# Cyanophyte algae with potential for obtaining efficient, resilient and adaptable biofertilizers to soils in the face of climate change

# Les cyanobactéries présentent un potentiel pour l'obtention de biofertilisants efficaces, résilients et adaptables aux sols face aux changements climatiques

**Sergiu DOBROJAN[1*], Gheorghe JIGĂU[1], Galina DOBROJAN[1], Victor MELNIC[1]**

[1] Scientific Research Center Integrated Natural Sciences, Moldova State University, Republic of Moldova

* Correspondence to: Sergiu DOBROJAN. E-mail: sergiudobrojan84@yahoo.com, sergiu.dobrojan@usm.md.



Vol. 36.1 / 2026, 93-105

GEOREVIEW

*Received:*
*11 May 2025*

*Accepted:*
*27 November 2025*

*Published online:*
*3 December 2025*

How to cite this article:

*Dobrojan, S., Jigău, G., Dobrojan, G., Melnic, V. (2025) Cyanophyte algae with potential for obtaining efficient, resilient and adaptable biofertilizers to soils in the face of climate change. Georeview, 36, 1, https://doi.org/10.4316/GEOREVIEW.2026.01.07*

**ABSTRACT:** Climate change is increasingly affecting soils, which makes it necessary to use algal biofertilizers on a large scale to maintain soil health. Algal biofertilizers should be administered preferentially in live form, to accelerate their development in the soil. For the selection and cultivation of algal biofertilizers, it is essential that the algae species are part of the biodiversity of the soils, to avoid imbalances in algal phytocenoses. Among these, certain cyanophyte species are of interest, being cosmopolitan, detected in most soil types, can be easily selected in culture and are suitable for the efficient production of biofertilizers. Thus, the following cyanophyte species have the greatest prospects: *Nostoc commune*, *N. punctiforme*, *Anabaena variabilis*, *Tolypothrix tenuis* and *Microcoleus vaginatus*.

**KEY WORDS:** cyanophyte algae, biofertilizers, soils, climate change.

**RÉSUMÉ :** Le changement climatique affecte de plus en plus les sols, rendant nécessaire l'utilisation à grande échelle de biofertilisants algaux pour préserver leur santé. Il est préférable d'administrer ces biofertilisants sous forme vivante afin d'accélérer leur développement dans le sol. Pour la sélection et la culture des biofertilisants algaux, il est essentiel que les espèces d'algues fassent partie de la biodiversité des sols, afin d'éviter les déséquilibres des phytocénoses algales. Parmi celles-ci, certaines espèces de cyanobactéries présentent un intérêt particulier : cosmopolites, présentes dans la plupart des types de sols, faciles à cultiver et adaptées à une production efficace de biofertilisants. Ainsi, les espèces de cyanobactéries suivantes offrent les meilleures perspectives: *Nostoc commune*, *N. punctiforme*, *Anabaena variabilis*, *Tolypothrix tenuis* et *Microcoleus vaginatus*.

**MOTS CLÉS:** cyanobactéries, biofertilisants, sols, changements climatiques.

## 1. Introduction

Global warming has become one of the most critical challenges for humanity, driven primarily by human-induced activities. Recent assessments show that the global mean surface temperature rose by approximately 1.1°C during 2011–2020 relative to the 1850–1900 baseline. Warming has been more pronounced over land (+1.59°C) than over the oceans (+0.88°C), and the post-1970 warming rate is the highest recorded in the past two millennia. Human influence is estimated to account for 0.8–1.3°C of this increase, with a central estimate of 1.07°C; greenhouse gases alone have contributed up to 2.0°C of warming, while aerosols have offset this by inducing up to 0.8°C of cooling. By 2019, cumulative $CO_2$ emissions reached 2400 ± 240 $GtCO_2$, with 58% emitted between 1850–1989 and 42% between 1990–2019. Atmospheric concentrations of $CO_2$ (410 ppm), $CH_4$ (1866 ppb), and $N_2O$ (332 ppb) in 2019 were the highest observed in the last 2 million, 800,000, and 800,000 years, respectively. (IPCC., 2023).

