Journal of Applied Phycology
https://doi.org/10.1007/s10811-020-02237-7

Cyanobacterial biofertilizer's successful journey from rural technology to commercial enterprise: an Indian perspective

Neeru Bhooshan[1] · Amarjeet Singh[1] · Akriti Sharma[1] · Chetan Verma[1] · Anjani Kumar[2] · Sunil Pabbi[3]

Received: 28 March 2020 / Revised and accepted: 18 August 2020

Abstract
This paper discusses the outcome of a study on the transition of cyanobacterial biofertilizer technology from laboratory to small-scale production to large-scale commercial use. The nitrogen-fixing ability of cyanobacteria helps to reduce the dose of chemical nitrogen fertilizer (urea) needed, so they are immensely important for paddy crops, especially in Southeast Asian nations, where soil quality is deteriorating and where large groups of farmers cannot afford the use of more costly chemical fertilizers. Inundated water is required for this technology to be effective in paddy crops and is also imperative for good paddy crop; fortunately, this is exactly how paddy is grown on the Indian subcontinent. This study elaborates the whole cyanobacterial biofertilizer technology chain and its development process, the triggering role played by industry partners, and industry's dissemination of the technology to farmers' doorsteps.

Keywords Cyanobacteria · Blue-green algae · Biofertilizer · Industry partner · Licensee · Technology transfer · Technical know-how

Background

Cyanobacteria, also referred as blue-green algae, are among a few known nitrogen-fixing organisms and are prevalent and active in lowland rice soils (De 1939). When abundant, these are the main agents contributing to paddy field fertility under tropical conditions due to their nitrogen-fixing characteristics. Singh (1961) advocated the use of cyanobacteria as fertilizer in paddy fields. Algal inoculation of the soil in paddy fields, also called algalization, was shown to be effective in increasing nitrogen content in rice grain as well as paddy straw (Venkataraman 1964). Soaking rice seeds with cyanobacterial extracts/culture before sowing enhanced germination and growth of seedlings, prolonged duration of tillering, healthy root growth, and increased grain weight and its protein content (Venkataraman and Neelakantan 1967; Jacq and Roger 1977; Jaiswal et al. 2018). A conservative analysis indicates that cyanobacteria could contribute 20–30 kg of nitrogen per hectare per season/crop, such that chemical fertilizer use could be reduced to that extent without affecting crop yield in fields where cyanobacteria are applied (Mishra and Pabbi 2004; Pabbi 2015). Cyanobacteria also promote plant growth by liberation of growth-promoting substances, including vitamins (nicotinic acid, folic acid, vitamin B_{12}, and pantothenic acid), sugars, auxins (3-methyl indole, indole acetic acid), gibberellins, and amino acids (Ahmad and Winter 1968; Singh and Trehan 1973; Misra and Kaushik, 1989; Jadhav et al. 2018). Besides contributing nitrogen and increased plant growth, resulting in higher yield, cyanobacteria also improve soil health. They excrete complex organic carbon compounds such as polysaccharides (Ohki et al. 2014) that help bind soil particles, thereby improving aggregation of soil and its structure.

In view of deteriorating soil health, the use of cyanobacteria in paddy cultivation in tropical conditions such as in India becomes even more pertinent. The use of cyanobacteria in rice cultivation in Asia in general, and India in particular, is well documented (Watanabe 1965; Venkataraman 1972, 1979; Roger, Zimmerman, and Lumpkin 1993; Dhar et al. 2015; Dash et al. 2017), but the understanding of the dissemination chain is limited. The continuous efforts of the Indian Agricultural Research Institute

✉ Sunil Pabbi
sunil.pabbi@gmail.com; sunil_micro@iari.res.in

[1] ZTM & BPD, ICAR-Indian Agricultural Research Institute, New Delhi 110012, India

[2] International Food Policy Research Institute, New Delhi, India

[3] Centre for Conservation and Utilisation of Blue Green Algae, Division of Microbiology, ICAR–Indian Agricultural Research Institute, New Delhi 110012, India

Published online: 03 September 2020

(IARI) in New Delhi, India, to accelerate the dissemination of cyanobacteria have finally paid dividends in terms of increased production resulting from their extensive use, thereby reducing fertilizer use and increasing yield and profit to farmers. This paper documents the cyanobacterial biofertilizer dissemination chain and its impact to identify the most efficient and effective ways to further expand its reach to end consumers (that is, farmers). Specifically, the paper highlights the activities undertaken for demonstration, creation of awareness, and dissemination of cyanobacterial biofertilizer through public-private partnerships (PPPs) among stakeholders, and the models adopted by the IARI.

