CHAPTER V

DISCUSSION

The study was conducted to evaluate the influence of environmental factors on N₂-fixing cyanobacterial persistence and population dynamics in different rice fields of Kamrup district (Assam).

Altogether 71 species of N₂-fixing cyanobacteria belonging to 20 genera under 9 families were recorded from nine rice fields situated at three different localities viz. Southwest (DHP-1, DHP-2, DHP-3), North (SUK-4, SUK-5, SUK-6) and Southeast (CHP-7, CHP-8, CHP-9) of Kamrup district of Assam. With 54% of species Nostocaceae was the dominant family followed by Chroococcaceae (14%), Rivulariaceae (13%), Scytonemataceae (7%), Oscillatoriaceae (6%), Stignemataceae (3%). Whereas, Mastigocladiaceae, Mastigocladopsidaceae and Microchaetaceae contributed with only 1% of species each (Figure.5.1). Species of Nostocaceae, Chroococcaceae, Rivulariaceae, Oscillatoriaceae, Scytonemataceae and Mastigocladopsidaceae were reported from all the rice fields of the district. Species of Stigonemataceae and Mastigocladiaceae were reported in the rice fields of Southwest Kamrup while Microchaetaceae in rice fields of North Kamrup only (Figure.5.1.).

*Anabaena* was reported to be the dominant genera with a total of 31% species. *Nostoc* (17%) and *Calothrix* (8%) were the second and third biggest genera followed by unicellular cyanobacteria *Aphanocapsa* (6%) (Figure.5.2.). The predominance of
Anabaena and Nostoc irrespective of chemical/biofertilizers supplementation and stage of crop growth was reported in different rice growing areas of India (Singh et al., 1996; Singh et al., 1997a; Nayak et al., 2001, 2004). Thamizh Selvi and Sivakumar (2011) also reported Anabaena and Nostoc as the dominant genera among the heterocystous form of cyanobacteria in rice fields of Cuddalore district, Tamil Nadu. Anabaena, Calothrix and Nostoc were recorded with maximum number of species in rice grown areas of Tripura (Singh et al., 1996). Singh et al. (1997a) also recorded highest number of species belonging to genera Anabaena and Nostoc in rice fields of Nagaland. In the rice field of Sonitpur district of Assam, Nostoc, Anabaena, Aulosira, Calothrix, Westiellopsis and Aphanocapsa were dominant (Dasgupta and Ahmed, 2013). Nostoc and Anabaena can be considered as one of the most versatile and highly competitive genera observed in all types of environments, that have the capacity to colonize as floating assemblages or as edaphic forms in rice fields soil (Singh et al., 1996; Singh et al., 1997a; Nayak et al., 2001, 2004; Prasanna and Nayak, 2007; Thamizh Selvi and Sivakumar, 2011).

Mostly the species of Anabaena, Nostoc and Calothrix showed higher relative abundance values from 66.66% to 83.33% respectively in the rice fields of Kamrup. Results was in conformity with Prasanna and Nayak (2007) who recorded cyanobacterial genera having higher relative abundance of Anabaena (100%) and Nostoc (100%) and Calothrix (89%) in different rice growing soils of India excluding Kamrup, Assam.
Figure 5.1. Percentage composition of N$_2$-fixing cyanobacterial species in different families in rice fields’ soil of Kamrup.

Figure 5.2. Percentage composition of N$_2$-fixing cyanobacterial species in different genera in rice fields’ soil of Kamrup.
The filamentous heterocystous (80%) cyanobacteria showed clear dominance over the unicellular/colonial (14%) and filamentous non-heterocystous (6%) forms. The dominance of filamentous heterocystous forms over other forms (unicellular and filamentous non-heterocystous) was also recorded in other rice field soils of India (Nayak and Prasanna, 2007). Hazarika (2007) reported 20.83% of unicellular/colonial and 30.56% of filamentous non-heterocystous form which was outnumbered by filamentous heterocystous cyanobacteria (48.61%) in soils of greater Guwahati.