Climate change profoundly impacts the environment, including soil, by disrupting its structure, moisture, nutrients, and biological processes (Brevik, 2012). Climate change induces major shifts in soil moisture, which in turn affects key physical, chemical, and biological properties essential for maintaining soil fertility and productivity. It alters organic matter inputs, thermal regimes, hydrology, and salinity levels, while research indicates significant impacts on soil texture, structure, bulk density, porosity, and nutrient-retention capacity. These changes contribute to salinization, reduced water and nutrient availability, disruptions in carbon and nitrogen cycling, and a decline in soil biodiversity. Chemical properties such as pH, cation exchange capacity, and nutrient dynamics are likewise affected, with cascading consequences for biological processes and biogeochemical regulation. In light of these trends, implementing effective mitigation and adaptation strategies—through emission reduction, sustainable policies, technological innovation, and shifts in consumer behavior—has become increasingly urgent (Choudhary et al., 2021).

According to the Intergovernmental Panel on Climate Change (IPCC), agriculture accounts for roughly 20% of global greenhouse gas emissions. Within this sector, nitrous oxide ($N_2O$) is a major contributor, largely originating from the use of synthetic fertilizers and the wastewater produced by livestock operations (IPCC Working Group III, 2001). In addition, according to estimates by the Food and Agriculture Organization (FAO), the demand for food and feed will increase by about 70% by 2050. Consequently, annual cereal production will have to rise to approximately 3 billion tons, up from the current 2.1 billion, while global meat output must expand by over 200 million tons, reaching an estimated 470 million tons. (FAO, 2024). To meet these demands, conventional chemical fertilizers will be used massively. This will result in an imbalance of soil nutrients and damage agricultural lands in the long term (Ghorai & Ghosh, 2022). As a solution to this problem, humanity aims to reduce the application of chemical fertilizers and increase the use of biofertilizers (John & Babu 2021).

Some of the most promising biofertilizers are cyanophyte algae (cyanobacteria), rightly considered the pioneers of life on Earth. They can survive in extreme conditions, often unacceptable for other life forms. Cyanophyte algae are the only living organisms that combine photosynthesis with atmospheric nitrogen fixation, which makes them the most efficient “autotrophic” organisms, capable of fixing nitrogen from the atmosphere and capturing and storing carbon. Thus, they represent a pinnacle of biochemical evolution of microorganisms (Gusev, M.V. 1968), having considerable potential in promoting sustainable agriculture and combating the effects of climate change.

Cyanophyte algae offer numerous benefits that make them suitable for use as biofertilizers. They improve soil porosity, reduce salinity, and produce biologically active substances such as exopolysaccharides, proteins, carbohydrates, lipids, vitamins, and phytohormones, which have positive effects on soil and plants. They also increase the soil's water retention capacity and contribute to bioremediation through various mechanisms, thus generating multiple effects (Chittora et al., 2020; Thapa et al., 2023; Kollmen et all., 2022).

Cyanophyte algae have an essential role in the accumulation of organic substances in the soil through the photosynthesis process, and after the decomposition of their biomass, they release (Maksimova, 2004; Davydov, 2006; Osman et al., 2003). They colonize areas not occupied by higher plants, acting as an additional source of biomass and solar energy. According to the data of (Golerbach & Shtina 1969) the wet biomass of the species Nostoc commune and N. sphaeroides varies between 73–15000 kg/ha (2.21–400 kg/ha dry biomass) and 800–1500 kg/ha (60–140 kg/ha dry), constituting a food source for heterotrophic organisms and intensifying the microbiological activity of the soil. The substances released by cyanobacteria act as chelating agents and improve the physical properties of the soil.

Nitrogen-fixing cyanophyte algae stimulate both diazotrophic and non-fixing bacteria. The administration of Chlorella, Tolypothrix and Anabaena biomass led to an increase in available phosphorus in the soil (16.4% with biofertilizers, compared to 13.6% in the control), as a result of secreted organic acids that dissolve phosphates. The efficiency of cyanophyte algae in the formation of organic matter increases in the presence of chemical fertilizers and is even greater when organic fertilizers are applied (Golerbach & Shtina, 1969).

In addition, the application of cyanophyte algae as biofertilizers contributes to the decontamination of agricultural soils polluted with heavy metals, organic pollutants, crude oil, industrial wastewater and other toxic substances (Nawaz et al., 2024).

In addition to improving soil health, cyanobacterial biofertilizers boost crop productivity. They act as biostimulants, improving stress tolerance, nutrient use efficiency, and crop quality. They also act as biopesticides, owing to their antimicrobial, antioxidant, antiviral, and antifungal activities. (GR et al., 2021).

An important advantage of using cyanophyta algae as biofertilizers is their ability to fix atmospheric nitrogen. According to data from the literature, they can fix between 10 and 53.1 kg N/ha, which can reduce the need for chemical fertilizers by 25% to 50% (Issa et al., 2014; Ghorai, 2022).