Development of cyanobacterial biofertilizer technology

Following earlier reports wherein the naturally occurring fertility and productivity of rice field soils were attributed to the presence of cyanobacteria, considerable progress has been made in developing cyanobacterial biofertilizer technology. In India, applied research on cyanobacteria, especially on their use as biofertilizers, is mainly conducted at the IARI (New Delhi), the University of Agricultural Sciences (Bangalore), the Central Rice Research Institute (Cuttack), and the Tamil Nadu Agricultural University including Tamil Nadu State Agriculture Department. The IARI conducted the pioneering work, developing an algal biofertilizer technology mainly for rice in the 1960s (Venkataraman 1972). The technology was cheap, simple, and mainly intended for small and marginal farmers.

For the first time in 1976, the Government of India (GoI) facilitated the transfer of the cyanobacterial biofertilizer technology developed at the IARI to farmers in many parts of the country, in collaboration with the State Departments of Agriculture and the Agricultural Universities under the All India Co-ordinated Project on Algae (AICPA) for fertilizer, feed, and fuel. The project was funded by the GoI's Department of Science and Technology. Roger et al. (1985) gave a comprehensive account of research on algalization technology in India after Roger's visit to India. They reported that algalization technology was mainly adopted and practiced in the Indian states of Tamil Nadu and Uttar Pradesh, comprising $\simeq 2 \times 10^6$ ha out of a total 42×10^6 ha of paddy-growing area countrywide. In Tamil Nadu, where only about 5% of the trials were reported unsuccessful, farmers strongly adopted the technology. In contrast, in Uttar Pradesh, farmers' adoption of the technology was lower. This was because in Tamil Nadu, farmers planted three crops of rice per year and inoculated every time, so cyanobacteria's performance over six successive crops could be analyzed in a short span of 2 years. After two successive years of continuous inoculation, the inoculated cyanobacterial strains established themselves and multiplied automatically when the rice crop was grown, eliminating the requirement to inoculate further. Aduthurai Station in Tamil Nadu conducted trials of cyanobacterial inoculation for several years, such that eventually practically no control plot was free of nitrogen-fixing cyanobacteria.

The method of production of soil-based cyanobacterial inoculum developed in the country was very simple and economical and thus easily adopted by farmers. In this method, a starter inoculum consisting of *Aulosira*, *Nostoc*, *Anabaena*, and *Tolypothrix* mixed together was made available to farmers by inoculum-producing centers. The starter inoculum was grown and multiplied in shallow metallic trays or pits/plots or tanks with 10–15 cm of water, about 3–4 kg of soil per m^2, 100 g of single super phosphate (SSP) per m^2, and an insecticide (malathion or carbofuran) to prevent mosquito breeding in production trays/pits. The soil pH was maintained at about 7.0–7.5 and lime added if necessary. In about 2 to 3 weeks, a thick layer of cyanobacterial growth would develop on the surface of soil and then subsequently float. Under favorable climatic conditions, two layers of algal growth would arise, one on the soil surface, the other floating in water. At this stage, no more water would be added and any leftover water in the trays/pits/tanks was allowed to evaporate naturally in the sun. The dried cyanobacterial flakes were collected and stored in polythene bags for use in rice fields. Despite being simple and economical, this technology had some disadvantages. Since the multiplication used soil as a carrier under local climatic conditions, the proportion of each of the cyanobacterial strains (*Aulosira*, *Nostoc*, *Anabaena*, and *Tolypothrix*) in the resulting flakes could not be assessed and it was more likely that those strains that adapted best to the local climatic conditions dominated in the final product. This method was thus valid only if a balanced starter inoculum (that is, one comprising all the four strains, viz. *Aulosira*, *Nostoc*, *Anabaena*, and *Tolypothrix*) was provided to farmers. The enumerations of cyanobacteria done in collected inocula by a number of laboratories, including at the IRRI (International Rice Research Institute) in the Philippines, further suggested to produce unialgal inocula of specific strains separately, dry them, check their quality, and mix them based on their CFU (colony-forming unit) to obtain a good-quality, balanced multistrain starter inoculum.

