Chapter 2

Nutrient Control and Water Quality

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2.1 Introduction

The understanding of the dynamics of the eutrophication process in the tropical environment is often limited by inadequate literature about the tropical water bodies (Huszar et al., 2006). The characteristics of tropical aquatic systems indicate the existence of very complex relationship between the presence of nutrients and primary productivity. Some specific features of tropical lakes such as high recycling rates, elevated primary production during the whole year, high nutrient assimilation, high settling velocity of nutrients, intense organic matter decomposition, and high grazing rate lead to the establishment of a very dynamic ecosystem (Sperling, 1997). Depletion of dissolved oxygen in the hypolimnion occurs in many tropical lakes regardless of trophic status. Higher year-round light and temperature can lead to less seasonality in development of algal blooms and to more efficient recycling of nutrients than in temperate lakes. The tropical lakes and reservoirs, mainly those situated in urban areas, are generally subjected to severe eutrophication problems mainly due to a lack of infrastructure regarding sewage collection and treatment (Sperling, 1997).

Recent studies on the eutrophication in tropical lakes revealed that lakes throughout the area are commonly undergoing the process of eutrophication: some are facing hypertrophication, and some lakes even approaching to hypertrophic level. In a study to examine the relationship between total phosphorus (TP) and chlorophyll (Chl) from 192 lakes of tropical and subtropical origin Huszar et al. (2006) observed that 15% of the systems studied were oligotrophic (< 3µg/LChl- a), 35% mesotrophic, and 50% eutrophic (> 11 µg/LChl- a). Twenty five percentage of the latter have average annual chlorophyll concentrations greater than 50 µg/LChl- a suggesting hypereutrophic conditions. Increased algal blooms, depletion of dissolved oxygen, frequent large-scale mortalities of fish, decline of endemic fish species, predominance in the fishery by introduced species, changes in other
biotic species composition, proliferation of water hyacinth, and increasing health risks also manifest the ecological degradation in Lake Victoria (Lungayia et al., 2001). The lakes and reservoirs all over India without exception are in varying degrees of environmental degradation. The degradation is mainly due to eutrophication from domestic and industrial effluents and agricultural practices. Gupta (2006) reported that pollution from uncontrolled domestic sewage and industrial pollution causes substantial algal blooms, dissolved oxygen depletion in subsurface waters, and fish kills in Hussain Sagar Lake, India. Extensive encroachment for intensive agriculture, usage of chemical fertilizers and fish feeds, and flow of municipal sewage and industrial waste in to the lake Kolleru, India affected it adversely and has led to eutrophication (Pattanaik et al., 2008).

**Trophic status of lentic freshwater body**

Nutrients play an important role in the health and functioning of aquatic ecosystems. Globally, nitrogen and phosphorus are the two elements that immediately limit, in a Liebig sense, the growth of photosynthetic organisms (Borchardt, 1996). Nitrogen generally limits overall productivity in the marine system.

Phosphorus limitation occurs most often in freshwater system, in environments of intermediate salinities, and along the coasts during periods of high freshwater input (Wetzel, 2001). Silicon could also become a more generally limiting nutrient particularly for diatom growth and appears to be more spatially and temporally variable. Although total algal biomass is not limited by silica availability, the algal community composition, inter specific competition and succession can be altered markedly (Yoshie & Yamanaka, 2005).

Systematic evaluation of the role of nutrient limitation in tropical lakes is not possible because too few of the wide variety of tropical lakes have been examined. East African lakes have received relatively more attention than other lakes. Nitrogen limitation may be widespread because of the low nitrate
concentrations and moderate to high phosphorus concentrations common in eastern African lakes. However, nitrogen to phosphorus ratios and uptake rates of radioactive phosphorus provide strong evidence for phosphorus limitation in some Kenyan lakes. In South American tropical floodplain lakes, seasonal and regional differences in the relative importance of nitrogen or phosphorus limitation occur. Concentrations of both total nitrogen and total phosphorus in South American reservoirs correlate with chlorophyll. Physiological assays and enrichment experiments carried out in Lake Titicaca, in Boliva and Peru provide good evidence for adequate phosphorus supply, while increased algal growth after nitrogen additions occurred in Lake Valencia, Venezuela. (www.unep.or.jp).

