*Int.J.Curr.Microbiol.App.Sci* (2017) *6*(10): 744-758

*International Journal of Current Microbiology and Applied Sciences*
*ISSN: 2319-7706* **Volume 6 Number 10 (2017) pp. 744-758**
Journal homepage: http://www.ijcmas.com

**Original Research Article** https://doi.org/10.20546/ijcmas.2017.610.091

# Growth Performance and Yield Potential of Cereal Crops (Wheat, Maize and Barley) in Association with Cyanobacteria

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**Keywords**

Cyanobacteria, Consortium, Biofertilizers, Wheat, Maize, Barley.

**Article Info**

***Accepted:***
07 September 2017
***Available Online:***
10 October 2017

**A B S T R A C T**

The effect of cyanobacterial isolates on growth performance and yield status of *Triticum aestivum*, *Zea mays* and *Hordium vulgare* was studied. Fifteen cyanobacterial isolates were used individually and in combination to study the effect of their consortium on the growth performance and grain yield of Wheat, Maize and Barley. The growth performance was measured in association with cyanobacterial isolates individually and in combination. The use of combination of all these cyanobacterial isolates in consortium with these cereal crops showed significant increase in shoot and root lengths and grain yield. The results reveal that these cyanobacterial isolates could bring about positive results in the improvement of Wheat, Maize and Barley crops and might prove to be an effective biofertilizers.

## Introduction

Cyanobacteria are oxygenic photosynthesizer commonly found in fresh water, marine water and soil. They are considered as an important group of microorganisms capable of fixing atmospheric nitrogen.

They have a unique potential to contribute to productivity in a variety of agricultural and ecological situations. Many cyanobacteria fix nitrogen under aerobic conditions in specialized cells called heterocyst which comprise 5-10% of cells in a filament (Ganter, 2000). Non- heterocystous cyanobacteria are also able to promote plant growth and can also be used as bio fertilizer.

Besides fixing atmospheric nitrogen, cyanobacteria play a major role in reducing soil erosion because of ability to secrete polysaccharides that bind soil (Nayak and Prassana, 2007). They also control soil run off and increase soil organic matter content and in producing certain substances which enhance the growth of plants (Ordog, 1999). Due to this important characteristic of nitrogen fixation, the utility of cyanobacteria in agriculture to enhance production is beyond doubt.

The algae constitute an important component of the soil micro flora. They act as a reserve

for plant nutrients, influence soil structure, influence the activities of other organisms, and contribute to the organic carbon and fixed nitrogen status of the soil through their photosynthesis and nitrogen fixation.

Many soil algal species are ubiquitous in distribution and there are no characteristic algal associations formed in any particular geographical region or soil type. In general blue- green algae do not occur in soils of pH less than 4.

Solar radiation, water, and temperature are the more important abiotic factors regulating the distribution, metabolism, and life histories of soil algae, whereas ionic factors, e.g., pH, redox potential, and soil texture are somewhat less important factors (Metting, 1981).

In the soil profile, most algal growth is confined to the upper few mm or cm, and the subterranean flora mainly includes resting stages or inactive cells carried along with the seepage water, agricultural activity, root growth, or soil animals. There is micro stratification of algal populations within the upper few mm or cm of soil profiles, rocks, or gravel deposits (Friedmann and Galum, 1974; Metting, 1981).

In semiarid environments, the upper surface tends to be colonized mainly by cyanobacteria (0-2cm), whereas the greatest cell numbers of Chlorophyceae and Bacillariophyceae occur at 4-6cm depths (Nordin and Blinn, 1972). However, work of Schubert (1984) has shown that soil algae fluctuate with the growing season and soil profile.

The blue- green algae dominate in deserts, forming surface crusts, The Oscillatoriaceae are common in cultivated and non-cultivated desert in Arizona, whereas the other cyanophytes are common in virgin or fallow areas (Cameron, 1963). In several tropical regions, *Schizothrix calcicola* is the most common blue-greens.

The algae are important in stabilizing the soil through aggregation of soil particles. They contribute to soil nutrients. Crusts of Cyanophyceae aid in the retention of silt and clay that produce a rearrangement of soil particles. These crusts greatly increase organic carbon and nitrogen contents of soil, improve water infiltration, decrease erosion, and furnish a suitable habitat for seed germination.

The terrestrial blue-greens show good adaptations to live and grow in those climates and microenvironments in which available water is the main limiting factor, and some soil algae can survive very long periods without water. In soils, algal growth is largely influenced by the temperature range. Species of *Stichococcus*, *Microcoleus*, and *Schizothrix* have a marked capacity to resist extremely low temperatures (even $-150^0$C) in crushed soil. Likewise, many soil algae when dry can tolerate abnormally high temperatures; thus, *Scytonema* is known to tolerate short exposure to $110^0$C, whereas *Spongiochloris typical* cells can survive a year in air-dried soil that has been dried in an oven at $100^0$C (Trainor and McLean, 1964).

The upper millimeter of dry soil often appears crusty in nature due to growth of microorganisms comprising cyanobacteria, algae and/or lichens. Soil particles form an intimate association among these organisms, resulting in a biological crust that covers the surface of the soil as a coherent layer (Belnep *et al.*, 2001). Biological soil crusts often occur in hostile environmental regimes that include extremes in temperature and light, and scarcity of water. Many microorganisms with stand such adverse ecological conditions and respond to the onset of dry conditions by entering into a dormant resistant state, and

thus have been distinguished as pioneers of succession on soil. As a component of the soil crust, the microflora acts as a reservoir of plant nutrients, as organisms influencing the soil structure and activity of other microorganisms, and as agents for the incorporation of organic carbon and nitrogen through photosynthesis and nitrogen fixation (Smith *et al.,* 1990; Adhikary *et al.,* 2000; Johansen, 1993). Occurrence of biological soil crust has been reported from almost all Eco regions worldwide. Despite their widespread occurrence, the global picture of distribution of soil crust biota and communities is not available in many regions, especially from Asia and almost nothing from the Indian subcontinent. Recently, it has been stated that biodiversity of biological crusts on the top soil surfaces is the most poorly researched habitats on earth (Moore, 1998; Copley, 2000). In India, there are few reports of soil cyanobacteria and algae, however, are independent of their relationship to biological soil crusts (Marathe and Kushaldas, 1997; Venkataraman *et al.,* 1974).