Nonetheless, the technology was promoted and adopted by farmers in many parts of India. Pillai's (1980) review on the adoption of biofertilizers in India presented the extent of adoption of algalization technology by 1980 (stating that "Apart from the work carried out at Research Stations, there has been very little organized work on development of the material for being adopted by the farmers, particularly in areas where it could be of potential benefit"). Subba Rao (1982) further reported that in India, the production capacity of algal flakes was around 40 t $year^{-1}$, accounting for a mere 0.01% of the country's total inoculum requirement. Forty tonnes would inoculate only 4000 ha at an application rate of 10 kg ha^{-1}—this would cover only a very low percentage of the total area under rice in Tamil Nadu and an almost negligible percentage of all rice fields in India. Non-adoption in other states was due to the difficulty of convincing farmers to do so, especially in the states of Haryana and Punjab, where farmers have large landholdings and use chemical nitrogenous fertilizers; hardly any adoption occurred despite successful demonstration trials. Availability of inoculum was another reason for non-adoption, as it was not profitable to produce on a commercial scale given the low cost of the final product (about 1 Indian Rupee (INR) per kg). Cyanobacterial biofertilizer's practical use and popularization depended more on demonstrations conducted on a trial and error basis without farmers' knowledge of the factors aiding multiplication of local/indigenous or inoculated cyanobacterial strains in the field or the factors responsible for increasing crop yield after inoculation. The increased yield in plots treated with cyanobacteria might be attributed to nitrogen, growth-promoting substances' production, organic matter addition, and/or phosphorus solubilization by these cyanobacteria, and even in some cases to better management of treatment plots by farmers. Above all, grain yield was the only criterion in such field experiments judged for success as in most of the field demonstrations/trials, grain yield was the only measured variable. Most of the inoculation experiments (or for that matter, similar technological interventions in the field) are still conducted in the same manner, with little or no information on the agroecological factors that influence the experimental field, the initial population of indigenous nitrogen-fixing and other cyanobacteria, and the population/functional dynamics of the algal flora as a community during the whole crop duration. Further, usually only the results of successful experiments are reported, while unsuccessful trials, which may provide valuable information on limiting factors, mostly go unnoticed (Roger et al. 1985).

Since the 1940s, cyanobacteria have been considered a promising source of nitrogen for rice crops and responsible for the inherent fertility of rice field soil. Until 1985 and possibly later, they were still considered promising and the only viable technology proposed, especially to small and marginal farmers, but cyanobacteria were not used sufficiently in rice-growing nations. Recognizing their significance for sustainable use not only in agriculture but also in industry and environment (Chakdar et al. 2012), the Department of Biotechnology (DBT), Ministry of Science and Technology, GoI, through the ICAR established the National Facility for Blue Green Algal Collections at the IARI, New Delhi, during the Seventh Five Year Plan of India (1986) to preserve this valuable cyanobacteria germplasm. The Facility gradually strengthened into a unique National Centre for research, teaching, and extension in agricultural algology. The Centre presently holds more than 800 unialgal cultures of cyanobacteria comprising unicellular, filamentous, and heterotrichous types, and acts as a repository for freshwater cyanobacteria. To improve cyanobacterial biofertilizer technology and to hold large-scale, national-level demonstrations of the newly developed inoculants, the GoI's DBT boosted cyanobacterial research in the country by initiating a multi-institutional "Technology Development and Demonstration Project," resulting in many refinements in the production technology. As stated earlier, cyanobacteria were produced in an open environment and random soil was used as a carrier, so the final product was prone to several kinds of contamination from soil and other external factors. Farmers were not able to get good-quality input product and thus did not get the desired results in terms of increased production. Moreover, the heavy dose of application required (10–12 kg ha^{-1} of soil-based cyanobacterial biofertilizer) created difficulties in production, storage, and transportation. As production was done in the open environment in the presence of sunlight, it was restricted to only three or four complete sunny months in a year. Therefore, although the technology had potential benefits, it could not be adopted on a large scale. Besides these technological shortcomings, a proper mechanism to scale up via public-private partnerships (PPPs) was lacking.