## 2. Study area

The work is based on the analysis and synthesis of the results of the algal flora of terrestrial soils to highlight the dominant species and those most suitable for use as biofertilizer. In particular, the work is focused on systematic research carried out on the European continent.

## 3. Methods

The study combined a literature review with experimental evaluations to identify cyanophyte algae species with the greatest potential for use as biofertilizers. A scientific literature analysis was conducted to catalog terrestrial cyanophyte species, their ecological distribution and preferred nutrient environments. Based on this analysis, the most promising species recommended as biofertilizers were selected. The research used the methods of synthesis, logical analysis, correlation, comparison, systematization and deductive reasoning.

## 4. Results and discussion

It should be noted that not all cyanophyte algae have this ability to fix atmospheric nitrogen, and their systematic classification is presented according to the classical specialist determinants (Elenkin, 1949; Shtina & Golerbakh, 1975), see (Tab. 1).

**Table 1** List of species of nitrogen-fixing cyanophyte algae according to Shtina E.A. and Golerbakh M.M., (1975).

| Taxa | | | | |
|---|---|---|---|---|
| **Class** | **Order** | **Family** | **Gen** | **Species** |
| *Hormogoneae* | *Stigonematales* | *Stigonemataceae* | *Chlorogloeopsis* | *Chlorogloeopsis fritschii* A.K.Mitra & D.C.Pandey |
| | | | *Stigonema* | *Stigonema dendroideum* Fremy. |
| | | | *Fischerellaa* | *Fischerellaa muscicola* (Thuret) Gom. |
| | | | *Fischerellaa* | *F. major* Gom. |
| | | | *Hapalosiphon* | *Hapalosiphon fontinalis* (Ag.) Born. emend. Elenk. |
| | | | *Westiella* | *Westiella* sp. |
| | | | | *Westiellopsis prolifica* Janet |
| | *Mastigocladales* | *Mastigocladaceae* | *Mastigocladus* | *Mastigocladus laminosus* Cohn. |
| | *Nostocales* | *Nostocaceae* | *Nostoc* | *Nostoc calcicola* Bréb. |
| | | | | *N. amplissimum* Setchell |
| | | | | *N. caeruleum* Lyngb. |
| | | | | *N. commune* Vauch. |
| | | | | *N. entophytum* Bornet & Flahault |
| | | | | *N. linckia* Bornet ex Bornet & Flahault |
| | | | | *N. muscorum* C.Agardh |
| | | | | *N. paludosum* Kützing |
| | | | | *N. punctiforme* (Kützing) Hariot |
| | | | | *N. sphaericum* |

| Taxa | | | | |
|---|---|---|---|---|
| **Class** | **Order** | **Family** | **Gen** | **Species** |
| | | | | Vaucher |
| | | | | |
| | | | | *N. sphaeroides* Kützing |
| | | | | *N. spongiiforme* C.Agardh |
| | | | | *Nostoc* sp. |
| | | *Anabaenaceae* | *Anabaena* | *Anabaena ambigua* C.B.Rao |
| | | | | *A. azotica* Ley |
| | | | | *A. azollae* Strasb. |
| | | | | *A. catenula* Kützing ex Bornet & Flahault |
| | | | | *A. circinalis* (Kützing) Hansg. |
| | | | | *A. cycadeae* Reinke |
| | | | | *A. cylindrica* Lemmermann |
| | | | | *A. doliolum* Bharadwaja |
| | | | | *A. fertilissima* C.B.Rao |
| | | | | *A. flos-aquae* (Lyngb.) Brébisson |
| | | | | *A. gelatinosa* Fritsch |
| | | | | *A. hallensis* (Jancz.) Bornet & Flahault |
| | | | | *A. humicola* Bortels |
| | | | | *A. karakumica* Kogan |
| | | | | *A. laxa* A.Braun |
| | | | | *A. levanderi* Lemmermann |
| | | | | *A. lemmermannii* P.G.Richter |
| | | | | *A. minutissima* Lemmermann |
| | | | | *A. naviculoides* F.E.Fritsch |
| | | | | *A. oscillarioides* Bory |
| | | | | *A. scheremetievii* Elenk. |