As per the report of Zhao (2004) in China 80% lake and reservoir eutrophication is restricted by phosphorus, about 10% lake and reservoir eutrophication is relative to nitrogen, and the rest 10% to other factors. Fisher et al. (1995) suggested that nutrient limitation in tropical areas as inferred from nutrient additions, physiological indicators, or dissolved N:P ratios do not show uniform N or P limitation but rather show seasonal and between system variance. An 8-year investigation on the changes of nutrients and phytoplankton chlorophyll-a in lake Taihu, China by Chen et al. (2003) revealed large spatial heterogeneity and revealed that nitrogen was not a limiting factor in the lake. Arcifa et al. (1995) in a review of experimental nutrient enrichment studies in 10 Brazilian lakes and reservoirs did not find clear cut N limitation, rather limitation varied both between systems and seasonally within single systems.

Natural standing waters range from ultra oligotrophic to eutrophic, with progressive increase in productivity and related parameters. Oligotrophic and eutrophic waters are part of a continuum in terms of water quality, and it is convenient to recognize five main groups - hypertrophic, eutrophic, mesotrophic, oligotrophic, and ultra-oligotrophic in descending order of
enrichment and productivity (Sigee, 2005). Organization for Economic Cooperation and Development (OECD), provides specific criteria for temperate lakes in terms of the mean annual values of total phosphorus, chlorophyll-a, and Secchi depth. The OECD classification is based upon a regression model, which observed the relationships between phosphorus and algal densities in various deep upland lakes during the nineteen seventies. On this scheme, for example, the mean annual concentration of total phosphorus ranges from 4 µg/L - 10 µg/L for oligotrophic lakes, and 35 µg/L - 100 µg/L for eutrophic lakes. Mean concentration of chlorophyll in surface oligotrophic water is in the range 1 µg/L - 2.5 µg/L and in eutrophic waters it is in the range 8 µg/L - 25 µg/L. Oligotrophic lakes have a mean annual value of secchi depth in the range 12m - 6m and if it is in the range 3m - 1.5m water body is classified as eutrophic (OECD, 1982).

The trophic state of lakes and reservoirs under both nutrient limiting and non nutrient limited conditions are expressed as Trophic State Index (TSI) based on the phytoplankton biomass (Carlson, 1977; Carlson & Simpson, 1996).

\[
\text{TSI (SD)} = 60 - 14.41 \ln(\text{SD}) \\
\text{TSI (CHL)} = 9.81 \ln(\text{CHL}) + 30.6 \\
\text{TSI (TP)} = 14.43 \ln(\text{TP}) + 4.15
\]

SD = secchi disc transparency (m)

CHL = Chlorophyll pigment concentrations (mg/m\(^3\))

TP = Total phosphorus (mg/m\(^3\))

TSI values of < 30 are common among lakes and reservoirs of classical oligotrophy and values from 50 -70 corresponds to classical eutrophy. Hyper-eutrophic conditions are common at TSI values of > 70. The TSI changes in some lakes over an annual period especially during the periods of intensive
zooaplankton grazing and with difference in non-algal turbidity and when there is a reduction in the availability of nutrients seasonally (Wetzel, 2001).