The GoI continued to push and the project was further supported by the DBT as a network Mission Mode project, with the IARI as the lead center to address the technological challenges. In the second phase of this project, the IARI developed two technologically new products where soil was excluded as a carrier and new carrier materials introduced: straw-based cyanobacterial biofertilizer and Fuller's earth-based (montmorillonite clay, or *Multani mitti* as it is referred to locally) cyanobacterial biofertilizer. The straw-based technology was successfully tested at different locations over years with a much reduced application dose (1 kg ha^{-1}). However, production constraints arose. The wheat straw used as the carrier in production needed pretreatment and chopping, which made its production tedious, labor-intensive, and more costly. It was difficult to uniformly mix cyanobacteria and wheat straw. Due to the straw's light weight, the final product was again voluminous and thus fraught with problems. Availability of wheat straw in large quantity and at reasonable price due to its other applications, including its use as fodder, was another major issue. Ultimately, it was neither easy to ensure the availability of input technology as per demand nor to apply cyanobacteria homogenously.

Tests of the Fuller's earth-based technology gave promising results in experimental fields as well as in on-farm trials. This technology was refined by modifying the production medium and changing the open environment to indoor production technology (Pabbi 2008). It consists of cyanobacteria multiplication units that are shallow ponds made either of reinforced cement concrete or brick and mortar or polythene-lined pits on the surface, as suggested for soil-based production. These multiplication units are lodged in a covered place (production unit) to accelerate cyanobacterial multiplication with year-round production and protection against contamination and infestation with parasites and predators. The biomass is harvested and wet cyanobacterial biomass is mixed with pre-soaked *Multani mitti* (a montmorillonite clay). The paste is spread into a thin layer about 1 cm thick on a polythene sheet and dried in the sun. The dried flakes are powdered to 200 mesh. This makes a very good inoculum and 1.2 kg is sufficient to inoculate 1 ha of rice-growing area. This method ensures year-round, faster, and more economical production of improved cyanobacterial biofertilizer with a better-quality product of longer shelf life, higher titer, and reduced application dose (Pabbi 2008). Field experiments with this new material show promising results and the new cyanobacterial biofertilizer technology holds great promise. The economics are also favorable to exploit the product commercially, considering its immense market potential.

Steps for popularization and dissemination of technology

(a) Demonstration and awareness creation

Demonstration trials of improved cyanobacterial technology have been conducted continuously since 2004 on research farms of various ICAR and other research institutes under different extension programs through the Centre for Agricultural Technology Assessment and Transfer (CATAT) and the Agricultural Technology Information Centre (ATIC). This has led to savings of chemical nitrogen in terms of urea and to increased grain yield, which has given farmers additional monetary gain (Table 1). Looking at the success of on-farm trials, national-level field demonstrations with cyanobacterial biofertilizer intervention were proposed in 2014, under the project "On-farm evaluation of microbial inoculants in different crops and agro ecosystems of India," wherein a large number of on-farm trials were conducted in collaboration with *Krishi Vigyan Kendra's* (KVKs or Agriculture Science Centres) in the Indian states of West Bengal, Tamil Nadu, Uttar Pradesh, Punjab, Chhattisgarh, Bihar, and Madhya Pradesh. The aim was to observe the influence of cyanobacterial biofertilizer on growth and productivity of different crops under integrated and organic nutrient management systems and nutrient management conditions in different agroecological areas. Another objective was to study the economics of nutrient management with cyanobacterial biofertilizer *vis-à-vis* conventional systems. In this attempt, along with field trials at farmers' fields, *Kisan Ghoshthis* (farmers' seminars) were conducted to simultaneously create mass awareness about the use of the technology.

(b) Gap identification

Undoubtedly, the use of cyanobacterial biofertilizer technology, combined with large-scale demonstrations for awareness building, its evaluation and farmers' regular feedback, led to a marked increase in crop yield as well as improved grain quality and reduced consumption of chemical fertilizer. Yet the lack of a proper mechanism to produce the product commercially at mass scale rendered it a counter-productive exercise in terms of resources wasted in development, adoption, and dissemination of the cyanobacterial technologies. The IARI itself produced only a limited quantity for demonstration/distribution purposes, catering to a very limited clientele in nearby areas. On average around 1200–1500 packets were produced per year between 2008–2009 and 2016–2017 (Fig. 1), sufficient for about 600 ha. Thus, the challenge was how to provide the innovative cyanobacterial biofertilizer technology-based input material to farmers as per demand, at the right time, at an affordable price, and right to their doorsteps. Obviously, its production needed to be scaled up to commercial level to cover the maximum area under cyanobacteria to reduce farmers' consumption of chemical fertilizers (urea). The best solution would have been to collaborate with the private sector, given its ability in-license, produce, sell, and distribute the improved cyanobacterial biofertilizer to farmers' doorsteps.