| Taxa | | | | |
|---|---|---|---|---|
| **Class** | **Order** | **Family** | **Gen** | **Species** |
| | | | | *A. spiroides* Klebahn |
| | | | | *A. torulosa* (Carm.) Lagerheim |
| | | | | *A. variabilis* Kützing |
| | | | | *Anabaena* sp. |
| | | | *Anabaenopsis* | *Anabaenopsis intermedia* Kogan |
| | | | | *A. circularis* (G.S.West) V.V.Miller |
| | | | | *Anabaenopsis* sp. |
| | | | *Cylindrospermum* | *Cylindrospermum licheniforme* (Bornet) Kützing |
| | | | | *C. gorakhpurense* R.N.Singh |
| | | | | *C. majus* Kützing |
| | | | | *C. michailovskoense* Elenkin |
| | | | | *C. muscicola* Kützing |
| | | | | *C. sphaericum* B.N.Prasad |
| | | | | *C. stagnale* Bornet & Flahault |
| | | | | *Cylindrospermum* sp. |
| | | *Nodulariaceae* | *Nodularia* | *Nodularia harveyana* (Thwait.) Thuret |
| | | | | *Nodularia* sp. |
| | | | *Aulosira* | *Aulosira fertilissima* S.L.Ghose |
| | | *Scytonemaceae* | *Scytonema* | *Scytonema arcangelii* Bornet & Flahault |
| | | | | *S. hoffmannii* C.Agardh |
| | | | | *Scytonema* sp. |
| | | | *Scytonematopsis* | *Scytonematopsis* sp. |
| | | | *Tolypothrix* | *Tolypothrix tenuis* Kützing |
| | | | *Tolypothrix* | *T.* |

| Taxa | | | | |
|---|---|---|---|---|
| **Class** | **Order** | **Family** | **Gen** | **Species** |
| | | | | *campylonemoides* S.L.Ghose |
| | | | *Tolypothrix* | *T. polymorpha* Lemmermann |
| | | | *Tolypothrix* | *T. rivularis* Hansgirg |
| | | | *Camptylonema* | *Camptylonema lahorense* S.L.Goshe |
| | | *Rivulariaceae* | *Calothrix* | *Calothrix antarctica* F.E.Fritsch |
| | | | | *C. brevissima* G.S.West |
| | | | | *C. clavata* G.S.West |
| | | | | *C. elenkinii* Kossinskaja |
| | | | | *C. parietina* (Nag.) Thur. |
| | | | | *C. scopulorum* (Weber et Mohr) Agardh |
| | | | *Gloeotrichia* | *Gloeotrichia echinulata* (J.Smith) P.Richter |
| | | | | *Gloeotrichia natans* (Hedw.) Rabenh. |

As can be seen from Table 1, most of the mentioned cyanophyte algae species belong to the orders *Stigonematales, Mastigocladales* and *Nostocales*, of the class *Hormogonophyceae* (systematically classified according to Elenkin). It is important to note that not all species included in the table can be used as biofertilizers, since many of them do not inhabit soils, but only aquatic environments, and their applicability in agriculture is therefore limited.

As reported by (Shtina & Golerbakh 1975) the optimal conditions for the development of edaphic cyanophyte algae include high soil moisture, a basic or slightly acidic pH and a good supply of soil phosphorus and calcium. Among the coenotic factors, the main one is the level of competition with other plants. Thus, despite their remarkable resistance and ability to adapt to extreme conditions, the mass development of these organisms is generally observed in ecosystems with reduced competition: on primitive soils, alluvial sands, in phytocenoses with low vegetation density, on lifeless anthropogenic substrates and on arable soils (Shtina & Golerbakh 1975).

The edaphic algal flora of the European continent is characterized by a large number of algae species (more than 900 species), which are generally attributed to the types of cyanophytes, green algae and diatoms. Of these, only certain species of cyanophytes have a wide distribution, practically in all types of soil (Shtina & Golerbakh 1975,; Elenkin, 1949). They can be selected and cultivated relatively easily and are of interest for obtaining efficient biofertilizers, which can be used for soil adaptation to climate change.

For the selection and obtaining of algal biofertilizers, it is necessary that the algae species (including cyanobacteria) are part of the biodiversity of the soils (in order not to create imbalances in the algal phytocenoses and their structural changes), to be tolerant to environmental factors (temperature, light, precipitation), to possess an increased capacity for reactivation upon soil wetting, to be dominant and edifying, not to disturb the systematic structure of the edaphic algoflora, to be easy to select in culture and to be cultivated industrially.