Elemental cellular stoichiometries of natural phytoplankton communities and seston can reflect the type and extent of nutrient limitation and availability (Wetzel, 2001). Red field ratio (C:N:P) of 106:16:1 (or 41:7.2:1 by weight) among marine plankton is generally supported by numerous studies (Hecky et al., 1993). The variation in this ratio is small, usually < 20%. It has been attributed to the relatively nutrient sufficient conditions of marine plankton. But these particulate composition ratios in lakes have been coupled to various physiological conditions such as rates of growth and productivity, nutrient conditions etc. (Sterner and Elser, 2002). Stoichiometric ratios are approximate indicators of relative nutrient limitations and it will be severe in case of C : N (µmol µmol\(^{-1}\)) > 14.6; N:P (µmol µmol\(^{-1}\)) > 26, C : P (µmol µmol\(^{-1}\)) > 258, Si : P > 100, C : Chla (µmol µg\(^{-1}\)) > 8.3 and alkaline phosphatase activity (AP) :Chla (µmol µg/h) > 0.005 (Wetzel, 2001). Streams, shallow lakes and reservoirs with short residence times have C: P ratios < 350 and N : P ratios < 26, whereas lakes with longer residence times (> 6 month) differentiate from their inflows typically with C:P > 400 and N:P > 30. Tropical lakes tend to have relatively high C:N ratios, indicative of potential nitrogen limitations although the number of lakes sampled were relatively small (Hecky et al., 1993).

**Hydrological aspects in eutrophication**

Although nutrients are often limiting for algal growth, other factors might be just as important (Reynolds, 1989). For example, light may limit algal growth in water containing high levels of suspended matter or algal cell concentrations. Light is scattered by particles and absorbed by algal pigments and dissolved organic matter (Bleiker & Schanz, 1997). Other environmental factors such as flushing rate, water temperature, pH and water hardness also influence growth rates and the composition of algal communities (Scholten et al., 2005). However, since nutrients form the
basis of ecosystem production, nutrient availability is the key factor affecting the functional role of algae as basic producers in the food web. Resuspension of inorganic sediment particles is mainly caused by wave action and occasionally, by foraging fish (Ogilvie & Mitchell, 1998). The dynamics of nutrients are also determined by the depth and stratification of lakes. In deep lakes, thermal stratification occurs during winter and summer. Nutrients present in the epilimnion will be transported to hypolimnion. The turn over in autumn and spring makes the nutrients from mineralised material in the hypolimnion available to the epilimnion. There is no stratification in shallow lakes but there is a continuous exchange of material between sediment and water. The mineralization rate of sediment and the subsequent release of nutrients will increase due to higher temperature in summer (Jeppesen et al., 1997). In the drier tropics, the hydrological changes linked to climatic change and especially rainfall has had consequences for biological communities in shallow lakes (Kalk et al., 1979).

**Nutrient uptake by algae under eutrophic condition**

The primary productivity which forms the basis of aquatic food webs flourishes during eutrophication. Algae can respond quickly and opportunistically to increases in nutrient availability (Scholten et al., 2005). However, the capacity of individual algae to store nutrients is limited. It is the population that retains the nutrients, but only during the growing season. Decaying algae release nutrients and the following season all nutrients must be reacquired. The algal biomass density is the net result of algal production and algal losses due to sedimentation and grazing by zooplankton or other secondary producers.

**Nutrients and Algal Communities**

Major changes in the seasonal succession of phytoplankton in lakes are related to changes in availability of phosphorus, nitrogen and silica. Although variability is large, the general patterns of seasonal succession of
In addition to a general increase in phytoplankton biomass, eutrophication also affects taxonomic composition, competitive strategy (Sommer, 1989; Valiela, 1993), and biodiversity. Species composition varies considerably in relation to water quality. Desmids and chrysophytes, for example, tend to be characteristic of low-nutrient waters, while colonial blue-greens, chlorococcales, and centric diatoms occur as dominant forms in more nutrient-rich habitats (Wetzel, 2001).