Table 1 Impact of cyanobacterial biofertilizer on use of chemical inputs, cost of cultivation, yield and farmers' income in North Western Indo-Gangetic Plains

	Before	After	Difference	% change	*t* value
Consumption of urea (kg ha^{-1})	279.12	208.8	− 70.32	− 25.2	14.62
Consumption of DAP (kg ha^{-1})	40.8	33.6	− 7.2	− 17.9	4.7
Consumption of potash (kg ha^{-1})	6.912	6.264	− 0.648	− 9.4	0.64
Consumption of zinc (kg ha^{-1})	12.168	13.536	1.368	11.2	1.44
Impact on cultivation cost (INR ha^{-1})	23,320.80	22,874.40	− 446.4	− 1.9	1.41
Impact on yield (q ha^{-1})	68.016	70.608	2.592	3.8	− 11.31
Impact on income (INR ha^{-1})	108441.6	112656	4214.4	3.9	− 11.42

Source: Field Survey, 2015–2016

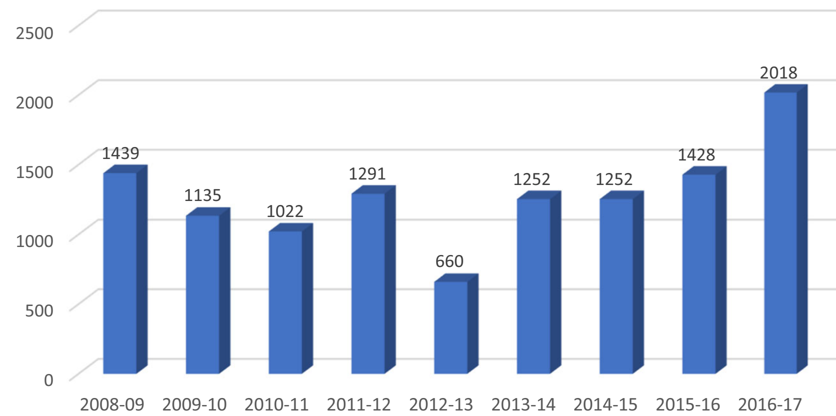

Fig. 1 Cyanobacterial biofertilizer packets (500 g packet per 0.4 ha) produced by IARI

(c) Dissemination of cyanobacterial biofertilizer through a PPP model

To realize the strengths of PPPs as well as to foster an intellectual property-based commercial ethos, comprehensive guidelines were introduced for systemwide "Intellectual Property Management and Technology Transfer/ Commercialization" (http://www.icar.org.in/files/ICAR-GuidelinesIPM&T-2014.pdf). Under these guidelines, a three-tier intellectual property management mechanism was established by the Indian Council of Agricultural Research (ICAR), 1) setting up an Agro-Technology Management Center (ATMC) at apex level; 2) Zonal Technology Management Centers (ZTMCs); and 3) Institute Technology Management Units (ITMUs) at each one of its institutes. In this process, IARI's Zonal Technology Management – Business Planning and Development (ZTM & BPD) Unit put in place an effective and innovative intellectual property management and technology transfer system for fast-tracking the transfer of proprietary and other new, exclusive technologies to agripreneurs and farmers. On the one hand, this approach boosted the local agribusiness industry; on the other hand, it created a competitive industrial environment to provide quality product at a reasonable price to farmers.

Starting in 2011, cyanobacterial biofertilizer technology was commercialized to five industry partners (Table 2). Under the licensing agreement, the IARI provides industry partners with the basic cyanobacterial resource material in limited quantity under a material transfer agreement, along with a technology production manual, demonstrations, training, and the technical know-how of production. It also handholds industry in the production and quality control of the first few batches of material at their production facilities. Out of five industry partners, three have already launched their commercial production in the market (Table 2). Within the span of around 5 years, they produced about 49,000 tons of cyanobacterial biofertilizers, disseminated in fields of over 27,000 ha in Punjab, Haryana, Uttar Pradesh, Bihar, Uttarakhand, and Andhra Pradesh (Fig. 2). The PPP intervention played a vital role in the out-scaling of this technology.