A basic indicator in the selection of algal biofertilizer species is cosmopolitanism – the ability of a species to be found in a wide variety of habitats and geographical regions. This characteristic is essential, because the global spread of an algal species suggests high ecological adaptability, tolerance to a wide range of abiotic factors (such as temperature, humidity, soil pH, salinity, insolation) and, at the same time, biological compatibility with various types of soil phytocenoses. In other words, a cosmopolitan species is usually "accepted" by local algal communities, without significantly disturbing their ecological balance or structure.

Moreover, cosmopolitanism can be seen as a form of natural validation of a species' potential to function effectively in diverse environments, suggesting that the species carries "ecological information" selected and transmitted by nature itself – a kind of message regarding its robustness, resilience and functional efficiency in ecosystems. This implicit ecological information is particularly valuable in the context of climate change, as selected biofertilizers must cope with an increasingly unpredictable and unstable environment.

Thus, among cyanophyte algae, in our view, of particular interest are those species that simultaneously meet essential criteria such as ease of cultivation under controlled conditions, the ability to adapt to different soil types and efficiency in increasing soil fertility (Dobrojan et al., 2014; Dobrojan et al., 2017; Dobrojan et al., 2019, Dobrojan et al., 2019). These species demonstrate a high practical potential for use as biofertilizers in agriculture, especially in the context of the need for transition to sustainable and ecological practices. Due to their accelerated growth rate, tolerance to abiotic stress factors, as well as the ability to fix atmospheric nitrogen, these cyanobacteria can significantly contribute to the regeneration of degraded soils, to reducing dependence on chemical fertilizers and to increasing agricultural yields under ecological conditions (Golerbach & Shtina, 1969).

Therefore, we consider that the following cyanophyte species stand out as the most promising for industrial-scale cultivation and direct application in agricultural practice, as biofertilizers:

***I. Stratonostoc (Nostoc) commune -*** *Stratonostoc* (*Nostoc*) *commune* - grows en masse in dry soils, primarily in steppes, or in more or less humid places, even in aquatic ecosystems, especially in arctic and high mountain areas, on flooded meadows, in tundra and swamps, in ponds and water holes, in quiet rivers or on irrigated rocks and stones, being also found under ice (fig. 1a). The species grows in various types of soil: gleyed, brown, peat bogs, carbonate, podzolic, all types of chernozem, solonchaks, mountain soils, including on well-moistened stones. Colonies of *N. commune* with a strong periderm, spherical in young individuals, with age becoming flat-spreading, densely plate-like, leathery-gelatinous, folded or wavy, in dry habitats variously twisted, very dark, almost black in color, in humid habitats - more or less widely spreading, sometimes irregularly torn or perforated, reaching several centimeters in diameter, mostly olive-green or yellow to yellow-brown, often very dark, almost black, less often bright blue-green in color. *Nostoc* is found in various types of plant communities, mass growths are confined to substrates devoid of vegetation and moss stations.

The habitats of *N. commune* are characterized by a wide ecological range: the species is found in steppes, dry and swampy meadows, in forest phytocenoses and epilithic synusia in places of increased moisture. The alga is characterized by a high growth rate and a significant ability to fix atmospheric nitrogen. In a significant number of habitats. *N. commune* is one of the dominant spore plants. It is found in the soils of the following countries of the continents: Europe – Republic of Moldova, Romania, Ukraine, Russian Federation, Belarus, Spain, France, Germany, Norway, Poland; Asia – Uzbekistan, Armenia, Azerbaijan, Georgia, China, Iran, India; North America – Canada, Mexico, United States of America; South America – Argentina, Ecuador; Australia – Australia; Africa – various regions; Polar regions – Arctic. The algae can be cultivated industrially, using the following nutrient media: BG11, Nr6, Z-8, Drew, DS, etc., and its application as a biofertilizer for various types of soil, especially for those strongly affected by climate change.

***II. Nostoc punctiforme*** – is one of the most widespread species of Nostoc, which inhabits both water and soil, practically in all types of soil, but with a major development in podzolic soils and chernozem areas (fig. 1 b). *Nostoc punctiforme* is generally characterized by unbranched filamentous growth and the formation of up to three types of differentiated cells, typically developing as colonies of filaments embedded within a gelatinous matrix.