Cyanobacteria – also called blue-green algae – evolved very early in the history of life, and share some of the characteristics of gliding bacteria on one hand and those of higher plants on the other. Cyanobacteria can both photosynthesize and fix nitrogen, and these abilities, together with great adaptability to various soil types, make them ubiquitous. Cyanobacteria also have a unique potential to contribute to productivity in a variety of agricultural and ecological situations. Cyanobacteria have been reported from a wide range of soils, thriving both on and below the surface. They are often also characteristic features of other types of sub-aerial environment and many intermittently wet ones such as rice fields. Most paddy soils have a natural population of cyanobacteria which provides a potential source of nitrogen fixation at no cost. Ammonia can be taken up by cyanobacteria through passive diffusion or as ammonium ($NH4^{+}$) by a specific uptake system. The amino acids arginine, asparagine and glutamine have also been reported to serve as nitrogen sources. Nitrate and nitrite are important sources, which later reduce into ammonia. Many cyanobacteria are also capable of using atmospheric dinitrogen (N2) as the source of nitrogen, and this is what most commonly termed nitrogen fixation. Like many other biological systems, nitrogen fixation in cyanobacteria is brought about by a high molecular weight, oxygen labile, metallo protein enzyme known as nitogenase. Nitrogenase reduces molecular nitrogen to ammonia in presence of hydrogen. Due to this important characteristic of nitrogen fixation, the utility of cyanobacteria in agriculture to enhance production is beyond doubt. Many studies have been reported on the use of dried cyanobacteria to inoculate soils as a means of aiding fertility, and the effect of adding cyanobacteria to soil on rice yield was first studied in the 1950s in Japan. The term 'algalization' is now applied to the use of a defined mixture of cyanobacterial species to inoculate soil, and research on algalization is going on in all major rice producing countries. The average of the results from all these studies has shown an increase in grain yield of 15-20% in field experiments. It has been suggested that the cyanobacteria introduced as a result of algalization can establish themselves permanently if inoculation is done consecutively for 3-4 cropping seasons. The basic method of mass production involves a mixture of nitrogen fixing cyanobacteria in shallow trays or polythene lined pits filled with water kept in open air, using clean, sieved farm soil as a carrier material. To each pit 10 kg soil and 250 g single super phosphate is added and water is filled up to a height of 12-15 cm. Starter culture, a mixture of *Anabaena, Nostoc, Aulosira* and *Tolypothrix,* is inoculated in each multiplication unit.

Malathion (5-10 ml per tank) or carbofuran (3% granules, 20 g per tank) is also added to prevent insect breeding. In hot summer months, the cyanobacteria form a thick mat over the surface after 10-12 days of growth in open sun. The contents are allowed to dry and the dried flakes are collected, packed and used to inoculate rice fields. The basic advantage of this technology is that farmers after getting the soil based starter culture can produce the biofertilizer on their own with minimum additional inputs. An inoculum of 10-12 kg is considered sufficient to inoculate one hectare of paddy field 3-4 days after transplantation (Upasana Mishra and Sunil Pabhi, 2004).

Many cyanobacteria are also capable of using atmospheric dinitrogen (N2) as the source of nitrogen, and this is what is most commonly termed nitrogen fixation. Like in many other biological systems, nitrogen fixation in cyanobacteria is brought about by an enzyme known as nitrogenase. Unfortunately, the open-air algal biofertilizers production technology for reproduction at farmers' level is not popular among the farming community. The main limitations of this technology are:

Due to open air nature of production it can be produced for only a limited period in a year (3-4 months in summer; production has to be stopped during rainy and winter season),

High level of contamination due to open type of production,

Slow production rate,

Low population density and hence need for heavy inoculums per hectare.

Therefore, efforts have also been made to improve the technology by developing new economically feasible protocols for production of quality inoculum so that these organisms can be practically exploited on a large scale. This is possible only if multiplication is carried out under controlled conditions. The production technology has been substantially improved with introduction of new and cheap carrier materials that support higher cyanobacterial load with longer shelf life, thus considerably reducing the quantity of inoculum per unit area. The basic changes in the technology has undergone include, a) indoor production of algal biomass under controlled conditions; b) a suitable and cheap growth medium for faster growth of the organisms, and c) mixing with a suitable carrier material. Indoor production involves the growth of algae in a unit that may be a polyhouse or glasshouse.

The individual unit in the polyhouses can be of either RCC, brick and mortar, or even polythene lined pits in the ground. The algae are grown individually as species, by inoculating separate tanks with laboratory grown pure cultures, so as to ensure the presence of each required strain in the final product. Once fully grown, the culture is harvested, mixed with the carrier material, presoaked overnight in water and multanimitti (in 1:1 ratio) and sun dried. The dried material is ground and packed in suitable size polythene bags, sealed and stored for future use. The final product contains 10,000 to 1,00,000 units or propagules per gm of carrier material and, therefore, 500 g material is sufficient to inoculate one acre of rice growing area.