To study various aspects of the out-scaling of cyanobacterial biofertilizer technology within a short span of time, we examined one case of the licensee and the details are presented in this paper. The company established a small production plant in the state of Punjab and produced around 7000 packets in its first year (2014). Simultaneously, the company (1) created marketing channels up to village level and (2) appointed 11 district heads, around 60 area managers in each of the 10–20 village clusters, and around 550 village centers, each of which was

Table 2 Cyanobacterial biofertilizer technology commercialization during 2010–2011 to 2016–2017

Name of Indian company	Licensing year	Product launched
M/s Sai Bio Organics, Moga, Punjab	2010–2011	2012–2013
M/s Ecological Products Industries, New Delhi	2010–2011	2012–2013
M/s Eco Inputs, Ludhiana, Punjab	2013–2014	2014–2015
M/s Forex Fastner (P) Ltd., Gobindgarh, Punjab	2014–2015	-
M/s Eco Fert AG. Samba, Jammu and Kashmir	2016–2017	-

Source: ZTM & BPD Unit, ICAR-IARI

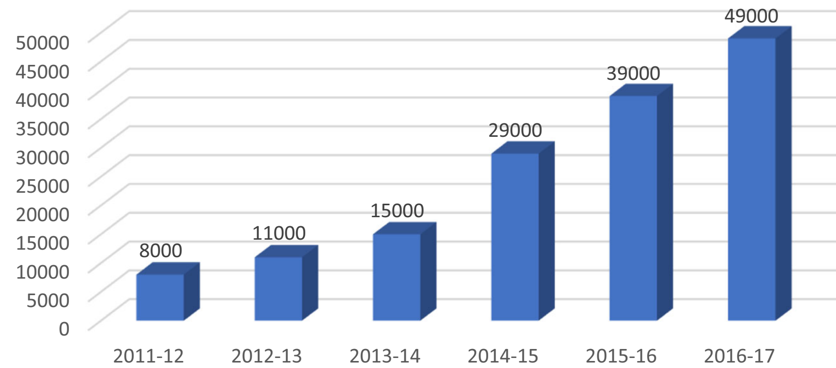

Fig. 2 Cyanobacterial biofertilizer production (tonnes) by three industry partners

managed by farmers of the same village only. The company also formulated 20 two-member extension teams. These teams worked on a salary-cum-commission basis to incentivize the result-related outputs. Extension teams created awareness about the cyanobacterial biofertilizer technology by organizing meetings with progressive farmers, demonstration trials on their fields, and *Melas* (farmer fairs) at block and village levels. The company distributed cyanobacterial biofertilizer packets free of cost to farmers for technology demonstration at their fields. The company spent a handsome amount in creating awareness as well as demonstration of the technology, which also led to brand promotion and marketing of the product. These efforts, spread over 3 years, resulted in the sale of around 14,000 packets (each packet applicable for 1 ha) of cyanobacterial biofertilizer in 550 villages of 16 districts in Punjab state. Under this model, the industry partner marketed the product through a long supply chain with intermediaries at district, block, and village levels who distributed the profit share at each step. This, however, led to increase in the cost of the product at the farm level. The study observed that farmers were satisfied with the technology and interested in its continued use on their fields but expressed concerns about its high price (which should be less than or equivalent to the savings due to decreased urea application). They also felt that an easy-to-understand technology application manual or instruction booklet in their local language would greatly help in realizing the technology's full potential.

As observed, the use of cyanobacteria reduced the application of urea by about 25% (Table 1) without affecting paddy yield, which instead increased by 3.8% with a marginal decrease in cultivation cost per hectare, from INR 23,320.80 (about 324 US$) to INR 22,874.40 (about 318 US$) for paddy crop. Farmers' income also increased, from INR 108,441.6 (about 1506 US$) to INR 112,656 (about 1565 US$) per hectare. In 2014–2015 in Punjab, Haryana, and Uttar Pradesh, area under paddy (average for 3 years) was 2.89 million hectares (MHa), 1.29 MHa, and 5.87 MHa, respectively (Agricultural Statistics at a Glance 2016). As stated, the use of cyanobacterial biofertilizer decreased urea consumption by 25.2%; thus, if cyanobacteria cover approximately 20% of this area, urea consumption may decrease to 31360, 9610, and 43730 tonnes in Punjab, Haryana, and Uttar Pradesh, respectively, based on 2014–2015 statistics. In 2017–2018, the GoI provided a subsidy of INR 54,000 crores (about 7500 million US$) on urea, so lower consumption of urea should reduce the burden of the subsidy in addition to generating a long-term positive sustainable impact on soil health.