Principal Component Analysis (PCA) was carried out using the XLSTAT software to find the effect of seasonal changes on cyanobacteria. The PCA ordination Map (Figure.5.3. to 5.5.) indicated close relationship between the species of N$_2$-fixing cyanobacteria and the months during which the species were mostly dominant. PCA (Figure.5.3.) showed that majority of cyanobacterial species reported from rice fields of Southwest Kamrup, were dominant during July-August. These species were *Chroococcus montanus*, *Anabaena anomala*, *A. fertilissima*, *A. vaginicola*, *A. variabilis*, *Aulosira prolifica*, *Nostoc ellipsosporum*, *N. punctiforme*, *Lyngbya rubida*, *Rivularia hansgirgi* (sp7, sp15, sp19, sp32, sp33, sp39, sp43, sp50, sp54, sp64). September-October was favourable for *L. perelegans*, *Calothrix brevissima*, *N. passerinianum*, *Gloeotrichia Pilgeri* and *Scytonema simplex* (sp55, sp56, sp47, sp63, sp64) and November-December was favourable for *A. constricta*, *A. oryzae*, *N. paludosum*, *C. scytonemicola*, and *S. fritschii* (sp17, sp25, sp48, sp60, sp65). *Synechococcus aeruginosus*, *Mastigocladosis jogensis*, *A. sphaerica*, *N. carneum* and *C. marchica* (sp10, sp12, sp28, sp41 and sp58) were the dominant species recorded
during January-February, whereas *Aphanocapsa roeseana, Anabaena spiroides, N. linckia* (sp4, sp29, sp45 and sp50) and *A. fuellebornii, N. calcicola, Gloeocapsa quaternata* and *Westiellopsis prolifica* (sp21, sp40, sp9, sp71) were the dominant species in March-April and May-June respectively.

**Figure 5.3.** PCA ordination analysis of N\textsubscript{2}-fixing cyanobacteria in respect to seasons in rice fields’ soil of Southwest Kamrup.
In the rice fields of North Kamrup, *Microchaete aequalis, Anabaena anomala, A. variabilis, Nostoc doliolum* and *Scytonema simplex* (sp13, sp15, sp18, sp40, sp67)

**Figure 5.4.** PCA ordination analysis of N$_2$-fixing cyanobacteria in respect to seasons in rice fields’ soil of North Kamrup.
were the dominant species during July-August. *N. calcicola, Lyngbya palmarum, L. rubida, Calothrix brevissima, C. marchica, C. membranacea, Rivularia hansgirgi* (sp33, sp53, sp54, sp56, sp58, sp59, sp64) were the dominant species during September-October and *Mastigocladopsis jogensis, A. fertilissima, A. oryzae, A. torulosa* and *N. linckia* (sp12, sp19, sp25, sp30 and sp45) during November-December. During January-February, *Aphanocapsa pulchra, Anabaena ambigu*a, *A. flos-aquae, A. smithii* (sp3, sp14, sp20, sp27), during March-April were *Aphanocapsa biformis, A. roeseana, Anabaena oscillarioideos, A. vaginicola* (sp1, sp4, sp26, sp32) and during May-June *Gloeocapsa decorticans, A. gelatinicola and N. paludosum* (sp8, sp22, sp48) were the dominant species occurring in the rice fields of North Kamrup (Fig.5.4).