A number of field trials conducted with this material have shown promising results both in terms of nitrogen saving as well as crop yield. However, statistical analysis of the data on alagalization in experimental fields has suggested that the effects of inoculation are inconsistent. The best results appear to be obtained when mixed inocula are produced from local stocks, and the bio fertilizers are

used in combination with a low level of nitrogenous fertilizer. Addition of fertilizer to rice fields generally leads to accelerated growth of algae. Cyanobacteria form a major component of the flora as long as nitrogen content is not very high. If high nitrogen fertilizer is used, green algae tend to dominate the soil flora. Surface application of fertilizer generally checks the growth of cyanobacteria but deep placement of urea does not prevent their growth. Most cyanobacteria inoculated in soil fail to dominate over the flora indigenous to soil receiving the inoculation, and inoculated species are able to dominate only when the indigenous flora is sparse. Thus, 'algalization' seems likely to be most useful where there are marked seasonal changes in land such as when ground is ploughed frequently before planting so that the natural soil inoculum is much reduced by the time of new paddy season. A number of studies have also been done on the selection of natural or mutant strains with the aim of maximizing the nitrogen fixing ability. These are strains that either show high levels of nitrogenase activity in laboratory studies, or in pot experiments, and it is, therefore, important to check whether they can also compete effectively with other native soil strains under field conditions.

In India, considerable progress has been made in the development of cyanobacteria based biofertilizer technology. It has also been demonstrated that this technology can be a powerful means of enriching the soil fertility and improving rice crop yields. However, the technology needs to be improved further for better exploitation under sustainable agriculture systems. It is important to obtain a much more detailed understanding of cyanobacterial population dynamics over the whole annual cycle in agriculture systems. Extensive field studies aimed at developing region specific high quality inoculum are also needed. Understanding the biology of drought resistant cyanobacteria may be useful in terms of extending this approach to dry crops.

The Cyanobacteria and their products find a conspicuous usage in maritime countries where most people use some algae or algal products daily, either directly or indirectly. Species of *Nostoc, Aphanothece*, and *Spirulina* are examples of freshwater or terrestrial blue- green algae that are edible.

The algal mixture obtained as byproduct of sewage treatment process, and the protein-rich fresh water alga *Spirulina* grown on wastewater can be fed to fishes, poultry, and cattle to improve their health and productivity. For this purpose, Spirulina has been successfully cultivated in wastewater in Lucknow, Nagpur, and Varanasi.

In respect of the nitrogen status of natural habitats, the nitrogen- fixing blue- green algae deserve special mention. These algae grow luxuriantly in tropical habitats, e.g. rice fields. The experiments conducted with *Tolypothrix tenuis* in Japan and with *Aulosira fertilissima* in India have shown that the yield of paddy is substantially increased following the inoculation of fields with these algae. The algologists at the Central Rice Research Institute, Cuttak (India), inoculated rice fields with four species of nitrogen- fixing blue-green algae; the grain yield increased by nearly 30%.

Over 15 genera of free- living blue- green algae are known to fix nitrogen, e.g. *Anabaena, Cylindrospermum, Nostoc, Aulosira, Scytonema, Oscillatoria, Plectonema, Aphanothece* etc. Their contribution to nitrogen fertility is especially important in flooded soils (e.g., rice fields) where the prevailing microaerobic or anaerobic conditions are highly conducive to nitrogenase activity in the blue- green algae. In Japan and Philippines, in nonfertilized

flooded plots, net gains of soil nitrogen range from 20- 70kgN/ha/year (Watanable and Roger, 1984). Fertilization with phosphorus and potassium increased these grains greatly. Some 25-30% of the nitrogen fixed by the blue- green algae is taken up by the rice plants (Watanabe and Roger, 1984).The role of cyanobacteria as biofertilizer has largely been reviewed by Dola Bhowmik *et al.*, (2010), Nayak and Prassana (2007) Ordog (1999), Haroun and Hussein (2003), Lakshmi and Annamalai (2008), Gallab and Salem (2001), Venkataraman (1972), Singh (1961) and Relwani and Surahmanyan (1963), etc.

The role of $N_2$ – fixing cyanobacteria in maintenance of rice fields has been well documented all over world. In India the beneficial effects of cyanobacterial consortium with rice varieties have been demonstrated in a number of field locations (Venkataraman, 1981; Gayatri and Anand, 2002; Goyal and Venkataraman, 1971; Kumar *et al.*, 2013; Sargeeva *et al.*, 2002 etc.). An additional benefit of cyanobacterial consortium with crops is their capacity to secrete bioreactive substances such as auxins, gibberrelins, cytokinins, vitamins, polypeptides, aminoacids, etc. which promote plant growth and development. Manoj *et al.*, (2013) have studied the Cyanobacterial consortium in the improvement of Wheat crop. Anand Mohan *et al.*, (2015) have studied the Cyanobacterial consortium in the improvement of Maize crop. The plant growth promontory effect on cow pea (*Vigna unguiculata*) using coir pith aqueous extract formulation of cyanobacterium Phormidium has been investigated by Pitchai Palaniappan *et al.*, (2010).

Plant growth promoting substances produced by cyanobacterial consortium with crops have largely been reviewed by Karthikeyan *et al.*, (2007), Prasanna *et al.*, (2008), Fatima and Venkataraman (1999), etc.

Effect of exopolysaccharides (EPS) produced by a consortium of cyanobacteria of three crops, wheat, rice and maize have been studied by MonuArora *et al.*, (2010). They investigated an improved seed germination, vigor index and mobilization efficiency in wheat, rice and maize on application of cyanobacterial EPS. Cyanobacterial production of extracellular polymers, mainly EPS is well documented (De Phillips *et al.*, 1998). Polysaccharides are characterized by an extreme structural diversity; as a result, they play very diverse roles in nature and may get modified under stress conditions (Ozturk and Aslim, 2009). Exopolysaccharides have been reported to play a significant role in providing protection to the cell as a boundary layer, contributing to soil aggregation due to its gluing properties and binding heavy metals due to the presence of several active functional groups onto it (Kaplan *et al.*, 1987; Sharma *et al.*, 2008).