Oligotrophic sites tend to be dominated over much of the growing season by unicellular phytoplankton such as nanoplanktonic diatoms and picoplanktonic blue-greens. These r-selected algae are adapted for rapid exploitation of nutrient resources under limiting conditions. In mesotrophic and eutrophic lakes, r-selected species is a particular feature of the clear-water phase, with K-selected species (large unicells and colonial blue-greens) forming dominant blooms over the major growth phase. At highest nutrient levels (hypertrophic lakes and ponds), there is a reversion to small, unicellular, rapidly growing species. These nanoplanktonic organisms form dense blooms of diatoms and green algae as soon as adequate light is available. An analysis of phytoplankton data in European lakes (Schreurs, 1992) shows that cyanobacteria dominate lakes with relatively low fractions of soluble reactive phosphorous (SRP), while green algae dominate systems with higher SRP. Blue-green dominance increases with total N concentrations. On the basis of total P, cyanobacteria dominate moderate classes (100 mgm⁻³– 800 mgm⁻³), while green algae dominate at higher levels (>800 mgm⁻³). Lakes with low nutrient concentrations encompass a significant representation of flagellates in their phytoplankton communities. In an enclosure experiment to investigate factors affecting the dominance of blue-green algae shows that with addition
of CO₂ and available nitrogen there occurred a shift in dominance from blue green algae to green algae (Shapiro, 1990).

**Laboratory aquatic microcosms in phytoplankton studies**

Water quality is the result of a complex interaction of biological components within environmental variation. A thorough understanding of these interactions is essential in effective water management. Laboratory aquatic microcosm systems can be effective experimental tools for the quantitative description of mineralization (Wilhm, 1970), nutrient recycling, community metabolism and succession (Romanuk *et al.*, 2006). Application of the microcosm approach to the aquatic systems not only furthers our understanding of the ecological processes but also facilitates experimental manipulations that are not easily controlled in the natural system. Microcosms should be small enough to be established in laboratories and manipulated easily; they should also be simpler compared to the degree of organisation of the natural system, so as to permit a level of comprehension which is not possible at the real world level. In addition, microcosm systems as physical models should be reliable experimental tools so that the community structure and dynamics of such a system should give good replication.

The response of phytoplankton and zooplankton to experimental alteration of nitrate and phosphorus levels in outdoor enclosures was investigated by Nandini and Rao (2000). A study of three food web structures in microcosms was investigated by Olsen *et al.* (2002) with the intention to study the effect of phosphorus limitation inhibition on dissolved organic carbon consumption in aquatic microbial food webs. Koch *et al.* (2004) used laboratory bioassays with light and nutrient amendments to assess resource limitation of phytoplankton in three Midwestern U.S. rivers, each characterized by different water regulation regimes. Piehler *et al.* (2004) carried out a series of nutrient bioassays to assess the relationship between increased inorganic nutrient concentration and phytoplankton community
structure and function. The total nitrogen, phosphorus, biomass, pH, dissolved oxygen and temperature of three eutrophic waters were investigated in the rapid-growth season of phytoplankton by Yeguang et al. (2006). Effect of bacteria in stoichiometry and nutrient limitation of phytoplankton was studied (Danger et al., 2007). Small-scale, short-term bioassays involving separate in vitro additions of nitrogen and phosphorus was carried out by Loureiro et al. (2008) to study primary production.

Objectives

The interaction of phytoplankton with major plant nutrients and their cycling is of great significance in the sustainable management of phytoplankton blooming. The suppression of eutrophication by reducing nitrogen and phosphorus contents of the water system is the ideal preventive strategy.

In this investigation the phytoplankton biomass and the trophic status of a natural pond was evaluated. The chances of its developing a persistent bloom was evaluated in microcosm experiments conducted in the laboratory in view of regulating nutrient input as a means of controlling algal blooms.

2.2 Materials and methods

Water and sediment samples were collected from an excavated pond in Kochi, during the summer months when the water level was minimal. The water samples were analysed for chlorophyll $a$, total phosphorus, total nitrogen and pH. The sediment samples were analysed to determine the pH, total nitrogen, total phosphorus and total organic carbon. A portion of water sample fixed in Lugol’s iodine was observed under the microscope to ascertain the composition of phytoplankton community.