In the rice fields of Southeast Kamrup, *Anabaena anomala, A. sphaerica, A. variabilis, Nostoc linckia, N. muscorum, N. piscinale, (sp15, sp28, sp33, sp45, sp49, sp46)* were the dominant species during July-August. *A. variabilis var. ellipsospora, Lyngbya palmarum and Calothrix weberi* and *Gloeotrichia longicauda* (sp34, sp53, sp61, and sp62) were dominant during September-October and *A. constricta, N. punctiforme, L. allorgei and C. marchica and Tolypothrix tenuis* (sp17, sp50, sp52, sp58 and sp69) during November-December. During January-February the dominant species were *Aphanothece microscopic, A. naegelii, Chroococcus montanus and N. spongiaeforme, (sp5, sp6, sp7 and sp51). Anabaena iyengarii and Anabaenopsis tanganyikae* (sp23 and sp36) were the only dominant species recorded during March-April. The dominant genera in May-June were *Gloeocapsa decorticans, Aulosira aenigmatica, N. hatei and N. paludosum* (sp8, sp37, sp44 and sp48) (Figure.5.5).
PCA analysis thus revealed that rice fields’ soil of Kamrup district were dominated by heterocystous filamentous forms of $N_2$-fixing cyanobacteria from July to December and unicellular forms from January to June. PCA too revealed that *Anabaena*...
and *Nostoc* were the most dominant genera among the heterocystous filamentous forms. Species of these two genera were observed in entire sampling period but their optimum growth recorded from July-December. *Calothrix, Lyngbya, Gloeothrichia, Scytonema, Tolypothrix* were the prominent genera next to *Anabaena* and *Nostoc* which mostly flourished during September to December. In contrast, the unicellular forms restricted themselves to a particular season. *Aphanocapsa* was the dominant genus recorded during January to April and *Gloeocapsa* during May-June. The changes in the environment or the seasonal variation might be the reason that affect particular species and induced the dominance of other species, which led to the succession of several species in a course of time (Muthukumar *et al.*, 2007).

Sørensen similarity coefficient revealed highest similarity between the rice fields of Southwest Kamrup and North Kamrup. This might be due to same alluvial soil type as the rice fields of both the sites were situated on the floodplain of the river Brahmaputra. The rice fields of Southeast Kamrup though located near the river, textural change was seen due to mixing of red hill soils with the riverian alluvium (Table.4.17.).

Shannon’s diversity indices were recorded overall low in the rice fields of Southeast Kamrup whereas the index attained upto 7.55 in some blocks (DHP-3) in southwest Kamrup and 6.62 (SUK-4) in North Kamrup. Shannon diversity indices are directly related to the abundance and evenness of the species present (Prasad and Prasad, 2001). The diversity indices of southwest Kamrup maintained higher values round the year. The values touched pick from July to October (Figure.5.6.).
The population number of N$_2$-fixing cyanobacteria too were recorded low in the rice fields of Southeast Kamrup whereas Southwest Kamrup maintained overall higher values. Population number attained upto 12.0 x$10^4$/g soil (DHP-3) in Southeast Kamrup, 3.10 x$10^4$/g soil (SUK-4) in North Kamrup and 2.28 x$10^4$/g soil (CHP-8) in Southeast Kamrup respectively. The population number touched maximum in July-August in all the rice fields of the district except DHP-2, which attained maximum in September-October (Figure 5.7.). Pearson’s correlation coefficient (r) analysis proved that physico-chemical properties of soil were the crucial factors in altering the population number of N$_2$-fixing cyanobacteria (Table.4.27. to 4.35.).
Figure.5.7. Population number of N$_2$-fixing cyanobacteria in rice fields of Kamrup.

