Present Scenario: Status of the Biofertilizer Industry in India

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Abstract-

Agriculture today is facing challenge of increasing productivity from decreasing arable land to feed the growing population. It must improvise and innovate to confront additional threats of global warming and climate change, deteriorating soil health, loss of biodiversity and incidence of crop disease resistance. Use of beneficial microbes identified from soil and plant microbiome can potentially mitigate these challenges. Biofertilizer product having viable cells of beneficial bacteria or spore of a mold can be applied to soil, seed or roots. They colonize the rhizospheric soil, rhizoplane or become endophytic. They extend benefits of nutrient acquisition, plant growth promotion and boosting plant resistance against abiotic and biotic stresses. Biofertilizer market in India is occupied by both public sector and private sector units. The Indian biofertilizers market is worth $110.07 million in 2022 and is expected to grow to $243.61 million by 2029, exhibiting growth of 12.02%. This surge is triggered by rising costs of chemical fertilizers and increased awareness about detrimental environmental impact of these chemical fertilizers. Though a gainful vocation, issues such as the storage, transportation and marketing of biofertilizer, seasonal nature of the product, lack of regulatory and certification control, few biofertilizer testing laboratories pose adversity. Government of India has set up a task force to oversee biofertilizer promotion work. It has set up NCOF and six regional centres, the main aim of these is to increase farmer awareness through training and demonstration of biofertilizer use. The present chapter will outline Government of India`s policy initiatives, discuss public and private sector contribution to biofertilizer production in India and review entrepreneurship hurdles.

Keywords- Biofertilizers, Production units, Indian market for biofertilizers, Biofertilizer entrepreneurship

1) Introduction-

The world population is growing. It increased from 7 billion in 2010 to 7.8 billion by mid-2020. (Gu et al 2021). It is expected to exceed 9.7 billion by 2050 (Hu et al 2022). Growing population presents many socio-economic challenges. The gravest challenge perhaps, is that of meeting food security needs of the global population. Food security, as defined by UN refers to physical, social and economic access to sufficient, safe and nutritious food that meets people`s food preferences and dietary needs for an active and healthy life (www.ifpri.org/topic/food-security). In other words, the global population is growing geometrically but food production is growing arithmetically (Ahmad and Rahim 2022). World production of primary crops, wheat (*Triticum* *aestivum*), rice (*Oryza sativa*), maize (*Zea mays*), and soy-beans (*Glycine max*), in 2021 was 4 billion metric tons (www.fao.org). It must increase by 2.4% per year to keep pace with the increasing population. However, these primary food crops are growing at only half of this required rate (www.oecd.org; Tian et al 2021).

Realizing food security requirements of the growing population has brought arable land under immense pressure. Agriculture today is confronted by additional challenges as increased frequency of extreme weather events/climate change, global warming, deforestation, land degradation, loss of biodiversity, spread of crop-animal disease, development of resistance to diseases, regulatory responses to new plant breeding techniques, agricultural sustainability issues (Ortiz-Bobea et al 2021; Hu et al 2022). An attempt was made to correlate weather effects on global agriculture`s Total Productivity Factor (TPF) to evaluate impacts of past climate trends on TFP. The results have indicated that weather effect has reduced global agricultural TFP by about 21% since 1961 which is equivalent to loss of last 7 years of productivity growth. The effect is substantially more severe (a reduction of ~26–34%) in warmer regions such as Africa and Latin America and the Caribbean. Overall, global agriculture has grown more vulnerable to ongoing climate change (Ortiz-Bobea et al 2021).

Agricultural growth in the world is highly varied and volatile. It encompasses operations from small scale subsistence to large multinational holdings. Though agricultural land use is broadly constant, however, current yield improvements and higher production intensity is driven by technical innovations of varietal development and increased agro-chemical inputs (www.fao.org).Higher yields during and after the Green Revolution are recognized to be sustained by higher chemical fertilizer input. In 2021, worldwide nitrogen chemical fertilizer consumption exceeded 110.8, phosphorus exceeded 50.0 and potassium exceeded 39.1 million metric tonnes (www.statista.com). East Asia and South Asia are the major consumers of NPK chemical fertilizers followed by Latin-America and the Caribbean, North America, Europe and Africa (www.statista.com).

