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Review Article

Developments in Cyanobacterial Biofertilizer

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Rice is the world's most important food crop as more than 40% of the world's population depends on rice as a major source of calories. Rice yield in India is about 1990 kg/ha against a maximum of 3346 kg/ha in Punjab. Though the rice yields in Punjab is highest in the country, it is quite low compared to China (5807 kg/ha). Such diversity in yields is due to insufficient use of fertilizer nitrogen. Nitrogen is present as elemental nitrogen in the atmosphere and constitutes more than 79 per cent of total gases. However, crop plants cannot utilize nitrogen in elemental form. On global level, out of 180 million tonnes of nitrogen added annually on the earth's surface, 2/3 is through biological processes, largely microbial activities. Cyanobacteria colonize rice fields and provide biologically fixed nitrogen to the rice crop to the extent of 25-30 kg nitrogen per hectare. In India, on an average, cyanobacteria accounts to about 33% of total algal flora of Indian rice field soils [66], whereas in some of the southern and eastern states this reaches up to 50%. Virtually all the dominant cyanobacteria in rice fields are nitrogen fixing.

Apart from increase in yield and saving of fertilizer nitrogen, cyanobacterial inoculation improves the physico-chemical properties of soil, gradual build-up of residual soil nitrogen and carbon, improvement in soil pH and electrical conductivity. The grain quality in terms of protein content was improved. Our recent studies have shown that the cyanobacteria (*Nostoc* and *Anabaena*) were capable of forming associations with wheat roots grown in liquid culture. Probably, such cyanobacteria contribute nitrogen and growth promoting substances to plants in the rhizosphere.

Key Words : Cyanobacteria; Biofertilizer; Rice Yield; Nitrogen Fixation; Phosphorus Solubilisation; Soil Properties

Introduction

Rice (*Oryza sativa* L.) is the world's most important food crop as more than 40% of the world's population depends on rice as a major source of calories. In India, rice crop is cultivated in about 44.97 million hectares with an approximate total production of 86.3 million tonnes. Rice yield in India is about 1990 kg/ha against a maximum of 3346 kg/ha in Punjab. Though the rice yields in Punjab are highest in the country, but quite low compared to China (5807 kg/ha) and Japan (6273 kg/ha). This widespread diversity in rice yields in India is due to limited use of chemical fertilizers and absence of organic inputs. The nutrients used through chemical fertilizers varies from 180 kg/ha in Punjab to as low as 28 kg/ha in Assam against a national average of 94.7 kg/ha including N, P_2O_5 and K_2O. Therefore, we are still in need of large quantities of nutrients through fertilizers to meet the ever-increasing human and animal population.

Nitrogen is an essential nutrient required for plant growth. It is present as elemental nitrogen and constitutes more than 79 per cent of total gases. However, crop plants cannot utilize nitrogen in elemental form. On global level, out of 180 million tonnes of nitrogen added annually on the earth's surface, industrial fertilizer nitrogen accounts for only 1/3, while 2/3 comes from biological processes, largely by microbial activities. The process of

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biological nitrogen fixation known so far is confined to prokaryotic cellular forms in nature. Among these, the cyanobacteria are free living as well as symbionts with lichens, ferns and cycads and their contribution in total nitrogen fixation by biological means probably comes next to the legume-*Rhizobium* symbiosis.

Distribution of Cyanobacteria

De [7] attributed the natural fertility of flooded rice field soils and its maintenance to the process of biological nitrogen fixation by blue-green algae (cyanobacteria). This was the first report, which recognized the agronomic potential of cyanobacteria in India [7]. Watanabe and co-workers [71, 72, 73, 74, 75] demonstrated that the N-fertility of soil is sustained well under flooded condition than under dry land conditions. The favourable conditions of rice fields for biological nitrogen fixation by such cyanobacteria is considered to be one of the reasons for relatively stable yield of rice under flooded conditions [66].

