

Table 5 Uptake of PO_4 by PO_4 - depleted and PO_4 - treated cultures of *Cylindrospermum sp* and *Nostoc sp*

S.No.	Time (min)	Concentrations of PO_4 (µmole/L)			
1		*Cylindrospermum* sp		*Nostoc* sp	
2		PO_4 -depleted	PO_4 -treated	PO_4 -depleted	PO_4 -treated
3	0	6	6	6	6
4	5	4.8	3.25	4.50	4.25
5	10	3.6	1.5	3.25	3.00
6	15	3.0	0.7	2.0	1.60
7	20	2.4	0.5	1.10	0.75
8	25	1.5	0.35	0.95	0.5
9	30	1.0	0.4	1.0	0.5

Table 6 Effect of Light and dark uptake of PO_4 in *Cylindrospermum sp* and *Nostoc sp*

Light Intensity (K Lux)	Uptake rate (n moles PO_4/g fresh weight/min) (V)	
	Cylindrospermum sp	*Nostoc* sp
0 (Dark)	3.22 (31)	0.08 (5.3)
0.5	10.39	1.5
1.0	9.40	0.75
1.5	6.93	0.7

(Values in parenthesis denote % over light uptake)

Table 7 Vmax and Ks for PO^4 uptake by *Cylindrospermum sp* and *Nostoc sp*

Blue-green algae	Vmax (n moles PO^4/g fresh wt/m)	Ks µM
Cylindrospermum sp	I 27.0 II 76.0	I 3.5 II 5.5
Nostoc sp	71.0	2.0

Table 8 Effect of Na^+ on growth of *Cylindrospermum sp* and *Nostoc sp*

Na^+ mM	Growth (Fresh weight g/L)	
	Cylindrospermum sp	*Nostoc* sp
0 (control)	25	45.0
0.01	23	50.0
0.05	31	52.5
0.1	47	52.5

Table 9 Growth of *Cylindrospermum sp* and *Nostoc sp* with Na^+ and PO_4 combinations

Treatment	Growth rate (divisions/day)	
	Cylindrospermum sp	*Nostoc* sp
Control (NO PO_4, NO Na)	0.46	0.48
BM + 5 µM PO_4 (Low)	0.76	0.52
BM + 0.01mM Na^+ (Low)	0.47	0.48

BM + 10 µM PO_4 (High)	0.73	0.54
BM + 0.1 mM Na^+ (High)	0.49	0.50
BM + 10µM PO_4 + 0.1 mM Na^+	0.75	0.55

(BM = Basal medium)

Table 10 Effect of Na and PO_4 on chla level in

Cylindrospermum sp and Nostoc sp

S.No.	Treatment	Chl a (µ/g fresh wt)	
		Cylindrospermum sp	*Nostoc* sp
1.	Control (NO PO_4, NO Na^+)	41.39	54.27
2.	BM + 5 µM PO_4 (Low)	47.5	65.82
3.	BM + 0.01mM Na^+ (Low)	40.4	57.82
4.	BM + 10 µM PO_4 (High)	77.7	87.06
5.	BM + 0.1 mM Na^+ (High)	41.2	51.02
6.	BM + 10µM PO_4 + 0.1 mM Na^+	62.5	78.9

Table 11 Effect of PO_4 and Na^+ on Phycobilins level in *Cylindrospermum* sp and *Nostoc* sp

S.No	Treatment	Phycobilins µg/g fresh weight					
		Cylindrospermum sp			*Nostoc* sp		
		PC	APC	PE	PC	APC	PE
1	Control (NO PO_4, NO Na^+)	0.123	0.026	0.066	0.05	0.10	0.9
2	BM + 5µM PO_4 (Low)	0.390	0.061	0.093	0.06	0.20	1.10
3	BM + 0.01mM Na^+ (Low)	0.230	0.037	0.07	0.25	1.25	3.5
4	BM + 10 µM PO_4 (High)	0.482	0.262	0.117	0.04	0.12	0.8
5	BM + 0.1mM Na^+ (High)	0.369	0.044	0.072	0.06	0.15	0.9
6	BM 10µM PO_4 + 0.1mM Na^+	0.530	0.270	0.108	0.4	1.50	4.5

Table 12 Effect of Na^+ on Uptake of PO_4 in *Cylindrospermum sp* and *Nostoc sp*

Conc. of Na^+ mM	Uptake rate n moles PO_4/g fresh weight/min (V)	
	Cylindrospermum sp	*Nostoc* sp
0 (control)	0.32 (3.6%)	1.02 (18%)
0.01	8.87	4.52
0.05	8.87	4.72
0.1	8.87	5.62

The values in parenthesis denote the % over maximum uptake

Table 13 Photosynthetic rate of *Cylindrospermum sp* and *Nostoc sp* under different light intensities

Light intensity K Lux	Rate of Photosynthesis (μg O_2 evolved /μg chl a/h)	
	Cylindrospermum sp	*Nostoc* sp
0.25	0.25	9.23
0.5	0.373	8.72
1.0	2.61	7.75
1.5	1.49	6.44

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