Maximum population number that was recorded in DHP-3 during July-August was attained at a temperature of 32.56±0.02$^0$C which was in conformity with the optimum temperature range of 30-35$^0$C for cyanobacterial growth (Subrahmanyan et al., 1965). Abdel Hameed et al. (2007), Castenholz and Waterbury (1989) also reported that cyanobacteria flourished in the soil, when the temperature fluctuates around 31.7$^0$C. The high temperature enhanced the rate of decomposition of organic matter to release more nutrients to the rice fields’ soil. Since rice is a rainfed crop of Brahmputra river floodplain, moisture content became the encouraging factor for the growth of N$_2$-fixing cyanobacterial population number along with temperature. Maximum cyanobacterial population number was recorded at DHP-3 (12.0 x10$^4$/g soil), DHP-2 (7.02 x10$^4$/g soil), DHP-1 (2.49 x10$^4$/g soil) when the rice fields’ soil contained a relatively higher amount of moisture content viz. 27.63±0.03 %, 29.56±0.03 %, 32.56±0.02 % respectively. Boussiba (1991) also recorded positive correlation between moisture and population...
number of N$_2$-fixing cyanobacteria in rice fields of Iran. Moisture was therefore, noted to be extremely important for the multiplication of cyanobacteria (Zimmerman et al., 1980). During July to September maximum uptake of nitrogen took place as the canopy of the rice plants increased due to its maturation and grains setting. Cyanobacteria, being a shade loving organism (Roger and Reynaud, 1976) showed their maximum growth with the increased of rice canopy which caused a decrease in light intensity in the surface of the soil (Song et al., 2005) and depletion of nitrogen which corroborate with the findings of Choudhary and Bimal (2010), Choudhary (2011).

Nitrogen, an important nutrient for plants showed significantly strong negative correlation with cyanobacterial population number, thus indicating its establishment in rice fields’ soil of Southwest Kamrup where the concentration of total nitrogen content was low. The findings were in conformity with Howarth et al. (1988), Kardinaal and Visser (2005). Cyanobacteria are abundant in places where there is a major nitrogen-deficiency in nature (Nayak and Prasanna, 2007). Granhall et al. (1987) also reported the predominance of N$_2$-fixing cyanobacterial number under low concentration of nitrogen fertilizer. Bunt (1961) proved that cyanobacteria were scarce in Australian rice fields, possibly due to the higher levels of copper sulfate and combined nitrogen present in the irrigation water. Heavy rainfall intensities during July to August might led to highly mobile nitrate to leach resulting in nitrogen deficit. Besides physical factors and nitrogen, other chemical factors also had a great impact on the organism.

The population number of N$_2$-fixing cyanobacteria increased mostly in rice fields of Southwest Kamrup (DHP-1, DHP-2 and DHP-3) with the increased in pH values
(8.32±0.04, 8.23±0.03 and 7.92±0.006). Brannon (1945), Mitra (1951) and Roger and Kulasooriya (1980) reported that under natural conditions cyanobacteria prefer to grow in soil where the pH level was neutral to alkaline. Highest percentage of abundance of heterocystous form was observed at pH 8.1 by Nayak and Prasanna, (2007). Acidic soils are, therefore, one of the stressed environments for these organisms and they are normally absent at pH values below 4 or 5 (Nayak and Prasanna, 2007). During July-August maximum cyanobacterial population number was recorded at DHP-3 (12.0 x10⁴/g soil) and DHP-1 (2.49 x10⁴/g soil) when the rice fields’ soil contained a relatively higher amount of available phosphorus of 152.4±1.12 meq/100g soil and 132.06±1.4 meq/100g soil. And during September-October population number was recorded highest at DHP-2 (7.02 x10⁴/g soil) and DHP-3 (9.18 x10⁴/g soil) with an increased amount of phosphorus (101.4±1.5 meq/100g soil and 132.46±1.56 meq/100g soil). Positive correlation between pH and available phosphorus content of the soil with the abundance of heterocystous forms was also observed by De and Sulaiman (1950), Okuda and Yamaguchi (1952), Bisoyi and Singh (1988), Roger et al., 1993, Mandal et al. (1993) and Saeton and Traichaiyaporn (2007). The growth of N₂-fixing cyanobacteria in rice fields were reduced with low pH and P deficiency (Roger and Kulasooriya, 1980; De and Sulaiman, 1950). Bisoyi and Singh (1988), De and Sulaiman (1950) also showed a good correlation between the level of phosphorus applied and biomass of cyanobacteria. Cyanobacteria were also been reported to excrete organic acids that render phosphorus solubilisation thus contributing available phosphorus to the soil (Fuller and Rogers, 1952; Whitton et al., 1991; Wilson 2006; Zulpa et al., 2008). Therefore, luxuriant growth of cyanobacteria during this period could be attributed to high amount of
phosphorus. Moreover, sodium was also found to be positively correlated which indicated that this nutrient too played a role in inducing the N$_2$-fixing cyanobacterial population number. This was in conformity with the earlier findings of Shubert and Starks (1980) and Issa et al. (2000). Significant positive correlation with potassium, calcium and magnesium too were observed in the present study. Calcium, potassium, iron and phosphorus enhanced the heterocystous cyanobacterial biomass (Reynaud, 1987). Wilson and Alexander (1979) carried out his experiment in situ on paddy soils and observed that development of indigenous cyanobacteria and nitrogen fixation were correlated with pH and the levels of extractable potassium, calcium and magnesium. Negative correlation was observed between cyanobacterial population and electrical conductivity as well as organic carbon which were in conformity with the findings of Reynaud (1987) and Dey et al. (2010).