Cyanobacteria are one of the earliest forms of life on Earth and are known to be the primary colonizers in most inhospitable habitats. Since the first report of cyanobacteria in rice fields, large numbers of forms have been reported from diverse habitats. The paddy field ecosystem provides an environment favourable for the growth of cyanobacteria with respect to their requirement for light, water, temperature, humidity and nutrient availability. According to reports, while nationwide cyanobacteria accounts to about 33% [67] of total algae population, in some of the southern and eastern states this reaches up to 50%. Virtually all the dominant BGA in rice fields are nitrogen fixing, and that gives the indication how rice has been grown continuously for many centuries without the addition of fertilizers [73].

Apart from increase in yield and saving of fertilizer nitrogen, the soil physico-chemical properties improved, residual soil nitrogen and carbon built up gradually, and soil pH and electrical conductivity improved. The grain quality in terms of protein content was improved, probably due to higher nutrient use efficiency by the use of organic inputs (unpublished). Our recent studies has shown that even the cyanobacteria mainly *Nostoc* and *Anabaena* were found to be capable of forming associations with wheat roots grown in liquid culture [22]. In recent years, evidence is accumulating on the production of signals by the cyanobionts, which affects the gene expression of the host plants, and thereby brings about qualitative and quantitative changes in the soil micro flora in the rhizosphere [31, 32, 76].

Nitrogen Fixation by Cyanobacteria

Cyanobacteria are both unicellular and multicellular filaments. Some of the forms have terminally differentiated specialized structures called heterocyst. All heterocyst bearing cyanobacteria are aerobic photodiazotrophs. The aerobic filamentous heterocystous as well as colonial forms represent the common flora of arable lands and are considered to be important in nitrogen economy of rice cultivation.

Cyanobacteria fix atmospheric nitrogen only under nitrogen deficient conditions and in the presence of combined nitrogen sources the enzyme nitrogenase remains repressed which, similar to oxygen effect, is a reversible inhibition. Venkataraman [68] reported that nitrogenase activity was not depressed in soil-rice-algae system in the presence of less than 40 ppm ammoniacal-N. He pointed out the importance of critical evaluation of the relative contribution by algae of N or other substances, or both at high levels of N. The nitrogen fixation by cyanobacteria was not inhibited at 30 ppm of urea nitrogen [28]. However, higher concentrations of combined nitrogen have been shown to inhibit both the growth as well as the nitrogen fixation ability of the cyanobacteria, and ammonium being toxic at 75 ppm [62]. Nitrate nitrogen is preferred by the cyanobacteria and is not detrimental even at 100 ppm concentration.

Nitrogen Contribution

The paddy field ecosystem provides an environment favourable for the growth of cyanobacteria with respect to their requirement for light, water, temperature, humidity and availability of nutrients.

Prasad [37] estimated *in situ* addition of nitrogen in soils of South Bihar by scrapping encrustations of cyanobacterial mats on soil surface collected from different places and found the estimated nitrogen input varied from 12 to 16 kg/ha after the harvest of the crop. Similarly De and Mandel [9] estimated nitrogen fixation by cyanobacteria in six rice-growing soils of West Bengal and reported values ranging from 13.8 to 44.4 kg/ha of nitrogen in cropped area, but the values were lower in uncropped area. In Japan, Watanabe *et al*. [72] observed addition of 20 kg/ha nitrogen by *Tolypothrix tenuis*. Watanabe and Cholitkul [74], using acetylene reduction technique, reported an addition of 18-45 kg N/ha by cyanobacteria. Using ^{15}N technique, MacRae and Castro [26] demonstrated an addition of 10-15 kg N/ha in rice fields due to cyanobacteria. Using same technique, Yoshida and Ancazas [78] found an addition of 40-80 kg/ha. Even in the temperate soils, nitrogen fixation by algae is substantial. Henriksson [18] showed annual fixation rate of 15-51 kg N/ha/year in an agricultural field where *Nostoc* was abundant. Metting [29] has reported supplementation of up to 90 kg N/ha/year by cyanobacteria. The relative contribution of cyanobacteria as a percentage of the total nitrogen fixed in paddy fields varies widely and is mainly dependent on physico-chemical properties of soil, climatic and biotic factors. Quantitative estimations from different countries are: Philippines 18-33 kg/ha Alimango *et al*. [4, 75], India 15-53 kg/ha De *et al*. [8, 60, 68], Senegal 0-30 kg/ha Reynaud *et al*. [45], Mali 50-80 kg/ha [65] and Japan 11-23 kg/ha Okuda *et al*. [36]. Application of other fertilizers, like phosphorus, has been demonstrated to have a beneficial effect on the establishment and growth of nitrogen fixing cyanobacteria [21].