In the present investigation an attempt has been made to study the role of heterocystous and non- heterocystous cyanobacterial consortium in the growth and yield potential of some cereal crops viz. wheat, maize and barley.

## Materials and Methods

The experiments related to growth performance and yield potential of Wheat (*Tritium aestivum*), Maize (*Zea mays*) and Oat (*Hordeum vulgare)* were conducted in earthen pots (20×30cm) with 5kg of sterilized field soil. Twenty five days old laboratory grown seedling of Wheat, Maize and Barley were separately planted to earthen pots. The experiments were conducted with the following amendments of Cyanobacterial biofertilizers:

Control: without addition of any cyanobacterial fertilizer.

Farmyard manure.

Seedlings associated with fifteen cyanobacterial isolates individually.

Seedling associated with consortium of fifteen cyanobacterial isolates.

The Cyanobacterial flora were isolated from shallow water body in agricultural field and identified by relevant monographs (Desikachary, 1959; Tilden, 1910; 1937; Hegewald, 1976). The cyanobacterial samples were maintained in pure culture in BG11 medium in a growth chamber under12/12hL/D cycle at 25±2°C and 1500 lux light intensity using fluorescent lamps. A consortium of fifteen cyanobacterial isolates viz., *Oscillatoria nigra, O. princeps, O. curviceps, Schizothrix vaginata, Lyngbya gracilis, Phormidium dimorphum, Calothrix clavata, Aulosora prolifica, Stigonema dendroideum, Nostoc muscorum, Nostoc calcicola, Anabaena oryzae, Scytonema varium, Gloeocapsa calcarea* and *Tolypothrix tenuis* was prepared by introducing equiproportional inocula (1ml each) in 400ml nutrient broth (pH 7.5) contained in 500ml flask.

For studying the effect of cyanobacterial association the Wheat, Maize and Barley seedlings were immersed overnight in the algal suspension, in culture of individual isolates, and in consortium of fifteen cyanobacterial isolates, to effect formation of association with the root system separately before plantation in earthen pots.

The shoat length of the seedling of Wheat, Maize and Barley was measured in cm, at two different stages, during 2$^{nd}$ month i.e., after fertilizer addition and during 3$^{rd}$ month i.e., at the grain stage. Wheat, Maize and Barley are short duration crops and mature grains were harvested ninety days after pot transplantation. The yield was measured in terms of gm/plant in pot and the results were statistically analyzed through one way Analysis of variance (ANOVA). The results obtained have been presented in Tables 2 and 3. Similar experiments were also conducted in randomized block design of 24×20 sq. ft area in the Campus of Department of Botany and Biotechnology, College of Commerce, Kankarbagh, Patna in replicates of three and the observed results have been presented in Tables 4, 5 and 6.

## Results and Discussion

The initial shoot length of *Triticum aestivum, Zea mays and Hordium vulgare* seedling before association and transplantation into earthen pots and field were observed to be 9.5cm, 10.0cm and 9.0cm respectively. The shoot length was measured at two different stages, one after two months and the other after three months i.e., at grain stage. The statistical analysis of data showed that there was a significant increase in the shoot length of all the three seedling viz., wheat, Maize and Barley associated with both heterocystous and non heterocystous cyanobacterial isolates. Heterocystous cyanobacterial isolates caused maximum increment in shoot length (71.25 to 75.00cm in Wheat), 177 to 215cm in Maize and 55.50 to 65.50cm Barley) after three months of transplantation (Tables 1, 2 and 3). The non-heterocystous cyanobacterial isolates, although promoted less increment in shoot length, but the observed value was greater in all the three cultivars in comparison to those treated with farmyard manure and untreated cultivars. The association with a consortium of fifteen cyanobacterial isolates caused significantly highest increment in shoots length of all the three cereal cultivars viz., Wheat, Maize and Barley after three months of plantation. This consortium caused an increment of shoot length to 74.00cm in Wheat, to 250cm in Maize and to 75.50cm in

Barley after three months of transplantation. Similarly in the field the shoot length after second and third month of transplantation was found to be 24.50cm to 30.55cm and 59.45cm to 73.50cm respectively in Wheat; 22.75cm to 36.50 and 160cm to 270cm respectively in Maize and 25.25cm to 31.50cm respectively in Barley (Tables 4, 5 and 6). A consortium of 15 cyanobacterial isolates when treated with seedling caused a significantly highest increment in shoot length in all the three cereal cultivars. An increment of 76.50cm, 275cm and 7550cm shoot length was noticed in Wheat, Maize and Barley respectively, after three months of transplantation when their seedling were treated with a consortium of fifteen cyanobacterial isolates (Tables 4, 5 and 6). The statistical analysis reveals that the use of a consortium of 15 cyanobacterial cultures results in a significant increase in the shoot length of seedling of Wheat, Maize and Barley.

The grain and straw yield of Wheat, Maize and Barley was also recorded and statistically analyzed. Similar to shoot length, the grain-straw yield in pot and fields were found to show a significant increase in seedling of Wheat, Maize and Barley associated with cyanobacterial isolates. The grain and straw yield in control plants of wheat was 0.10 g/plant and 7.0g/plant; of Maize was 12.25 g/plant and 18.50 g/plant and of Barley 0.06g/plant and 6.0g/plant (Tables 1, 2 and 3). The grain and straw yield in farmyard manure treated plants of Wheat was 1.8 g/plant and 17.0 g/plant respectively; and of barley was 1.4 g/plant and 13.0 g/plant respectively (Tables 1, 2 and 3). The statistically data reveals that there was a significantly high yield of grains of all the cereal cultivars when their seedling were treated with cyanobacterial isolates. Maximum grain yields was recorded with heterocystous cyanobacterial isolates in pot condition 3.75g/plant in Wheat; 25.25 to 35.00 g/plant in Maize and 2.5 g/plant to3.5 g/plant in Barley. A consortium of 15 cyanobacteria isolates on the other hand caused a significantly highest yield (4.50 g/plant in Wheat; 45.00 g/plant in Maize and 4.3 g/plant in Barley) (Tables 1, 2 and 3).