2.2.1 Experimental design and culture conditions of microcosms

The pond ecosystem was simulated in fifteen litre glass tank micro-ecosystems. The sediment removed from the pond was laid on the bottom of
fifteen litre glass tanks with a surface area of 0.1 m² at a thickness of 5 cm. Ten litres of pond water were added to each of the tanks. The tanks were enriched with nutrients (NH₄Cl and K₂HPO₄) such that the resultant N : P was 8 : 1, 30 : 1 and 90 : 1. The unmodified (unenriched) microcosm was taken as control to represent the natural trophic state of the pond. The pond water had a N:P value of 4:1. Three replicate tanks were maintained for each. All tanks were exposed to sunlight. The ambient temperature was 30 ± 3 °C. The water and sediment samples were withdrawn from each tank for 28 days with a time-step of seven days. The samples were analysed for chlorophyll a, total phosphorus, total nitrogen and total organic carbon.

2.2.2 Analytical work

The digestion and distillation of water sample for total nitrogen were done according to Radojevic and Bashkin, (1999). The water sample for total nitrogen determination was first boiled with NaOH to expel ammonia. Sodium hydroxide-thiosulphate reagent was added to it after cooling. It was then distilled with H₂SO₄ and catalyst CuSO₄. The distillate was collected in boric acid and analysed by indophenol blue colourimetric method for ammonium ion (Solorzano, 1969).

A known volume of water sample was digested with persulphate and its phosphorus was determined by ascorbic acid method to determine total phosphorus (Standard methods, 1999). The pH of water sample was measured using a digital pH meter.

Total nitrogen was calculated from concentration of NH₃-N of the sediment sample. Ammonium distillate collected in boric acid after digestion with sulphuric acid containing potassium sulphate in kjeldahl flask was analysed by indophenol blue colorimetric method for ammonium ion (Solorzano, 1969).

Soil sample ignited at 550°C was cooled and extracted with H₂SO₄ to determine the total phosphorus content of sediment. Total phosphorus content
of the extracted sample was determined by ascorbic acid method spectrophotometrically (Standard methods, 1999).

Organic carbon was estimated by potassium dichromate back titration. Distilled water was added to pre weighed wet sediment sample at 2:1 ratio and stirred vigorously for one hour. After 30 minutes settling pH of the supernatant was measured using a pH meter.

Planktonic algae were concentrated from the water sample by filtration through membrane filters of pore size 0.45µm. Chlorophyll \(a\) was extracted from the algal concentrate in to 90 % aqueous acetone and the absorbance of the extract was determined with a spectrophotometer. The concentration of chlorophyll \(a\) was computed using the trichromatic equation,

\[
\text{chlorophyll } a = 11.85(\text{OD664}) - 1.54(\text{OD647}) - 0.08(\text{OD630}) \quad \text{(APHA, 1999)}
\]

2.3 Observations

The pond water community of phytoplankton was dominated by green algae. Diatoms were also present. The most abundant genera were *Chlorella, Selanastrum, Pediastrum, Scenedesmus* and *Cyclotella*. The amount of chlorophyll \(a\) was estimated to be 13.43 ± 0.01 µg/L. The total nitrogen content of water was 392 ± 0.02 µg/L and total phosphorus 92 ± 0.13 µg/L. The pH of the water sample was 7.7. Over an incubation period of 28 days, there was increase in phytoplankton productivity as measured through chlorophyll \(a\). The observations are detailed below.