Nutrients fixed by algae are released either through exudation or through microbial decomposition after the cells die [49]. This fixed nitrogen is partly released extracellularly during growth and remaining through microbial decomposition after death. In paddy fields, the death of algal biomass is associated with alternate desiccation and wetting during cultivation cycle or finally after the harvest of the crop. It results in gradual build-up of soil fertility with a residual effect on succeeding crop also. N-uptake studies indicated that 39% of the nitrogen from ^{15}N-labelled *Aulosira* sp. spread on soil and 51% from the algae incorporated into the soil was recovered in the rice crop. It shows that nitrogen fixed through cyanobacteria is readily available to rice [77]. Using ^{15}N, [46] have also shown that at least some of the nitrogen fixed and liberated by *Westiellopsis prolifica* is assimilated by rice plant (Table 1).

Soil Organic Matter

Table 1: Uptake of ^{15}N previously fixed by *Aulosira fertilissima* by rice plant

Days	Mean atom % mean ^{15}N
7	0.0332
14	0.185
21	0.387
28	0.479

The most important constituent to determine the fertility of a soil is organic carbon. A continuous use of inorganic inputs mainly fertilizers without addition of organic manures has led to the depletion of soil carbon reserves in Punjab and Haryana states of India where the soil has reached to the level of becoming unfertile. Under such situations, photosynthetic microorganisms, particularly algae and cyanobacteria, may play a role in contributing organic carbon into the soil. As early as 1950 De and Sulaiman [10], a decisive build-up of organic matter due to cyanobacterial inoculation was reported. Later, a number of workers supported the work; however, a wide variation in the reported values of organic carbon addition by cyanobacteria exists. Using ^{15}N, Nekrasova and Aleksandrova [34] confirmed that algal biomass contributed significantly to humus formation in soils, despite the absence of typical lignin in them. Roger *et al*. [50] indicated that under favourable conditions a good algal bloom in rice fields yields about 6-8 t of fresh biomass on an average. A 0.03% (672 kg/ha) increased soil organic carbon content was reported due to encouragement of native algal flora alone under laboratory conditions in six months period [23], whereas inoculation of halotolerant cyanobacterial strains to sodic soils led to an addition of 5.3-7.6 t carbon/ha in a cropping season [63].

Microbial biomass carbon is well established as a much more sensitive indicator of changing soil condition, rather than soil organic matter or total counts of bacteria, fungi and actinomycetes [3]. In one of our studies, the microbial biomass carbon was significantly enhanced in all the treatments over uninoculated control at full dose, 2/3 or 1/3 dose N + PK levels at mid-crop and harvest stages. This was clearly indicative of the microbial build up in the soil as a result of cyanobacterial inoculation (Table 2).