In the experimental plots there was significant increase in the grain and the straw yield in all the three cereal cultivars when the cyanobacterial isolates were used. The grain and straw yield of Wheat were 2700 kg/acre and 2500kg/acre respectively; of Maize were 2600kg/arc and 2800 kg/arc respectively, and of Barley were 2600 kg/arc and 2450 kg/arc respectively in control field. In farmyard manure treated fields the grain and straw yield were slightly high, 3050 kg/acre and 3360 kg/acre respectively in Wheat; 2850 kg/acre and 3050 kg/acr respectively in Maize and 3150 kg/acre and 3350 kg/acre respectively in Barley (Tables 4, 5 and 6). Among fifteen cyanobacterial isolates, heterocystous cyanobacteria viz., *Aulosira prolfica, Stigonema dendroideum, Nostoc muscurum, N. calcicola, Anabaena oryzae, Scytonema varium* and *Tolypothrix tenuis* caused a significantly high yield of both grains and straw in all the three cereal cultivars. A consortium of 15 cyanobacteria isolates (consisting of both heterocystous and non-heterocystous), when treated caused a significantly highest record yield of both grains and straw of all the three cereal cultivars. The grain and straw yield in Wheat were 4550 kg/acre respectively; in Maize 3870 kg/acre and 4950 kg/acre respectively and in Barley 3570 kg/acre and 3500 kg/acre respectively. The statistically data shows that the shoot length and yield of wheat, Maize and Barley was significant at 95% level. The present findings are in agreement with the work of Anand Mohan *et al.,* (2015) and Kumar *et al.,* (2013) who have observed a more or less similar increase in growth and yield potential with cyanobacterial consortium in Maize and Wheat crops respectively.

**Table.1** Showing Shoot length[a] (cm) after addition of cyanobacterial biofertilizers in 2nd month, and 3rd month and grain yield[a] (g/plant) and straw yield[a] of *Triticum aestivum* in Earthen pot[a]

| Treatment | Shoot length in 2nd month | Shoot length in 3rd month | Grain yield | Straw yield |
|---|---|---|---|---|
| | X ± SD | X ± SD | X ± SD | X ± SD |
| Control. | 18.50±0.04 | 37.00±0.01 | 0.10±0.02 | 7.0±0.03 |
| *Farmyard manure* | 22.25±0.02 | 48.50±0.03 | 1.8±0.04 | 17.0±0.02 |
| *O. curviceps* | 25.00±0.05 | 66.00±0.02 | 2.15±0.01 | 16.25±0.03 |
| *O. nigra* | 25.25±0.04 | 64.50±0.06 | 2.75±0.02 | 17.25±0.03 |
| *O. princeps* | 25.75±0.06 | 65.25±0.04 | 3.25±0.03 | 18.00±0.04 |
| *Sch. vaginata* | 24.00±0.03 | 63.00±0.04 | 2.10±0.03 | 16.50±0.02 |
| *L. gracilis* | 26.00±0.05 | 66.00±0.02 | 2.15±0.01 | 16.45±0.04 |
| *Ph. dimorphum* | 25.75±0.04 | 55.00±0.02 | 1.8±0.03 | 15.3±0.04 |
| *Cal. clavata* | 26.25±0.02 | 65.5±0.03 | 3.00±0.03 | 17.50±0.02 |
| *Aul. prolofica* | 30.25±0.05[b] | 72.00±0.05 | 3.50±0.03[b] | 15.55±0.03[b] |
| *Stig. dendroideum* | 32.25±0.04[b] | 74.15±0.05[b] | 3.70±0.03[b] | 25±0.05[b] |
| *N. muscurum* | 32.50±0.03[b] | 72.15±0.04[b] | 3.25±0.02[b] | 20.25±0.03[b] |
| *N. calcicola* | 33.50±0.04[b] | 75.00±0.02[b] | 3.85±0.03[b] | 25.00±0.04[b] |
| *Anab. oryzae* | 33.45±0.04[b] | 74.75±0.01[b] | 4.15±0.04[b] | 25.50±0.03[b] |
| *Scyt. varium* | 30.50±0.04[b] | 71.25±0.04[b] | 3.25±0.02[b] | 15.25±0.02[b] |
| *G. calcarea* | 19.00±0.02 | 50.00±0.03 | 1.45±0.02 | 12.0±0.04 |
| *Tolyp. tenuis* | 32.50±0.03[b] | 75.00±0.04[b] | 3.75±0.02[b] | 25.15±0.02[b] |
| *Consortium of 15 isolates* | 34.75±0.04[b] | 74.00±0.05[b] | 4.50±0.02[b] | 25.25±0.04[b] |

a= average of four pots, b= P<0.05 level.