The algae possesses the ability to colonize and create symbiotic relationships with fungi to form lichens and host plants and chemotaxis behavior towards non-host plants such as *Anthoceros punctatus*, species of the genus *Gunnera, Trifolium repens, Arabidopsis thaliana*. The algae can regulate programmed cell death of plants and is of interest for use as a biofertilizer. In culture, it grows well on soil extract with the addition of N, P, K, with periodic shaking of the cultures, and also on nutrient media specific to nitrogen-fixing cyanophyte algae (Drew, BG11, Bold Basal, etc.). It has a significant capacity to fix atmospheric nitrogen, and its use as a biofertilizer leads to a significant increase in crop productivity. It is found in the soils of the following countries of the continents: Europe - Republic of Moldova, Romania, Russian Federation, Belarus, Georgia, Ukraine, Ireland, France, Germany; Asia - India, Tajikistan, Pakistan, Bangladesh, Uzbekistan, Armenia, Azerbaijan, China; North America - United States of America, Canada; Australia - Australia; Africa - Africa (without mentioning a specific country); Polar regions - Arctic. The algae is widespread in all regions of the Earth.

***III. Nostoc linckia*** – and other forms of this species are widespread on all moist soils. It has the ability to biologically fix atmospheric nitrogen.

The colonies of the algae are underwater or terrestrial, first spherical, then more or less shapeless, prostrate, smooth or folded-tibial, sometimes irregularly broken, floating freely or attached to the substrate (soil or moss) in the form of a plate, soft or rarely hard, with very varied shades of yellow-brown, yellow-brown, yellow-violet or blue-brown with red shades. The trichome chains are poorly distributed with a yellow or brown color. The algae is found in nature in stagnant waters, less often in flowing waters, very rarely in thermal springs, frequently on moist soils, on moss, less often in greenhouses. *N. linckia* can be cultivated on specific nutrient media (No. 6, Drew, BG11, Gromov, Allen). It is found in the soils of the following countries of the continents: It is found in the soils of the following countries: Europe – Republic of Moldova, Romania, England, Ireland, Russian Federation, Belarus, Germany, Serbia, Slovakia, Georgia, Spain, Czech Republic, Bulgaria, Iceland; Asia – Uzbekistan, Tajikistan, Armenia, Azerbaijan, Georgia (also included in Europe), China, Japan, Iraq, Turkey, India; North America – United States of America, Mexico, Canada; South America – Argentina, Brazil; Australia – Australia; Africa – Africa (without mentioning a specific country); Polar regions – Arctic. The algae is widespread in all regions of the Earth.

***IV. Anabaena variabilis*** – the algae lives on and inside moist soils and in stagnant waters, at the bottom of lakes, very rarely in free floating form (plankton). It is widespread in all sufficiently moist soils (fig. 1 d). It is a biological fixer of nitrogen in the soil and can be cultivated on nutrient media (No. 6, BG11, DREW, Chu-10, Allen). It is found in the soils of the following countries of the continents: Europe – Republic of Moldova, Romania, England, Ireland, Slovakia, France, Germany, Spain, Iceland; Asia – India, Kazakhstan, China, Israel, Iraq, Japan; North America – United States, Canada; South America – Brazil, Argentina; Africa – Egypt, Africa (without mentioning a specific country); Oceania – New Zealand; Polar regions – Arctic. The algae is widespread in all regions of the Earth.

***V. Tolypothrix tenuis*** – lives in slow-flowing waters, inside the soil (edaphon) and less often on the soil surface (aerophyton). The algae is widespread on sufficiently moistened soils (fig. 1 e). In culture medium, it has a rather low but skillful growth; it can be cultivated on nutrient media (BG11, Naway, No. 6). It is found in the soils of the following countries of the continents: Europe – Republic of Moldova, Romania, England, Czech Republic, Germany, Ireland, Norway, Poland, Portugal, Serbia, Slovenia, Spain, Georgia; Asia – Japan, Israel, India, Russian Federation, Belarus, Ukraine, Turkey, Tajikistan, China, Iran; North America – Canada, United States of America; South America – Argentina, Brazil; Oceania – New Zealand, Australia. The algae is widespread in all regions of the Earth.