Production of Growth-Promoting Substances

In addition to contributing nitrogen, cyanobacteria also benefit crop plants by producing various growth-promoting substances. A number of workers observed an increase in seed germination, root and shoot growth, grain weight and protein content of wheat [20, 31, 61], seed germination of wheat [17], fruit weight of tomato [25, 48], seed germination of radish [48] and peas [16]. Growth promotory substances were reported to be gibberellins [61], cytokinins [48], auxins [1] or abscisic acids [27]; while others have described them either as vitamins particularly vitamin B/B12 [15, 31, 70] or as amino acids [71], antibiotics and toxins [30]. Kaushik and co-workers [22, 31, 32] reported the different vitamins in the range of ng such as niacin 80-320 ng/mg, pantothenic acid 5-10 ng/mg, folic acid 0.79-1.08 ng/mg and vitamin B12 3.6 x 10^{-3} ng/mg [31, 32].

Heterotrophic Contributions

The earliest reports of cyanobacteria existing in the rhizosphere dates back to the 1980s, wherein cyanobacterial associations in the rhizosphere of several grasses were investigated [13, 53]. Most of the works related to cyanobacterial biofertilizers have been in relation to rice crop, and few reports are available on epiphytic growth of *Gleotrichia pisum* on the aquatic roots/stem of deep water rice [76]. Co-cultivation of wheat with cyanobacteria is known to enhance root dry weight and chlorophyll [35]. Gantar and co-workers [14] assessed the role of extracellular polysaccharides in the colonization process by cyanobacteria on wheat roots and characterized the nature of sugars and linkages aiding in the attachment process.

Cyanobacterial inoculation of wheat crop showed visible differences in terms of the appearance of plants, enhancement in plant height, dry weight and grain yields of wheat crop which is attributed to IAA-like compounds and photoheterotrophic/heterotrophic abilities of the cyanobacterial strains [22]. Ibrahim and co-workers [19] observed an increase in the total microbial populations, especially in the numbers of nitrifiers and the genera *Azotobacter* and *Clostridium*. Rao and Burns [42] observed 500-fold, 16-fold and 48-fold increase in bacteria, fungi and actinomycetes respectively after 13 weeks inoculation with cyanobacterial consortia. In our studies also, inoculation with *Hapalosiphon intricatus* K2 and *Nostoc* sp. K3 strains exhibited higher microbial population (Table 2).

Transformation of Soil P

Phosphorus is the second major plant nutrient after nitrogen in terms of quantitative requirements for crop plants. The problem of P management in soil is highly intricate, as the applied phosphate through fertilizers is often fixed and becomes unavailable to the crops. In organic matter rich soils, P availability is greatly enhanced due to excretions of enzymes or acidic metabolites produced by microorganisms including cyanobacteria [53].

Fuller and Roger [12] observed a greater uptake of P by plants from algal materials than from inorganic phosphates when applied in equal amounts. They concluded that: (1) P in algal material is available to plants more than inorganic phosphates over longer periods, (2) chemical fixation is not so important a factor with respect to algal material as with respect to inorganic phosphates, and (3) temporary conversion of available soil or fertilizer P into cell materials by soil algae may be a desirable process from the stand-point of long-term availability. Algae

Table 2: Microbial biomass in soils of wheat variety HD 2687 as influenced by cyanobacteria under pot culture in glasshouse conditions

Treatments	Microbial biomass carbon (mg kg^{-1} soil)	
	Mid crop stage	Harvest stage
Full dose of NPK	125.7	82.0
2/3 N + PK	116.7	77.3
1/3 N + PK	106.3	68.7
1/3 N + PK + *Calothrix ghosei* (K1)	159.0	111.0
1/3 N + PK + *Hapalosiphon intricatus* (K2)	167.0	118.7
1/3 N + PK + *Nostoc* sp. (K3)	170.0	124.0
1/3 N + PK + *C. ghosei, H. intricatus*	199.0	130.7
1/3 N + PK + *C. ghosei, Nostoc* sp.	207.0	118.0
1/3 N + PK + *H. intricatus, Nostoc* sp.	208.0	133.0
1/3 N + PK + *C. ghosei, H. intricatus, Nostoc* sp.	227.0	137.7
SEd	7.25	5.75
CD ($P < 0.05$)	15.12	12.00

also have long been known to take up P in excess of their immediate needs, which may subsequently be released in the form of dissolved organic P [26].