The box plot graphics where the average range of physicochemical properties and population number of N$_2$-fixing cyanobacteria in rice fields’ soil of Southwest, North and Southeast Kamrup were considered revealed that rice fields of Southeast Kamrup harboured with the minimum population number (Figure.5.8.A) among the rice field of the entire district. This might probably due to the presence of high level of average nitrogen, organic carbon and low level of phosphorus and moisture (Figure.5.8.F, L, G and C). The acidic pH of the soil was also the other controlling factor for the luxuriant growth of cyanobacteria (Figure.5.8.D). On the other hand, rice fields’ soil situated in Southwest Kamrup which was characterized by higher level of phosphorus and moisture (Figure.5.8.G and C), recorded maximum cyanobacterial
population growth. Low nitrogen and organic carbon contents could be attributed to increase in their population number (Figure.5.8.F and L). Slightly higher alkaline pH too, along with sodium, calcium and magnesium (Figure.5.8.I, J and K) could also be attributed for higher population number of N₂-fixing cyanobacteria in Southwest Kamrup.
Electrical conductivity (µs)

Nitrogen (%)

Phosphorus (mg/100g soil)

Potassium (meq/100g soil)
Figure 5.8. Box plot graphics of soil physico-chemical parameters and N₂-fixing cyanobacteria number. + = Mean, top dot = maximum, bottom dot = minimum values. SWK=Southwest Kamrup, NK=North Kamrup and SEK=Southeast Kamrup.
Management action plan of the district:

The present study also evaluated the efficiency of seven strains of N\textsubscript{2}-fixing cyanobacteria out of total 21 species recorded, that can be used as inocula for region specific biofertilizer production. The strains were selected based on the amount of total nitrogen fixed in soil medium. Their N\textsubscript{2}-fixing abilities were 4.58±0.76% (Anabaena oryzae), 4.18±0.87% (Nostoc muscorum), 4.01±0.69% (N. punctiforme), 3.10±0.87% (Westillopsis prolifica), 2.92±0.17% (A. variabilis), 2.46±0.37% (N. paludosum) and 2.12±0.25% (Calothrix membranacea). With these 7 strains four consortia were developed. The consortia showed better performance in total nitrogen fixation than that of individual strains. ConsANCW (A. oryzae, N. muscorum, C. membranacea, W. prolifica) with 5.04±0.94% of total nitrogen was the most efficient inoculum followed by ConsN (N. muscorum, N. muscorum, N. passerinianum N. punctiforme) with 4.29±0.46%, ConsA (A. oryzae, A. sphaerica, A. variabilis) with 4.01±0.45% and ConsC (C. bravessima, C. membranacea, C. weberi) with 3.58±0.23% respectively (Table.4.37.).