Soil health management is vital for the maintenance of biodiversity and ensuring sustainability of agriculture. The health of soil is impacted by soil properties as physicochemical and biological properties. Though chemical fertilizers play an essential role in increasing crop productivity and soil fertility but simultaneously they alter soil physicochemical and biological properties. Continuous utilization of chemical fertilizers results in the decline of soil organic matter content (SOM) coupled with a decrease in the quality of agricultural soil. The overuse of chemical fertilizers hardens the soil, reduces soil fertility, pollutes air, water, and soil, and decreases important nutrients of soil and minerals. Utilization of chemical fertilizers decreases soil microbial activity and soil microbial biodiversity. It changes the pH of soil, increases acidification and pests, hardens soil crust which results in decreased organic matter content, decreased humus content, loss of beneficial organisms, stunting of plant growth and also emission of greenhouse gases. All of these consequences are detrimental to soil well-being because of long time persistence in it (Pahalvi et al 2021; Basu et al 2021; Chakraborty and Akhtar 2021; Mohanty et al 2021).

Agricultural productivity and sustainability can be improved by scientific breakthroughs and technological innovations. These include, but are not limited to, next generation plant breeding strategies based on genome editing, improving nutritional quality of crops by metabolic engineering and synthetic biology approaches, plant and rhizospheric microbiome engineering for efficient nutrient acquisition and resilience to biotic and abiotic stresses, increasing efficiency of agricultural resources, domestication of wild varieties and using them in varietal development programs, increasing plant diversity of crops including perennial crops, introducing food diversity to reduce dependency on ‘resource high’ crops, reducing post-harvest losses, etc. (Hu et al 2022; Caixia 2021, Tian et al 2021). Additonally, engineering of plant endophytic microbiome and plant rhizospheric microbiome are environment friendly and economical approaches which involve use of biofertilizer strains for enhanced nutrient utilization and developing plant resistance to biotic and abiotic stresses. The present chapter will focus on of use of these microbial inoculants to offset the detrimental effect of chemical fertilizers on environment.

2) Biofertilizer and their benefits and limitations-

Biofertilizer are products that contain viable microorganisms which when applied to seeds, plants or soil have the ability to colonize the rhizospheric soil or endophytic tissue of the plants thereby promoting plant growth by enhancing nutrient acquisition by the host plant (Bardi and Malusa 2012; Malusa and Vassiley 2014). Nitrogen fixing bacteria and cyanobacteria fix atmospheric nitrogen and make it available to the plant. Phosphate solubilizing and mobilizing bacteria and fungi amend unavailable form of phosphorus to an available form which can be absorbed and assimilate by the plants.Potassium solubilizing or potassium dissolving bacteria are capable of solubilizing inorganic potassium from insoluble compounds and providing it for plant uptake. In addition, some biofertilizers exhibit plant growth-promoting traits as production of IAA, Cytokinnins, Gibberellic acid, Abscisic acid,siderophores, ACC deaminase, HCN, NH^{+4}, exopolysaccharides; enzyme activity- cellulose, amylase, lipase, protease, xylanase, pectinase, and solubilization of Zn and Fe (Ahemad and Kibret 2014, Verma et al 2018; Parani and Saha 2012). Biofertilizers are reported to increase yield by 10-14% in some crops as legumes and improve plant and soil health. Increase in yield is attributed to increased proteins, amino acids and vitamins in the plants (Bhardwaj et al 2014). The biofertilizers are economical to use and leave little environment footprint (Mazid and Khan 2015).Overall, biofertilizers carry out nutrient cycling and ensure optimal growth and development of crops.

Many bacterial strains are popularly used as biofertilizers. *Rhizobium*, *Bradyrhizobium*, *Agrobacterium*, *Allorhizobium*, *Azorhizobium*, *Mesorhizobium* and *Burkholderia* are effectively used in legume crops. They have a symbiotic association with legume crops. They are characterized by their ability to form 'functional' root nodules with the legume host. These rhizobia have the ability to fix as high as 200-300 kg nitrogen/ha/crop. However, their capability is limited only to legume plants (Pirttilä et al 2021). Apart from symbiotic association, atmospheric nitrogen is fixed by non-symbiotic associative association as well. *Azospirillum* has the ability to colonize rhizoplane, lateral roots of many crops as cereals and soybeans. It exhibits a wide array of activities as nitrogen fixation, plant hormone production, phosphate solubilization, proliferation of root system, mitigation of abiotic stresses and biocontrol activity (Cassán et al 2021). Among free living nitrogen fixers, *Azotobacter* is probably the most studied. It fixes nitrogen aerobically. It has been used extensively for nitrogen acquisition, solubilizing phosphate, plant hormone production in cereals like wheat, rice, oat, corn, barley; vegetable crops like tomato, eggplant, onion and potato (Macik et al 2020). Cyanobacterial nitrogen fixers as *Nostoc, Anabaena, Calothrix* and *Tolypothrix* are used for crops as rice. They are reported to produce plant hormones, decrease soil salinity and solubilize phosphate. *Azolla-Anabaena* association is an example of symbiosis for nitrogen fixation and nutrient enrichment in the rice paddy (Sadatnia and Riahi 2009; Ibraheem 2007, Wilson 2006).