Improvement in Soil Physical Properties

Cyanobacteria are known to excrete extracellularly a number of compounds like polysaccharides, peptides and lipids during their growth in soil [6]. These compounds diffuse around soil particles, glue and hold them together in the form of microaggregates. Besides these compounds, polysaccharides are made of fibres, which can also entangle clay particles and form clusters. These clusters or microaggregates, in turn, grow and take the shape of macroaggregates and subsequently of larger soil aggregates. The interwoven nature of growing algal filaments may also help in binding the soil particles along with the organic C added through algal biomass. The importance of these compounds in soil-aggregate formation or soil stabilization has been indicated by many workers [51, 52, 55, 58].

Kaushik and his co-workers [24, 55, 63] observed significant increases in soil aggregate stability due to an increase in the polysaccharide content of soils as a result of algal inoculation and an improvement in the water-holding capacity and aeration status of soils (Table 3) [55, 60]. Further, the mucilaginous thalli formed a compact grey substratum firmly holding the soil particles together, which checked both wind and water mediated soil erosion, particularly, in light and sandy soils subjected to heavy grazing. Such improvement in soil aggregation due to algal inoculation ultimately favoured better seedling emergence of upland crops sown after the paddy harvest [52].

Crop Response

Singh *et al.* [59] reported that grain yield of paddy, when the field was inoculated with algae and 60 kg/ha urea, was comparable to that obtained with 120

Table 3: Effect of blue-green algal inoculation of water-stable soil aggregates [54]

Soil	% Water-stable aggregates (50 µm)		
	Control	Algae inoculated	% increase
Sandy loam	2.2	4.1	85
Loam	2.6	6.0	130
Silty clay loam	3.5	9.1	160

kg nitrogen alone. Similarly, beneficial effects of algalization in the presence of nitrogenous fertilizers have been reported by large number of workers [24, 57, 60, 69]. From the results of field experiments done earlier, it appears that average algal inoculation, when effective, causes a relative increase in grain yield of paddy about 14% over the treatments and 16% over the control, corresponding to about 4.5 quintal grain per hectare per crop [43, 44, 56]. In an experiment involving 0, 50, 100 and 150 kg N as urea, a statistically non-significant interaction was observed between nitrogen and algalization, indicating a uniform beneficial effect of inoculation at every level of nitrogen [2]. In field trials conducted at farmer's field in Haryana, a 10-15% increase in rice yield in the presence of 150 kg/ha fertilizer nitrogen was reported [24]. Thus, the response to algalization was generally positive at every level of nitrogen applied in the field, though the response being lower at higher levels. Algal biofertilizer is recommended only as a supplement to nitrogenous fertilizers and the supplementation effects remains perceptible even in the presence of high levels of fertilizer nitrogen [68]. An interesting observation made on that algalization reduced the grain sterility in rice from 16 % in control to 11 % in algalized series [64]. In field experiments, algalization in combination with different doses of lime, phosphorus and molybdenum application was more efficient than algalization alone [21, 43, 44, 56].

Field cum demonstration trials were conducted extensively under All India Project on Algae. Results led to conclude that (i) by the use of cyanobacteria in unfertilized fields, a 10-15% increase in paddy yield is obtained (Table 4), (ii) in presence of low doses of chemical fertilizer, nitrogen yield equivalent to 25 kg N/ha could be obtained, (iii) even at higher levels of fertilizer nitrogen, similar benefits could be obtained (Table 5). Application of cyanobacterial biofertilizer in rice followed by wheat, along with other biofertilizers in consortia-phosphate solubilizing *Pseudomonas striata* (PS) and mixed inoculum of vesicular arbuscular mycorrhiza (VAM) showed the beneficial effects of inoculation in both the crops (Table 6). Application of bioinoculants alone (cyanobacteria, PS or VAM) in presence of 50% single super phosphate (SSP) plus 50% rock phosphate (RP) as a source of P were at par with P 100% SSP in paddy but not in wheat. The significant enhancement of paddy yield was observed only when cyanobacteria plus PS or cyanobacteria plus PS plus VAM were employed, whereas highest wheat yield was obtained when all the three biofertilizers were applied in presence of SSP and RP both at 50% level.