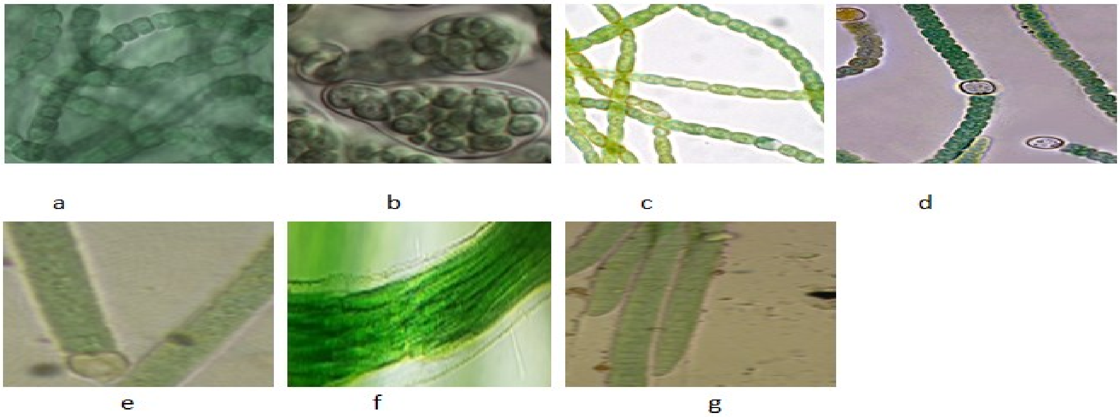


**Figure 1** Cyanophyte algae recommended as biofertilizer (a – *Stratonostoc commune,* b – *N. punctiforme*, c - *N. linckia,* d - *Anabaena variabilis*, e - *Tolypothrix tenuis*, f - *Ph. Autumnale*, g - *Microcoleus vaginatus*).

***VI.*** Some species of the **genus *Phormidium*** (*Ph. autumnale* and *Ph. tenue*) – are widespread on all soils, but have a skillful development on soils rich in organic nitrogen, sometimes creating a film (fig. 1 f). The species can be cultivated on nutrient media No. 6, BG-11, Bold Basal, etc. It is found in the soils of the following countries of the continents: Europe – Republic of Moldova, Romania, Ukraine, Russian Federation, Belarus, Ireland, Italy, Serbia, Slovakia, Czech Republic, France, Germany, Spain, Greece; South America – Argentina, Brazil, Paraguay, Cuba; North America – United States of America, Canada; Oceania – New Zealand, Iceland; Asia – India, Pakistan, China, Korea, Japan, Taiwan, Tajikistan, Georgia, Iraq, Turkey, Kazakhstan.

***VII. Microcoleus vaginatus*** – is widespread on a wide range of soil types, forms biocrust and plays an essential role in primary terrestrial successions (fig. 1 g). It is found in the soils of the following countries of the continents: Europe – Republic of Moldova, Romania, Spain, Germany, Poland, Iceland; South America – Brazil, Argentina; North America – United States of America, Mexico; Oceania – Australia; Asia – China, Iran; Africa – Africa.

The selected cyanophyte species are preferential for the mentioned regions, but in order to select all cyanophyte algae species applicable to all soils of the Earth, it is necessary to carry out more extensive and thorough investigations.

## 5. Conclusion

The selection of cyanophyte algae used as efficient, resilient and adaptable biofertilizers for soils subject to climate change must be carried out taking into account population criteria, high tolerance to the instability of environmental factors, increased reactivation, non-disequilibrium of phytocenotics, easy selection in culture and industrial cultivation. The main cyanophyte species recommended as soil biofertilizers are *Nostoc punctiforme, Nostoc linckia, Anabaena variabilis, Tolypothrix tenuis*, with modest growth but capable of cultivation; species such as *Phormidium autumnale* and *Ph. tenue* and *Microcoleus vaginatus*.

**Acknowledgements**

The research was carried out within the framework of scientific research projects of the Scientific Research Laboratories of Algology V. Salaru, Pedogenetic Processes and Plant Biochemistry of the Moldova State University.

## References

Brevik, E.C. (2012). Soils and climate change: gas fluxes and soil processes. Soil Horizons, 53. https://doi.org/10.2136/sh12-04-0012

Chittora, D., Meena, M., Barupal, T., Swapnil, P., Sharma, K. (2020). Cyanobacteria as a source of biofertilizers for sustainable agriculture. *Biochemistry and Biophysics Reports Volume 22*, https://doi.org/10.1016/j.bbrep.2020.100737

Choudhary, D.K., Mishra, A., Varma, A. (2021). Climate change and the microbiome sustenance of the Ecosphere. Soil Biology Volume 63, https://doi.org/10.1007/978-3-030-76863-8

Davydov, D. (2006). Cyanoprokaryotes and their role in the process of nitrogen fixation in terrestrial ecosystems of the Murmansk region. Abstract of Cand. Biological Sciences Dissertation. Syktyvkar, 23.