The GoI could address the relatively high price of the technology by providing a subsidy on cyanobacterial biofertilizer similar to that given for chemical fertilizer. Needless to say, the price of cyanobacterial biofertilizer will decease with increased production over time, while an easy-to-understand technology application manual or instruction booklet in local languages will help in realizing the technology's full potential. On the basis of the feedback, the licensee company revised the long supply chain model to a direct marketing model (Fig. 3) by contacting cooperative societies and retailers able to purchase on cash payment, as well as supplying directly to farmers from factory outlets. As a result, the product cost was brought down by around 15%, helping to further scale up use of the technology. This proved to be a more efficient method to create systematic awareness, demonstration, and marketing and to ensure the availability of biofertilizer at farmers' doorsteps. The IARI helped the licensee to develop the literature in local languages for easier application in their fields. The IARI also collaborated with the licensee company to create awareness about the technology by participating as resource persons and answering farmers' queries in the *Melas* (fairs) organized by the industry.

Conclusion and policy implications

IARI's scale-up of cyanobacterial biofertilizer technology by involving a few licensee industry partners and the technology's transfer from lab to land was phenomenal,

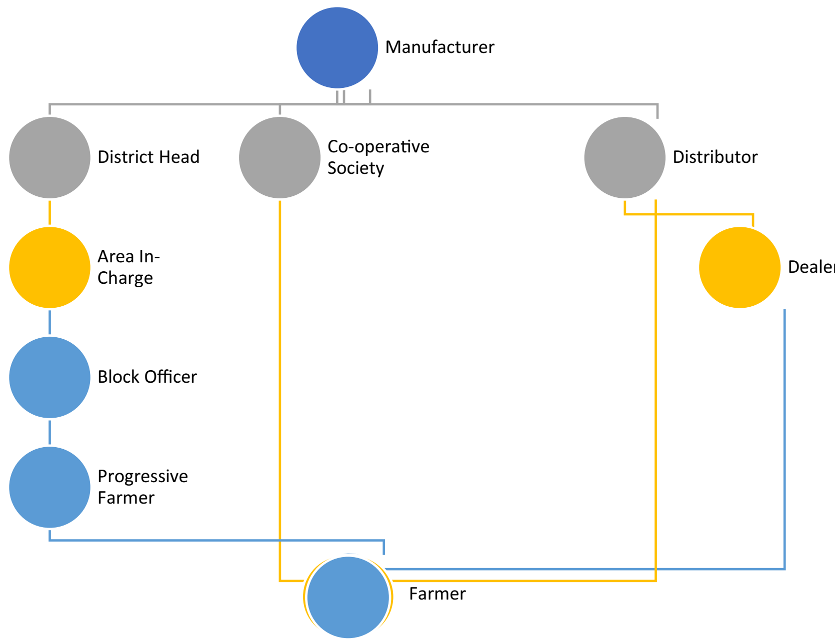

Fig. 3 Different supply chains of cyanobacterial biofertilizer

productive, and efficient. It led to development of a new biofertilizer input supply chain, assuring demand-based supply at an affordable price. IARI's technical and business units both played pivotal roles in the scale-up process, but attracting industry partners and establishing PPPs for commercializing this innovative technology turned out to be the most crucial steps. The IARI provided partners with much-needed support for technology know-how, demonstration, and extension activities. These licensees played a significant role in enhancing the production, marketing, and distribution of the technology to farmers in adequate quantity, at a competitive price, and to their doorsteps. They were focused and had a technology-specific approach and invested significantly in both monetary and human resources to create awareness and provide demonstrations. They imparted know-how of cyanobacterial biofertilizer use among farmers which led to technology adoption as well as dissemination in larger areas. A subsidy on cyanobacterial biofertilizer would increase farmers' demand and application, as is clear from the farmers' perceptions revealed in this study. This model has worked successfully for cyanobacterial biofertilizer technology, which has been available for quite some time without appreciable progress and produced only at village level or by government agencies. Needed now is commercialization of more promising technologies by establishing PPPs, which if strongly backed up by the national research institutes like the IARI could accelerate their dissemination, an activity critical to enhance sustainable agricultural growth in India.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Agriculture Statistics at a Glance 2015 (2016) Ministry of Agriculture & Farmers Welfare, Directorate of Economics and Statistics, GoI Controller of Publication, pp xxv+479. https://www.agricoop.nic.in