Besides bacteria, mycorrhizal fungi are the most used biofertilizers. They act by extending the root system of the host plant, aid in water and nutrient uptake, mitigate abiotic stresses and act as biocontrol agents against fungal and nematodal pathogens. Mycorrhizal fungi improve soil physical structure by creating macro-aggregates of soil particles. Arbuscular mycorrhizal fungi (AMF) penetrate the cortical cells of the root and form branched structures called arbuscules. AMF are reportedly present in 90% of plant species. They are shown to increase yield in cereal crops (Pirttilä et al 2021). 26 % increase in yield of tomato and 300% increase in yield of carrots has been reported in literature. Success of mycorrhizal inoculation depends on condition of soil fertility, soil pH and soil salinity (Affokpon et al 2011; Hoeksema et al 2010). Commonly used AMF include *Glomus*. *Rhizofagus irregularis*, *Funneliformis mossae*, and *Claroideoglomus etunicatum* (Aamir et al 2020).

Biofertilizers are also biocontrol agents. In addition to competing for nutrition and space, the biocontrol action is mediated by production of one or more. antibiotic compounds, enzymes which lyse microbial cell wall, scavenging iron from rhizospheric soil and making it unavailable to potential pathogens (Kloepper et al 2004). Biocontrol agents also act by induce systemic resistance (ISR) and systemic induced resistance (SAR) (Parani and Saha 2012). *Pseudomonas trivalis* strain BIHB 745 is reported to produce siderophores (Parani and Saha 2012). Siderophores pyochelin and pyoverdine are produced by *P fluorescens* (Sharma et al 2017).

Various other soil fungi can be used in agriculture. Example *Penicillium bilaiae,* a rhizospheric fungi aids in phosphate acquisition (Aamir et al 2020). *Trichoderma* is another popularly used fungi which helps the plant in coping with biotic and abiotic stresses. *Trichoderma viride,* is an oft used biocontrol agent against *Fusarium, Sclerotinia, Pythium* and *Rhizoctonia*. *Trichoderma harzianum* can control *Botrytis, Sclerotinia* and *Verticillium* and wood-rot fungi (Vosátka et al

2012). It can also induce growth and flowering in plants. Co-inoculation of *Trichoderma* spp with AMF *Glomus* has shown increased growth of tomato, melon and lettuce by as much as 56-167% (Colla et al 2015).

Notwithstanding the enormous advantages presented by use of biofertilizers, their utilization is limited. Many reasons can be ascribed to this. Primarily, selection of inefficient strain and compromised quality of the biofertilizer product in terms of low viable cell count and presence of contaminant diminish the benefit a biofertilizer can extend. Once applied, the biofertilizer strain competes with indigenous soil microflora. A strain which is not able to survive, multiply and dominate fails to extend the expected benefit. Coupled with these vulnerabilities, unsuitable storage conditions, transportation and marketing constraints further reduce farmer confidence in biofertilizer technology (Bharti and Suryavanshi 2021). It is pertinent to mention that the lack of farmer awareness and training on use of biofertilizers is also a deterrent in their acceptance. Fertilizer Control Order (1985), is a Government of India`s biofertilizer standard which was revised in 2016 and one of its clauses was amended in 2021. It outlines the quality parameter specifications of both bacterial and fungal biofertilizer products. Poor compliance to these standards, lack of regulatory mechanism and too few biofertilizer quality testing laboratories clear the way for presence of sub-standard and spurious biofertilizers in the market which erode farmer confidence. Selection of robust strain tested under different weather and environmental conditions and quality control can heighten consumer confidence (Mamnabi et al 2020; Zeefa et al 2020).

3) Biofertilizer market in India- public and private sector.