**Table.2** Showing Shoot length[a] (cm) after addition of cyanobacterial biofertilizers in 2nd month, and 3rd month and grain yield[a] (g/plant) and straw yield[a] of *Zea mays* in Earthen pot[a]

| Treatment | Shoot length in 2nd month | Shoot length in 3rd month | Grain yield | Straw yield |
|---|---|---|---|---|
| | X ± SD | X ± SD | X ± SD | X ± SD |
| Control. | 20.25±0.02 | 150±0.03 | 12.25±0.03 | 18.50±0.03 |
| *Farmyard manure* | 22.50±0.01 | 156±0.04 | 13.25±0.04 | 18.25±0.01 |
| *O. curviceps* | 23.55±0.02 | 158±0.03 | 14.25±0.03 | 21.75±0.02 |
| *O. nigra* | 23.50±0.05 | 158±0.04 | 14.00±0.02 | 22.00±0.01 |
| *O. princeps* | 23.25±0.04 | 158±0.03 | 14.50±0.01 | 22.25±0.02 |
| *Sch. vaginata* | 23.15±0.01 | 157±0.02 | 14.00±0.06 | 21.50±0.03 |
| *L. gracilis* | 22.75±0.01 | 156±0.04 | 13.50±0.02 | 21.50±0.03 |
| *Ph. dimorphum* | 22.50±0.02 | 156±0.05 | 13.25±0.01 | 21.15±0.03 |
| *Cal. clavata* | 22.55±0.06 | 158±0.02 | 14.00±0.04 | 21.25±0.04 |
| *Aul. prolofica* | 34.00±0.06[b] | 178±0.06b | 25.50±0.04[b] | 37.50±0.03[b] |
| *Stig. dendroidum* | 34.25±0.04[b] | 177±0.03[b] | 25.25±0.03[b] | 38.15±0.02[b] |
| *N. muscurum* | 35.00±0.03[b] | 180±0.03[b] | 29.25±0.07[b] | 55.25±0.03[b] |
| *N. calcicola* | 35.75±0.04[b] | 185±0.04[b] | 32.50±0.06[b] | 58.25±0.04[b] |
| *Anab. oryzae* | 36.50 | 215±0.03[b] | 35.00±0.03[b] | 60.50±0.04[b] |
| *Scyt. varium* | 35.25±0.01[b] | 175±0.02[b] | 28.50±0.06[b] | 57.25±0.03[b] |
| *G. calcarea* | 23.25±0.02 | 157±0.04 | 13.25±0.03 | 18.50±0.02 |
| *Tolyp. tenuis* | 34.50±0.03[b] | 180±0.02[b] | 26.00±0.04[b] | 40.25±0.01[b] |
| *Consortium of 15 isolates* | 42.50±0.06[b] | 250±0.04[b] | 45.00±0.04[b] | 62.25±0.05[b] |

a= average of four pots, b= P<0.05 level.

**Table.3** Showing Shoot length[a] (cm) after addition of cyanobacterial biofertilizers in 2nd month, and 3rd month and grain yield[a] (g/plant) and straw yield[a] of *Hordum vulgare* in earthen pot[s]

| Treatment | Shoot length in 2nd month | Shoot length in 3rd month | Grain yield | Straw yield |
|---|---|---|---|---|
| | X ± SD | X ± SD | X ± SD | X ± SD |
| Control. | 18.25± 0.03 | 32.50± 0.04 | 0.06± 0.03 | 6.0± 0.02 |
| *Farmyard manure* | 22.50± 0.01 | 51.50± 0.02 | 1.4 ±0.03 | 13.0± 0.04 |
| *O. curviceps* | 23.25 ±0.02 | 54.50± 0.03 | 1.8± 0.04 | 15.0± 0.03 |
| *O. nigra* | 23.00 ±0.01 | 52.50± 0.03 | 1.6± 0.02 | 12.75 ±0.03 |
| *O. princeps* | 23.50± 0.01 | 53.25± 0.02 | 1.7± 0.03 | 14.0 ±0.01 |
| *Sch. vaginata* | 23.75 ±0.04 | 51.50± 0.04 | 1.8 ±0.02 | 15.25± 0.03 |
| *L. gracilis* | 23.15± 0.03 | 52.25± 0.06 | 1.7± 0.02 | 14.50± 0.04 |
| *Ph. dimorphum* | 23.25± 0.04 | 53.25± 0.06 | 1.6± 0.02 | 13.25 ±0.04 |
| *Cal. clavata* | 22.75± 0.06 | 53.50 ±0.05 | 1.8± 0.01 | 15.50± 0.04 |
| *Aul. prolofica* | 26.50± 0.04 | 56.25 ±0.07 | 2.5± 0.03 | 17.50 ±0.04 |
| *Stig. dendroidum* | 26.00± 0.02 | 55.50± 0.06 | 2.3 ±0.01 | 16.50 ±0.03 |
| *N. muscurum* | 29.00± 0.04 | 65.00 ±0.05[b] | 3.2± 0.04[b] | 18.25± 0.03[b] |
| *N. calcicola* | 28.75± 0.03[b] | 62.00± 0.05[b] | 3.0± 0.02[b] | 18.00± 0.04[b] |
| *Anab. oryzae* | 30.00 ±0.06 | 68.00 ±0.04[b] | 3.5 ±0.03[b] | 19.50 ±0.04[b] |
| *Scyt. varium* | 29.25± 0.03[b] | 64.25± 0.01[b] | 3.4 ±0.03[b] | 18.50± 0.02[b] |
| *G. calcarea* | 22.50 ±0.05 | 21.35± 0.00 | 2.3 ±0.02 | 17.00± 0.02 |
| *Tolyp. tenuis* | 29.50± 0.01 | 65.50± 0.06[b] | 3.5± 0.04 | 19.25 ±0.03[b] |
| *Consortium of 15 isolates* | 34.50± 0.07[b] | 75.50± 0.05[b] | 4.3± 0.04[b] | 20.25± 0.04[b] |

a= average of four pots, b= P<0.05 level.