Table 4: Yield of rice due to cyanobacteria biofertilizer in absence of N-fertilizers

State/organisation	No. of trials (294)	Yield t ha^{-1}		% increase
		– cyanobacteria	+ cyanobacteria	
AP	1	3.64	4.44	21.9
AICRIP	20	3.04	3.37	10.8
Bihar	1	2.31	3.08	32.8
J & K	1	3.75	3.90	4.0
MP	161	2.48	2.85	14.9
Maharashtra	91	3.05	3.91	28.1
Orissa	1	2.97	3.71	24.6
Punjab	1	5.04	5.27	4.5
UP	17	3.29	3.82	16.1
Average yield		3.28	3.81	16.1

(Varieties differed from state to state, trials were mainly in summer paddy in the year 1986-87)

Table 5: Algalization and yield of rice at reduced levels of fertilizer-N

State/organisation	N kg/ha	N kg/ha + cyanobacteria	Yield t ha^{-1}		N saving kg/ha	Additional yield kg/ha
			N kg/ha	N + cyanobacteria		
AICRIP, TN	50	25	4.42	4.46	25	40
AP, MP	60	40	4.15	4.22	20	70
TN	75	50	5.07	4.93	25	0
AP, TN	80	50	4.83	5.04	30	210
AP, UP	80	60	4.39	4.61	20	220
AP	100	60	5.36	5.38	40	20
TN	100	70	4.70	4.88	25	180

Table 6: Influence of biofertilizer application on average 2 years (2007-2008) yield of paddy variety Pusa-44 and wheat var. HD 2687

Treatments (kg/ha)	Average paddy yield (q ha^{-1})	Average wheat yield (q ha^{-1})
Control (N: P:K, 120:0:60)	40.62	45.16
P 60 as SSP	47.65	51.29
P30 as SSP	43.96	50.17
P 60 as RP	47.56	45.86
P30 as RP	43.75	45.05
P30 as SSP + P30 as RP	46.28	47.28
P30 as SSP + P30 as RP + PS	47.30	49.89
P30 as SSP + P30 as RP + VAM	47.74	49.57
P30 as SSP + P30 as RP + cyanobacteria	47.69	47.74
P30 as SSP + P30 as RP + PS + VAM	47.83	52.05
P30 as SSP + P30 as RP + PS + cyanobacteria	49.76	48.56
P30 as SSP + P30 as RP + VAM + cyanobacteria	45.09	51.24
P30 as SSP + P30 as RP + PS + VAM + cyanobacteria	49.56	53.60
P30 as SSP + PS + VAM + cyanobacteria	49.39	52.92
P30 as RP + PS + VAM + cyanobacteria	46.26	50.99
CD at 5%	3.00	3.32

(Application of N: K at 120:60 kg^{-1} constant to all treatments)

These results indicated the possibility of substitution of 50% of P_2O_5 through RP along with biofertilizers. It resulted in a net saving of 30 kg P_2O_5 or 188 kg SSP/ha with an additional yield of paddy and wheat. On an average, 4.0 quintals of additional grain yield including paddy and wheat can be obtained by using the three bioinoculants i.e. VAM, PS and cyanobacteria. A similar pattern of observations has been reported by many workers based on the interaction studies between nitrogen fixing microorganisms [5, 11, 33, 40, 41]. These benefits may also be due to the combined influence of nutrient supply as well as bioprotection [38].

The quality of agricultural produce is known to be enhanced by the use of organic input including biofertilizers. Similarly, inoculation with bioinoculants led to increase in the protein content of paddy and wheat to the extent of 9.18% and 10.25% respectively.