- The unmodified microcosms that had originally an N:P of 4:1 produced 18.39 ± 0.05 µg/L of chlorophyll \(a\) in seven days which increased to 55.42 ± 0.01 µg/L by 28\textsuperscript{th} day. During this period the total nitrogen in the water reduced slightly whereas total phosphorus showed much more reduction changing the N:P to 6:1(Fig. 2.1).
Sediment analysis showed that total nitrogen decreased over time while total phosphorus had increasing tendency as also total organic carbon (Table 2.1). The results indicate that there is sediment release of nitrogen, which could have been absorbed by the algae, but phosphorus added into the sediment by biomass settling and adsorption has more residence time. The natural concentration of nitrogen and phosphorus is sufficient to support the algal bloom for at least a month even at the initial level of 4:1.

**Table 2.1** Temporal variability of total nitrogen, total phosphorus and total organic carbon of soil samples in N:P = 4:1 microcosm during the four week study

<table>
<thead>
<tr>
<th>Period (Days)</th>
<th>TN (g/Kg)</th>
<th>TP (mg/Kg)</th>
<th>TOC (g/Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0.93 ± 0.00</td>
<td>0.56 ± 0.01</td>
<td>2.24 ± 0.15</td>
</tr>
<tr>
<td>14</td>
<td>0.82 ± 0.01</td>
<td>0.68 ± 0.01</td>
<td>10.82 ± 0.48</td>
</tr>
<tr>
<td>21</td>
<td>0.65 ± 0.01</td>
<td>0.68 ± 0.01</td>
<td>22.09 ± 0.40</td>
</tr>
<tr>
<td>28</td>
<td>0.58 ± 0.01</td>
<td>0.65 ± 0.00</td>
<td>26.53 ± 0.17</td>
</tr>
</tbody>
</table>
The microcosm enrichment at N:P = 8:1 produced a sudden induction of algal growth, pushing up the chlorophyll $a$ to $48.03 \pm 0.02 \mu g/L$ in a week’s time; but tending to decline after three weeks. The maximum biomass was observed on 21st day with a chlorophyll $a$ concentration of $74.65 \pm 0.02 \mu g/L$ (Fig. 2.2). The dominant genera were *Pediastrum*, *Chlorella* and *Scenedesmus*. Compared to the control microcosm, the concentration of both nitrogen and phosphorus was high and therefore it was congenial to greater biomass build up; but nitrogen limitation could have occurred beyond three weeks.

![Graph]

**Fig 2.2** Temporal variability of chlorophyll $a$, total phosphorus and total nitrogen of water samples from N:P = 8:1 microcosm during the four weeks study.

The sediment analysis showed decrease in total nitrogen and an increase in total organic carbon and total phosphorus as in control (Table 2.2).
Table 2.2 Temporal variability of total nitrogen, total phosphorus and total organic carbon of soil samples in N:P = 8:1 microcosm during the four week study

<table>
<thead>
<tr>
<th>Period (Days)</th>
<th>TN (g/Kg)</th>
<th>TP (mg/Kg)</th>
<th>TOC (g/Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>1.29 ± 0.04</td>
<td>0.57 ± 0.00</td>
<td>13.78 ± 0.38</td>
</tr>
<tr>
<td>14</td>
<td>1.24 ± 0.05</td>
<td>0.74 ± 0.01</td>
<td>17.73 ± 0.90</td>
</tr>
<tr>
<td>21</td>
<td>1.07 ± 0.04</td>
<td>0.61 ± 0.01</td>
<td>23.98 ± 0.33</td>
</tr>
<tr>
<td>28</td>
<td>0.66 ± 0.00</td>
<td>0.58 ± 0.00</td>
<td>28.31 ± 0.74</td>
</tr>
</tbody>
</table>

- The enrichment systems with N:P = 30:1 had slow bloom induction, as the chlorophyll $a$ values showed a lag phase upto 3 weeks. But the bloom outburst was exponential between the third and fourth week so that the 28th day chlorophyll $a$ was 107.42 ± 0.01 µg/L. The trend of utilisation of nitrogen and phosphorus was similar (Fig. 2.3). Excessive nitrogen in the system did not induce the bloom. Therefore it is the N: P ratio that is important in the induction of bloom.