**Table.4** Showing Shoot length[a] (cm) after addition of cyanobacterial biofertilizers in 2nd month, and 3rd month and grain yield[a] (g/plant) and straw yield[a] (kg/arc) of *Triticum aestivum* in plots field.

| Treatment | Shoot length in 2nd month | Shoot length in 3rd month | Grain yield | Straw yield |
|---|---|---|---|---|
| | X ± SD | X ± SD | X ± SD | X ± SD |
| Control. | 19.25± 0.02 | 52.50± 0.04 | 2700± 4.5 | 2500± 7.2 |
| *Farmyard manure* | 23.50± 0.04 | 60.50± 0.04 | 3050± 5.4 | 3360 ±5.5 |
| *O. curviceps* | 24.65± 0.03 | 63.75± 0.03 | 3170± 4.2 | 3500± 2.5 |
| *O. nigra* | 25.25± 0.04 | 65.50± 0.03 | 3250± 4.1 | 3600± 3.5 |
| *O. princeps* | 2500± 0.03 | 64.50± 0.04 | 3025± 3.7 | 3350± 4.2 |
| *Sch. vaginata* | 24.75± 0.06 | 64.00± 0.05 | 3225± 4.1 | 3530± 3.2 |
| *L. gracilis* | 2500± 0.04 | 65.25 ±0.02 | 3075± 3.2 | 3315± 2.6 |
| *Ph. dimorphum* | 25.25± 0.02 | 64.75 ±0.04 | 3215± 4.6 | 3550 ±4.5 |
| *Cal. clavata* | 24.50± 0.05 | 63.25± 0.06 | 3200± 3.5 | 3400 ±4.6 |
| *Aul. prolofica* | 28.50± 0.06c | 70.25± 0.07c | 3840 ±5.6c | 3650± 3.7c |
| *Stig. dendroideum* | 27.25 ±0.04[c] | 68.50± 0.08[c] | 3225± 2.6[c] | 3500± 3.5[c] |
| *N. muscurum* | 29.15±0.03[c] | 65.25±0.03[c] | 3275±0.04[c] | 3500±4.0[c] |
| *N. calcicola* | 29.50± 0.05[c] | 71.50± 0.02[c] | 3950± 6.5[c] | 3725± 4.5[c] |
| *Anab. oryzae* | 30.55± 0.04[c] | 72.75 ±0.03[c] | 4125 ±6.2[c] | 3825± 5.5[c] |
| *Scyt. varium* | 29.25 ±0.03[c] | 70.45± 0.07[c] | 37.25± 6.1[c] | 3615 ±2.6[c] |
| *G. calcarea* | 23.75± 0.01[c] | 59.45± 0.05[c] | 2840 ±3.6[c] | 3150± 3.7[c] |
| *Tolyp. tenuis* | 30.55± 0.06[c] | 73.50± 0.05[c] | 4200± 3.2[c] | 3970 ±4.1[c] |
| *Consortium of 15 isolates* | 34.50 ±0.08[c] | 76.50 ±0.06[c] | 4550± 4.6[c] | 4250± 3.6[c] |

a = average of 10 plants, b= average of 3 replication, c= P< 0.05 level.

**Table.5** Showing Shoot length[a] (cm) after addition of cyanobacterial biofertilizers in 2nd month, and 3rd month and grain yield[a] (g/plant) and straw yield[a] (kg/arc) of *Zea mays* in plots field.

| Treatment | Shoot length in 2nd month | Shoot length in 3rd month | Grain yield | Straw yield |
|---|---|---|---|---|
| | X ± SD | X ± SD | X ± SD | X ± SD |
| Control. | 20.25± 0.02 | 155 ±0.04 | 2600± 3.4 | 2800 ±6.5 |
| *Farmyard manure* | 22.50± 0.01 | 158 ±0.03 | 2850 45 | 3050 ±4.6 |
| *O. curviceps* | 23.55 ±0.02 | 200± 0.03 | 3050± 4.5 | 3450± 3.8 |
| *O. nigra* | 23.50± 0.04 | 215 ±0.03 | 3075± 4.2 | 3860 ±4.7 |
| *O. princeps* | 25.50± 0.04 | 225± 0.04 | 3050± 4.6 | 3850± 3.5 |
| *Sch. vaginata* | 23.25± 0.01 | 200± 0.01 | 3025± 4.1 | 3840± 4.7 |
| *L. gracilis* | 23.00± 0.01 | 215± 0.05 | 3060± 3.5 | 3875± 5.2 |
| *Ph. dimorphum* | 22.75± 0.01 | 215± 0.04 | 3015± 4.7 | 3865 ±4.8 |
| *Cal. clavata* | 23.00± 0.03 | 225± 0.02 | 3025± 3.6 | 3850± 5.6 |
| *Aul. prolofica* | 33.25± 0.04[c] | 250± 0.06[c] | 3650 ±5.4[c] | 4450± 7.5 |
| *Stig. dendroidum* | 35.50± 0.04[c] | 255± 0.04[c] | 3660± 3.6c | 4525± 6.7 |
| *N. muscurum* | 36.00±0.02[c] | 270±0.03[c] | 3740±3.5[c] | 4630±5.5[c] |
| *N. calcicola* | 36.25± 0.03[c] | 270 ±0.04[c] | 3750± 4.4[c] | 4660± 6.0 |
| *Anab. oryzae* | 36.50± 0.05[c] | 275± 0.03 | 3675 ±3.6[c] | 4600± 2.3 |
| *Scyt. varium* | 36.25± 0.01[c] | 200± 0.04[c] | 3640 ±2.6[c] | 4625± 3.8 |
| *G. calcarea* | 23.50± 0.03 | 160± 0.02 | 2825± 3.2 | 3250 ±3.5 |
| *Tolyp. tenuis* | 35.50± 0.04[b] | 200 ±0.03[b] | 3700± 2.5[c] | 4600 ±2.8 |
| *Consortium of 15 isolates* | 43.00± 0.05[b] | 275± 0.04[b] | 3870 ±3.8[c] | 4950± 2.3 |

a = average of 10 plants, b= average of 3 replication, c= P< 0.05 level.