Dobrojan, S., Jigău, Gh., Șalaru, V. (2019). Application of biomass of the algae *Nostoc gelatinosum* (Schousboe) Elenkin as a biofertilizer in the cultivation of sunflower (*Helianthus annuus*). "Chernozems of Eastern Europe - 140 years after V. Dokuchaev". Chisinau, 377-380 (in Russian).

Dobrojan, S., Şalaru, V., Jigău, Gh., Ciobanu, E. (2019). Utilisation biomass of *Nostoc linckia* Bornet ex Bornet et Flahault algae as biofertilizer for cultivation Sunflower (*Helianthus annuus*). VI International Conference Advances in Modern Phycology, Kiev, 33-34. ISBN: 978-966-02-8876-8.

Dobrojan, S., Şalaru, V., Stratulat, I., Dobrojan, G., Semeniuc, Ev. (2017). The use of nitrogen-fixing cyanophyte algae as biofertilizers in the cultivation of tomatoes in greenhouse conditions. Studia Universitatis Moldaviae, nr.1(101), 57-60.

Dobrojan, S.N., Shalaru, V.V., Shalaru, V.M., Stratulat, I.I., Semenyuk, E.N. (2014). Use of some species of blue-green nitrogen-fixing algae as biological fertilizer. Algologiya. 24(3), 426-429. (in Russian).

Elenkin, A. (1949). Blue-green algae of the USSR. Special part 1-2. From. Academy of Sciences of the USSR, 1908. (in Russian).

FAO. (2024). *How to feed the world in 2050.* chrome-extension. www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

Ghorai, P., Ghosh, D. (2022) Ameliorating the performance of NPK biofertilizers to attain sustainable agriculture with special emphasis on bioengineering. Bioresource Technology Reports, *Vol. 19*, https://doi.org/10.1016/j.biteb.2022.101117

Ghorai, P., Ghosh, D. (2022). Ameliorating the performance of NPK biofertilizers to attain sustainable agriculture with special emphasis on bioengineering. *Bioresource Technology Reports,* 19. doi.org/10.1016/j.biteb.2022.101117.

Golerbach, M., Shtina, E. (1969). Soil algae. From. Science, 228. (in Russian).

Golerbach, M.M., Shtina, E.A. (1969). Soil algae. Leningrad, Iz. Nauka, 227. (in Russian).

Gusev, M.V. (1968). Biology of blue-green algae. Lectures. From. Moscow State University, 101. (in Russian).

IPCC Working Group III (2001). *Summary for Policymakers: Climate Change 2001 – Mitigation*. https://www.ipcc.ch/site/assets/uploads/2018/07/wg2TARsummaries.pdf.

IPCC. (2023). Climate change 2023 synthesis report summary for policymakers. *Geneva, Switzerland, 1-34*. doi: 10.59327/IPCC/AR6-9789291691647.001.

Issa, A.A., Abd-Alla, M.H., Ohyama, T. (2014). Nitrogen fixing cyanobacteria: future prospect. Advances in Biology and Ecology of Nitrogen Fixation, doi:10.5772/56995

John D.A., Babu G.R. (2021). Lessons from the aftermaths of green revolution on food system and health. Published in final edited form as: Front Sustain Food Syst. doi: 10.3389/fsufs.2021.644559

Kollmen, J., Strieth D. (2022). The Beneficial Effects of Cyanobacterial Co-Culture on Plant Growth. Life (Basel), doi: 10.3390/life12020223

Maksimova, E. (2004). Species diversity and ecology of soil algae of mineral springs of Baikal Siberia. Abstract of Cand. Sci. (Biol.) Dissertation. Ulan-Ude, 21. (in Russian).

Nawaz, T., Saud, S., Gu, L., Khan, I., Fahad, S., Zhou, R. (2024). Cyanobacteria: Harnessing the power of microorganisms for plant growth promotion, stress alleviation, and phytoremediation in the era of sustainable agriculture. *Plant Stress*, Vol. 11, doi: https://doi.org/10.1016/j.stress.2024.100399

Osman, M., El-Naggar, A., Omar, H., Esmail, G. (2003). Distribution of different soil algal taxa in relation to physico-chemical characteristics of soil at gharbia governorate. *Egyptian J. of Phycol.* Vol. 4(1), 37-54.

Shtina, E.A., Golerbakh, M.M., 1975. Ecology of soil algae. Moscow: Nauka, 142. (in Russian).

Thapa, S., Vishwakarma, R., Nagaraju, Y. (2023). Cyanobacterial bioinoculants for abiotic stress management in the changing climate scenario, doi: 10.1007/978-981-99-2973-3_8