![Temporal variability of chlorophyll $a$, total phosphorus and total nitrogen of water samples from N:P = 30:1 microcosm during the four week study](image)
It was observed that the N: P on 28\textsuperscript{th} day is 11:1 which is much closer to the Redfield ratio. The dominant genera in this microcosm were *Selenastrum*, *Scenedesmus*, *Pediastrum* and *Chlorella*. Sediment analysis showed a decrease in nitrogen development of the bloom and an increase in phosphorus and total organic carbon (Table 2.3.).

**Table 2.3** Temporal variability of total nitrogen, total phosphorus and total organic carbon of soil samples in N: P = 30:1 microcosm during the four week study

<table>
<thead>
<tr>
<th>Period (Days)</th>
<th>TN(g/Kg)</th>
<th>TP(mg/Kg)</th>
<th>TOC (g/Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>2.10 ± 0.073</td>
<td>0.53 ± 0.003</td>
<td>19.96 ± 1.33</td>
</tr>
<tr>
<td>14</td>
<td>1.95 ± 0.021</td>
<td>0.61 ± 0.006</td>
<td>19.97 ± 0.70</td>
</tr>
<tr>
<td>21</td>
<td>1.55 ± 0.018</td>
<td>0.61 ± 0.005</td>
<td>18.52 ± 0.55</td>
</tr>
<tr>
<td>28</td>
<td>1.18 ± 0.016</td>
<td>0.71 ± 0.004</td>
<td>22.33 ± 0.57</td>
</tr>
</tbody>
</table>

- The enriched system at N: P = 90:1, had the same N content as the previous one, but phosphorus was only 1/3 and the resultant algal biomass on 28\textsuperscript{th} day was low i.e. 73.83 µg/L.

![Fig 2.4](image)

**Fig 2.4** Temporal variability of chlorophyll \(a\), total phosphorus and total nitrogen of water samples from N:P = 90:1 microcosm during the four weeks study.
Dominant genera in this microcosm were *Pediastrum, Scenedesmus* and *Cyclotella*. Nitrogen was in far excess of P and therefore it is phosphorus limitations that have retarded algal biomass production.

The results of sediment analysis are given in Table 2.4.

**Table 2.4** Temporal variability of total nitrogen and total phosphorus and total organic carbon of soil samples in N:P = 90:1 microcosm during the four week study

<table>
<thead>
<tr>
<th>Period (Days)</th>
<th>TN(g/Kg)</th>
<th>TP(mg/Kg)</th>
<th>TOC (g/Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>1.96 ± 0.010</td>
<td>0.57 ± 0.005</td>
<td>5.55 ± 0.11</td>
</tr>
<tr>
<td>14</td>
<td>1.74 ± 0.050</td>
<td>0.77 ± 0.019</td>
<td>15.58 ± 0.38</td>
</tr>
<tr>
<td>21</td>
<td>1.44 ± 0.015</td>
<td>0.65 ± 0.003</td>
<td>28.69 ± 0.90</td>
</tr>
<tr>
<td>28</td>
<td>1.38 ± 0.005</td>
<td>0.67 ± 0.005</td>
<td>32.16 ± 0.97</td>
</tr>
</tbody>
</table>

### 2.4 Discussion

The assessment of algal population based on chlorophyll revealed the eutrophic nature of the pond selected for the study. The concentration of chlorophyll *a* in eutrophic lentic water bodies is widely reported to be in the range 8 - 25 µg/L (Sigee, 2005)

The total phosphorus content of the pond was 92 ± 0.13 µg/L. According to Porcella *et al.* (1980) total phosphorus content > 25 µg/L is the threshold value for eutrophication. Sigee (2005) describes total phosphorus in the range 35 – 100 µg/L as an index of eutrophic state of temperate freshwater lakes. Richardson *et al.* (2007) reported that a surface water mean total phosphorus threshold concentration exceeding 15 µg/L causes ecological imbalance.