**Table.6** Showing Shoot length[a] (cm) after addition of cyanobacterial biofertilizers in 2nd month, and 3rd month and grain yield[a] (g/plant) and straw yield[a] (kg/arc) of *Hordium valgare* in plots field

| Treatment | Shoot length in 2nd month | Shoot length in 3rd month | Grain yield | Straw yield |
|---|---|---|---|---|
| | X ± SD | X ± SD | X ± SD | X ± SD |
| Control. | 20.50± 0.04 | 53.50± 0.05 | 2600± 2.6 | 2450± 6.5 |
| *Farmyard manure* | 24.50± 0.06 | 61.25± 0.06 | 3150± 5.7 | 3350± 5.4 |
| *O. curviceps* | 25.25± 0.04 | 62.25± 0.07 | 3200± 6.7 | 3400± 5.1 |
| *O. nigra* | 25.65 ±0.03 | 62.75± 0.04 | 3250± 5.4 | 3450± 4.7 |
| *O. princeps* | 2540± 0.02 | 62.00± 0.4 | 3215 ±5.2 | 3425± 3.7 |
| *Sch. vaginata* | 24.75± 0.06 | 62.15± 0.3 | 3170 ±6.5 | 3200± 2.8 |
| *L. gracilis* | 24.50± 0.07 | 61.50± 0.04 | 3125 ±3.6 | 3300 ±2.7 |
| *Ph. dimorphum* | 24.75± 0.08 | 61.75± 0.05 | 3150± 2.8 | 3250± 2.2 |
| *Cal. clavata* | 2535± 0.04 | 62.15 ±0.08 | 3260 ±3.8 | 3350± 2.6 |
| *Aul. prolofica* | 27.65± 0.08[c] | 71.25± 0.06[c] | 3750± 4.7[c] | 3560 ±6.5[c] |
| *Stig. dendroideum* | 28.25± 0.03[c] | 71.50 ±0.02[c] | 3670± 3.6[c] | 3515± 5.8[c] |
| *N. muscurum* | 30.35 ±0.07[c] | 76.40± 0.07[c] | 3950 ±7.3[c] | 3650 ±6.5[c] |
| *N. calcicola* | 30.50± 0.02[c] | 73.25 ±0.03 | 3540± 4.3[c] | 3550 ±6.0[c] |
| *Anab. oryzae* | 31.50± 0.04 | 74.25± 0.06 | 3850 ±6.3[c] | 3600 ±4.8[c] |
| *Scyt. varium* | 30.75 ±0.03[c] | 71.35± 0.07 | 3550 ±2.7[c] | 3450± 3.5[c] |
| *G. calcarea* | 25.50 ±0.07 | 61.50± 0.04 | 3150± 5.6 | 3300± 2.7 |
| *Tolyp. tenuis* | 30.65± 0.06[c] | 72.50± 0.04 | 3570 ±3.6[c] | 3500± 3.9[c] |
| *Consortium of 15 isolates* | 3550± 0.02[c] | 75.50± 0.03[c] | 4175 ±4.3[c] | 3650 ±2.7[c] |

a= average of 10 plants, b= average of 3 replication, c= P<0.05 level.

The use of cyanobacteria as a biofertilizers for rice crops was first reported by De (1939). The results of several field trials clearly demonstrated the positive residual effect of cyanobacterial inoculation on rice yield (Kannaiyan, 1979). The importance of cyanobacterial biofertilizers as a nitrogen source has been well documented by Roger and Kulasooriya (1980) and Roger (1996). Surendra Singh *et al.,* (1995) reported cyanobacterial inoculation increases the yield of rice in wetland. Similarly growth promontory activity of cyanobacteria on Cow Pea (*Vigna unguiculata*) has been documented by Pitchai Palaniappan *et al.*, 2010. Dola Bhowmik *et al.,* (2010) have recorded high yield of pulses o inoculation with *Spirulina*.

In the present study, the use of cyanobacterial isolates in a consortium form was found to significantly increase the yield of all the three cereal cultivars, viz., Wheat (*Triticum aestivum*), Maize (*Zea mays*) and Barley (*Hordeum vulgare*) when compared to control, farmyard manure treated and treatment with individual cyanobacterial isolates. The study also revealed that the naturally associated cyanobacteria could bring about positive results in the improvement of these cereal crops. It has been demonstrated that high yielding varieties which need high levels of nitrogenous fertilizers also respond to cyanobacterial inoculation by increasing yields up to 25%, which has been attributed to the growth promoting substances secreted by cyanobacteria.

Cyanobacteria show the most evident response in the different agro-ecosystems, and consequently seem to be the most suitable group to adopt as a soil bioindicator of land use. There is a general need to improve our knowledge of cyanobacteria to better appreciate the many benefits that humans derive from their existence. Further information, using standard quantification methods and precise identification procedures, should therefore be obtained in order to draw general conclusion about the potential role of soil cyanobacteria as bioindicators and as "biofertilizers".

## Acknowledgement

The first author is thankful to Dr. Baidyanath Kumar, Visiting Professor, Department of Biotechnology, Patna Science College, Patna for providing necessary suggestion.

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**How to cite this article:**

Anand Mohan and Baidyanath Kumar. 2017. Growth Performance and Yield Potential of Cereal Crops (Wheat, Maize and Barley) in Association with Cyanobacteria. *Int.J.Curr.Microbiol.App.Sci.* 6(10): 744-758. doi: https://doi.org/10.20546/ijcmas.2017.610.091