Ahmad MR, Winter A (1968) Study on the hormonal relationships of algae in pure cultures 1. The effect of Indole-3-acetic acid on the growth of blue green and green algae. Planta 78:277–286

Chakdar H, Jadhav SD, Dhar DW, Pabbi S (2012) Potential applications of blue green algae. J Sci Ind Res 71:13–20

Dash NP, Kumar A, Kaushik MS, Abraham G, Singh PK (2017) Nitrogenous agrochemicals inhibiting native diazotrophic cyanobacterial contribution in wetland rice ecosystem. J Appl Phycol 29:929–939

De PK (1939) The role of blue-green algae in nitrogen fixation in rice-fields. Proc Roy Soc B 12–139

Dhar DW, Prasanna R, Pabbi S, Vishwakarma R (2015) Significance of cyanobacteria as inoculants in agriculture. In: Das D (ed) Algal biorefinery: an integrated approach. Capital Publishing Co, New Delhi, pp 353–392

Jacq V, Roger PA (1977) Decrease of losses due to sulphate reducing processes in the spermosphere of rice by presoaking seeds in a culture of blue-green algae (in French, English summary). Cah ORSTOM sérBiol 12:101–108

Jadhav SD, Pabbi S, Gopal M, Chand S (2018) Physicochemical confirmatory evidences for cyanobacterial released plant growth hormones governing escalation of rice (*Oryza sativa* L.) and wheat (*Triticum* sp.) crop. Int J Res BioSci 7:1–17

Jaiswal A, Das K, Koli DK, Pabbi S (2018) Characterization of cyanobacteria for IAA and siderophore production and their effect

on rice seed germination. Int J Curr Microbiol Appl Sci Special Issue-7: 5212–5222.
Mishra S, Pabbi S (2004) Cyanobacteria: a potential biofertilizer for rice. Resonance 9:6–10
Misra S, Kaushik BD (1989) Growth promoting substances of cyanobacteria. I. Vitamins and their influence on rice plant. Proc Indian Natl Sci Acad 55:295–300
Ohki K, Le NQT, Yoshikawa S, Kanesaki Y, Okajima M, Kaneko T, Thi TH (2014) Exopolysaccharide production by a unicellular freshwater cyanobacterium *Cyanothece* sp. isolated from a rice field in Vietnam. J Appl Phycol 26:265–272
Pabbi S (2008) Cyanobacterial biofertilizers (Review). J Eco-friendly Ag 3:95–111
Pabbi S (2015) Blue green algae: a potential biofertilizer for rice. In: Sahoo DB, Seckbach J (eds) The algae world. Springer, New Delhi, pp 449–466
Pillai KG (1980) Biofertilizers in rice culture. Problems and prospects for large scale adoption. All India Coordinated Rice Improvement Project (AICRIP) Technical Publ no. 196. ICAR-Indian Institute of Rice Research, Hyderabad, India
Roger PA, Grant IF, Reddy PM (1985) Blue-green algae in India, a trip report. IRRI, Manila, Philippines, p 93
Roger PA, Zimmerman WJ, Lumpkin T (1993) Microbiological management of wetland rice fields, In: Metting B (ed) Soil microbial ecology. M. Dekker Publ, NY pp 417–455
Singh RN (1961) Role of blue-green algae in nitrogen economy of Indian agriculture. Indian Council of Agricultural Research. p. 175.
Singh VP, Trehan K (1973) Effect of extracellular products of *Aulosira fertilissima* on the growth of rice seedlings. Plant Soil 38:457–464
Subba Rao NS (1982) Advances in agricultural microbiology. In: Subba Rao NS (ed) Studies in the agricultural and food sciences. Butterworth Scientific, London, pp 295–303
Venkataraman GS (1964) Algalization. Phykos 5:164–174
Venkataraman GS (1972) Algal biofertilizers and rice cultivation. Today and Tomorrow's Printers and Publishers, New Delhi, p 75
Venkataraman GS (1979) Algal inoculation of rice fields. In: Nitrogen and rice. International Rice Research Institute, Los Banos, pp 311–321
Venkataraman GS, Neelakantan S (1967) Effect of cellular constituents of nitrogen fixing blue-green alga *Cylindrospermum* on root growth of rice plants. J Gen Appl Microbiol 13:53–62
Watanabe A (1965) Studies on blue green algae as green manure in Japan. Proc Natl Acad Sci India 35:361–369