Another important parameter described in the trophic status of water body is total nitrogen. Eutrophic criterion of total nitrogen as per Mason (2002) is > 500 µg/L. As per Wetzel (2001) total nitrogen of mesoeutrophic lake is the range 500 – 1100 µg/L. The total nitrogen content of the natural
pond studied had a value of $392 \pm 0.02$ µg/L. Total nitrogen content of the present study matched the oligomesotrophic criterion (250 - 600 µg/L) as described in Wetzel (2001).

Excessive nutrients enter the water bodies from point sources such as from sewage, industry and non point sources like surface run off, irrigation water etc. Nitrogen and phosphorus input and enrichment in water are the primary factors held for eutrophication. According to Zhao (2004) 80% of the lakes and reservoirs eutrophication in China is due to phosphorus limitation, about 10% controlled by nitrogen and rest 10% by other factors. In many ecosystems, the phytoplankton biomass is affected by the concentration of nitrogen and phosphorus (Cloern, 2001; Bledsoe et al., 2004; Reynolds, 2006).

In the present investigation, it was observed that when nitrogen was in excess, the biomass was related to phosphorus concentration. The ratio of N:P in the water body have been used as an indicator of predicting the likely development and persistence of algal blooms. In freshwaters, if N:P is over 20:1, phosphorus is considered to be the limiting element; if N:P is below 10:1, nitrogen is considered to be the limiting element. If the ratio is between 10:1 and 20:1, the limiting element becomes uncertain (Yeguang et al., 2006). Lin et al. (2008) have stated that many tropical and subtropical lakes are nitrogen limited. This agrees with the present observation where the pond water has an N:P of 4:1. According to Yang et al. (2008) red tides are induced when total nitrogen reaches 300 µg/L and phosphorus reaches 20 µg/L. Therefore, the pond in the present investigation is eutrophic and potent enough to promote phytoplankton bloom; but sustenance of bloom for long term is doubtful as the system is nitrogen limited.

Additional input of nutrients into the system changed the pattern of induction and sustenance of the algal bloom. At 8:1, there occurred induction of bloom but the bloom declined after three weeks, probably due to nitrogen limitation. Under same concentration of phosphorus, when the level of
nitrogen was increased, the bloom persisted beyond three week in fact, the curve was exponential between third and fourth week producing 107 µg/L Chl \textit{a} on the 28\textsuperscript{th} day. The same trend was observed when the concentration of phosphorus was lowered keeping the high nitrogen level constant, although the biomass attained was less. Therefore, it is derived that by further input of nitrogen the system will only result in sustained algal bloom, but the concentration of phosphorus will limit the biomass i.e. in such systems the final biomass build up depends on the concentration of phosphorus. In nitrogen limited systems bloom induction is quick, but soon nitrogen starvation leads to decline of the bloom. Therefore, there is less chance of persisting blooms in nitrogen limited systems.

In this investigation, based on the nutrient studies it is evident that an N:P of 8:1 can induce a sudden bloom, but for persistence of the bloom, higher N:P is required. The threshold couldn’t be defined.

Therefore, what are the options for control of algal blooms in an enclosed water body? Definitely it is reduction of the nitrogen and phosphorus inputs, together with monitoring of the ratio of nitrogen and phosphorus. The sediment absorption and release, the temperature and hydrodynamics are important factors to be studied.

The pond under investigation although nitrogen limited, has sufficient growth of phytoplankton as to classify it in eutrophic category based on chlorophyll \textit{a}, total nitrogen and total phosphorus. The source of nutrients is traced to surface run off i.e. non point pollution. Controlling inputs of nutrients will not be a practical solution in such systems. When similar pond and lake waters are used for drinking purpose after treatment or for industrial use interference of the algal bloom on the treatment efficiency is a major problem. Hence, effective methods of algal control in the intake waters are required. Therefore, the existing algal bloom control methods are reviewed and alternate methods are probed further in this investigation.
2.5 References


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