Technology Development

The idea of utilizing algal biofertilizer to supplement the nitrogen requirement of rice crop was mooted as early as 1939. The potential of cyanobacteria in rice field was demonstrated by Singh [60]. However, the systematic approach was undertaken at IARI and an algal biofertilizer technology was developed [66]. The technology was named as rural oriented mass multiplication technology and the application in field was often referred as algalization. In this process, cyanobacteria were allowed to grow with soil as carrier and then applied at 10kg/ha dry soil based inoculum in rice fields. Farmers adopted this all over India because of its simplicity and economic benefits. Depending upon the requirement of algal biofertilizer, the production technology could be scaled up to troughs, pits, and field plots, cemented tanks or polythene layered tanks.

However, the technology could not become popular due to (1) non-availability of inoculum at the time of application, (2) large variation in inoculum quality, and (3) presence of contaminants. Hence, the cyanobacterial biofertilizer of assured quality in terms of known population density, and nature of each strain with better competitiveness was necessary to develop. With the financial assistance provided by Department of Biotechnology, a new technology was developed in which cyanobacteria were grown in a formulated medium in glass/polyethylene house and soil was replaced with lighter carrier (straw). The quantity required was reduced from 10 kg/ha to 1 kg/ha since the final product contained 105 to 106 propagules per gram carrier [24, 39].

The first ever production of cyanobacterial biofertilizer in India is reported to be in 1972 at IARI, New Delhi. Since then, considerable progress has been made, mainly in the technology of production, identifying efficient strains, newer techniques of inoculation for better establishment of inoculated organism in various soils and in demonstrating their beneficial effect on the crop yield in field trials on different crops. Presently, several technologies are available for cyanobacterial biofertilizer production. The important ones are soil based [66] and straw based technologies [24]. The latter is indoor technology and production is in defined growth media. Most commonly used species in biofertilizer production are *Anabaena variabilis, Nostoc muscorum, Aulosira fertilissima*, and *Tolypothrix tenuis*.

New Approaches

Belowground diversity studies include the microorganisms associated with rhizosphere, rhizoplane or even endophytic associations. Our studies have established that the cyanobacteria enters into the root hair of wheat seedlings, establishes in the root cortex and has the potential to undertake acetylene reduction activity, probably drawing energy from plant photosynthate. These studies confer the earlier observation that some of the cyanobacteria have mixotrophic mode of nutrition [47] and can probably be exploited in future as endophytes for crops like wheat and rice. Further work to establish the colonization xylem is in progress at the Indian Agricultural Research Institute, New Delhi.

Conclusion

Traditional conservation based method with modern technology can reduce farmers' dependence on chemical fertilizers and pesticides, as well as reduce the farming costs and environmental hazards. Emphasis is placed on integrated plant nutrient supply concept involving regular use of organic resources such as organic manures/compost/green manure and biofertilizers and should be integrated with low doses of chemical fertilizers in the cropping system for better results.

Application of cyanobacterial biofertilizer to rice crop would bring an improvement in the soil physico-chemical properties and increased availability of phosphorus (30 kg P_2O_5) when used along with rock phosphate and 25-30 kg N/ha/season biologically fixed nitrogen. Some of the cyanobacteria would also provide growth-promoting substances and the quality of grain would be superior. A 10-15 percent increased grain yield along with a net saving is also accomplished.

Depletion of soil fertility, low fertilizer-use efficiency and growing environmental pollution are of major concern to agriculture, in terms of crop productivity. Biofertilizers, such as cyanobacteria can provide a suitable supplement to the chemical fertilizers and 'organic farming' can become a reality in the future. There is a definite need to deploy these biofertilizers in combination with organic composts and minimal doses of chemical fertilizers for reaping 'cleaner' and healthy harvests, securing food production and human health, protecting the environment and saving scarce natural resources.

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