Efficient N\textsubscript{2}-fixing strains belonging to genera Nostoc, Anabaena, Tolypothrix, Aulosira, Cylindrospermum, Scytonema, Westillopsis were widespread in Indian rice field soils and number of field trails conducted with these materials have shown promising results both in terms of nitrogen saving as well as crop yield (Venkataraman, 1981; Kaushik, 1994; Prasad and Prasad, 2001; Nayak et al., 2004; Begum et al., 2008; Gafur and Pervin, 2008 and Shinde et al., 2010). Inoculation of soil with the mixture of N\textsubscript{2}-fixing cyanobacteria (Nostoc commune, N. linckia and Anabaena iyengarii var.
tenius) decreased the use of N fertilizer by 50% to get the same yield and quality of rice compared with the full dose of chemical fertilizer (Pereira et al., 2008). Ghose and Saha (1997) also reported that the inoculation of soil with the soil based mixed culture of *Aulosira fertilissima*, *N. muscorum*, *N. commune* and *Anabaena* sp. significantly increased the release of inorganic nitrogen to the soil.

So, the present study recommends the indigenous strains of *Anabaena oryzae*, *Nostoc muscorum*, *N. punctiforme*, ConsANCW, ConsN, ConsA, ConsC, for field application in rice fields’ soil of Kamrup district. Four standard methods viz. trough or tank, pit, field scale production and nursery cum algal production could be used for mass cultivation of the above selected N₂-fixing cyanobacterial strains.
CHAPTER VI

SUMMARY AND CONCLUSION

- The present endeavour was aimed to study the diversity and population dynamics of N\textsubscript{2}-fixing cyanobacteria in relation to seasonal variation and soil physico-chemical parameters in rice field’s soils of Kamrup district, Assam. Accordingly nine rice fields, situated at three different locations viz. Southwest (DHP-1, DHP-2, DHP-3), North (SUK-4, SUK-5, SUK-6) and Southeast (CHP-7, CHP-8, CHP-9) were selected from both the bank of the river Brahmaputra.

- Altogether 71 species of N\textsubscript{2}-fixing cyanobacteria belonging to 20 genera under 9 families were recorded from the rice fields’ soil of Kamrup district.

- The filamentous heterocystous cyanobacteria showed clear dominance over the unicellular/colonial and filamentous non-heterocystous forms.

- Among filamentous heterocystous, Nostocaceae topped with 4 genera (Anabaena, Anabaenopsis, Aulosira and Nostoc), followed by Rivulariaceae with 3 genera (Calothrix, Gloeotrichia, Rivularia) and Scytonemataceae with 2 genera (Scytonema, Tolypothrix). The rest of the filamentous heterocystous families had only 1 genus each and were belonged to Stignemataceae (Hapalosiphon), Mastigocladaeae (Mastigocladius), Mastigocladosidaceae (Mastigocladius) and Microchaetaceae (Microchaete). Oscillatoriaceae was the lone filamentous non-heterocystous family and Lyngbya was the only representative genus belonging to
the family. The Chroococcaceae was also the only unicellular family represented by *Aphanocapsa, Aphanothece, Chroococcus, Gloeocapsa* and *Synechococcus*.

- With 54% of species, Nostocaceae was the dominant family followed by Chroococcaceae (14%), Rivulariaceae (13%), Scytonemataceae (7%), Oscillatoriaceae (6%), Stigonemataceae (3%). Mastigocladaceae, Mastigocladopsidaceae and Microchaetaceae contributed the rest 3% in total.

- Species belonging to Nostocaceae, Chroococcaceae, Rivulariaceae, Oscillatoriaceae, Scytonemataceae and Mastigocladopsidaceae were reported from all the rice fields of the district. Species belonging to Stigonemataceae and Mastigocladaceae were reported from the rice fields of Southwest Kamrup while that of Microchaetaceae from rice fields of North Kamrup only.

- *Anabaena* was reported to be the dominant genera with 31% species followed by *Nostoc* (17%). *Calothrix* with 8% of species was the third biggest genus followed by *Aphanocapsa* (6%), *Lyngbya* (6%), *Aulosira* (4%), *Scytonema* (4%), *Aphanotece* (3%), *Gloeocapsa* (3%), *Gloeotrichia* (3%) and *Tolypothrix* (3%) respectively.

- PCA analysis revealed that rice fields’ soil of Kamrup district were dominated by heterocystous filamentous forms of N\(_2\)-fixing cyanobacteria from July to December and unicellular forms from January to June.

- Higher relative abundance values from 66.66% to 83.33% were mostly showed by species of *Anabaena, Nostoc* and *Calothrix*.
Shannon’s diversity indices were low in the rice fields of Southeast Kamrup whereas, fields of southwest Kamrup maintained higher values round the year.

Sørensen similarity coefficient revealed highest similarity between the rice fields of Southwest Kamrup and North Kamrup.

The box plot graphics revealed that rice fields of Southeast Kamrup recorded with the minimum population number whereas Southwest Kamrup recorded with the maximum number.

Pearson’s correlation coefficient (r) analysis revealed that temperature, moisture, pH, phosphorus, nitrogen were the controlling factors in maintaining the population number of N₂-fixing cyanobacteria in rice fields of Kamrup.

The nitrogen fixing capacity of the major selected strains were 4.58±0.76% (Anabaena oryzae) > 4.18±0.87% (Nostoc muscorum) > 4.01±0.69% (N. punctiforme) > 3.10±0.87% (Westillopsis prolifica) > 2.92±0.17% (A. variabilis) > 2.46±0.37% (N. paludosum) > 2.12±0.25% (Calothrix membranacea) respectively.

Of the four consortia developed, ConsANCW (Anabaena oryzae, Nostoc muscorum, Calothrix membranacea, Westillopsis prolifica) with 5.04±0.94% of total nitrogen fixed was considered the most efficient followed by ConsN (N. muscorum, N. passerinianum, N. punctiforme) with 4.29±0.46%, ConsA (A. oryzae, A. sphaerica, A. variabilis) with 4.01±0.45% and ConsC (C. bravessima, C. membranacea, C. weberi) with 3.58±0.23% respectively.
Plate 1. Enumeration of population number of N$_2$-fixing cyanobacteria by MPN methods
Plate 2.1. Pure cultures: A = Anabaena variabilis var. ellipsospora, B = Nostoc pisinale, C = N. hatei, D = Aphanocapsa pulchra, E = Anabaena oryzae, F = A. variabilis, G = Calothrix weberi, H = N. punctiforme, Q1 = Lyngbya palmarum
Plate 2.2. Pure cultures: M1-Scytonema hofmanni, M2-Calothrix bravessima, M3-Anabaena anamola, M4-C. membranaceae, M5-N. linckia, K=N. passeriniaux, Q=N. muscorum, X=A. sphaerica, R=N. paludosum
Plate 2.3. a- Pure cultures: U=Gloeocapsa decorticans, J=Nostoc commune, T=Westillopsis prolifica

b- Some preserved strains of N₂-fixing cyanobacteria
Plate 7. Species of *Anabaena*. a- *A. sphaerica*, b- *A. orientalis*, c- *A. vaginicola*, d- *A. oryzae*
Plate 8. Species of *Anabaena* and *Nostoc*. a-*A. gelatinicola*, b-*A. fertilissima*, c-*A. circinalis*, d-*N. carneum*
Plate 9. Species of *Anabaena* and *Anabaenopsis*. a-*Anabaena doliolum*, b-*A. anomala*, c-*A. constricta*, d-*Anabaenopsis tanganyikae*
Plate 10. Species of Nostoc. a-N. hatei, b-N. passerinianum, c-N. commune, d-N. muscorum
Plate 12. Species of Calothrix. a-C. membranacea, b-C. clavatoides, c-C bravissima, d-C. weberi
Plate 13. Species of Calothrix, Rivularia and Gloeotrichia. a- C. marchica, b- R. hansgirgi, c- G. longicauda, d- G. pilgeri
Plate.14. Species of Scytonema, Tolypothrix, Westiellopsis and Hapalosiphon. a-S. simplex, 
b-T. nodosa, c-W. prolifica, d-H. welwitschii