Organic and natural farming has been driven largely by consumer awareness about safety and quality of food. ‘Organic’ and ‘natural’ farming terms are not rigidly distinct but overlap with each other. They refer to agricultural practices and nature of agricultural inputs used at the farm level. Availability of organically products has increased in many countries as USA, Germany, Switzerland, Denmark, India and China (Kumar et al 2022).

According to Verma et al. (2019) biofertilizers constitute around 5% of total fertilizers available in the market. Presently, the biofertilizer market is worth 2.3 billion USD. It is projected to increase to 3.9 billion USD by 2025 (www.globenewswire.com). Among biofertilizers, approximately 150 products are microbial strains which are registered for farming (Verma et al 2019). Among various biofertilizer strains, *Rhizobium* is dominant, occupying about 79% of global demand. Phosphate solubilizing bacteria (PSB) occupy 15% of global market share. *Azospirillum* strains are commercially available for use in wheat, maize and soyabean (Cass´ an and Diaz-Zorita 2016; Cassán, et al 2020). Commercial use of *Azospirillum* has been reported in South American markets of Argentina, Brazil, Uruguay, Paraguay. *Azospirillum* is also available in Mexico, India, China and US, South Africa, Australia and France (Cassán, et al 2020).

Leading biofertilizer producing companies include Novozymes (Denmark), Symborg (Spain), Kiwa Biotech (China), Mapleton Agribiotech (Australia), Lallemand Inc. (Canada), Rizobacter Argentina S.A (Argentina). Indian companies dominating the market are International Panaacea Limited, SOM Phytopharma Limited, Kan Biosys, Multiplex Biotech Private Limited Karnataka, Krishak Bharati Cooperative Limited (KRIBHCO), National Fertilizers Limited (NFL), Indian Farmers Fertilizer Cooperative Limited (IFFCO), The Fertilizers and Chemicals Travancore Limited, Rashtriya Chemicals & Fertilizers Limited (RCFL) (www.timesofagriculture.com). It is pertinent to mention here, that in India and China, around one lakh hectares and 167 million hectares of area is under organic farming, respectively (Sekhar et al., 2016; Bharti and Suryavnashi 2021).

In 2020-2021, India produced 134,323 tonnes of solid carrier based biofertilizers (Table 1 and Figure 1). 50% of it was produced by states in South of India, 28% by states in West India, 19% by North Indian states and 3% by East India states. North Eastern states produced negligible amount of it (Khurana and Kumar 2022). Leading states in order of their production are Tamil Nadu (50%), Gujarat (14%), Maharashtra, (12%), Uttar Pradesh (10%) and Haryana (6%). About 26,442 kilolitres of liquid biofertilizers were produced in India in 2020-2021 (Table 2 and Figure 2). Southern states produce 50% of it followed by Western state (40.2%), Northern states (7.6%), Eastern states (3.4%) and North Eastern states (0.4%). Karnataka is the leading state for liquid biofertilizers (37% of total production) followed by Gujarat (31%), Maharashtra and Kerala (8%) and Uttarakhand (4%). As per Government of India`s records, there are over 532 units producing biofertilizers in India. Unofficial count puts the number of units producing biofertilizers between 600-650. Of these 532 units, 424 units produce solid carrier based biofertilizers. They are located in 28 states and Union Territories (UTs). 108 units produce liquid biofertilizers. They are spread across 17 states and UTs (Khurana and Kumar 2022).

Indian Farmers Fertilizer Cooperative Limited (IFFCO) is a farmer owned cooperative. Set up post independence in 1967, IFFCO expanded its fertilizer portfolio to include biofertilizers. It produces liquid biofertilizers- *Rhizobium, Azotobacter, Acetobacter* and *Azospirillum*. It also produces PSB, KMB and (Zinc Solubilizing Bacteria) ZSB. NPK liquid consortia biofertilizer contains *Rhizobium, Azotobacter, Acetobacter*, PSB *Pseudomonas* sp and KSB *Bacillus* sp. (Indian Farmers Fertilizer Cooperative Limited 2022). IFFCO is in direct/indirect contact with five crore Indian farmers through its 36,000 cooperatives. In addition, it has 21 marketing offices and 115 farmer service centers. IFFCO has MoU with Indian Council for Agricultural Research (ICAR) for technology transfer through ICAR institutes and Krishi Vigyan Kendras (KVKs). IFFCO in 2021-2022 has reported sales of Rs 3021.57 crore of complex fertilizers which includes biofertilizers, primary nutrients, secondary nutrients, etc (Indian Farmers Fertilizer Cooperative Limited 2022).

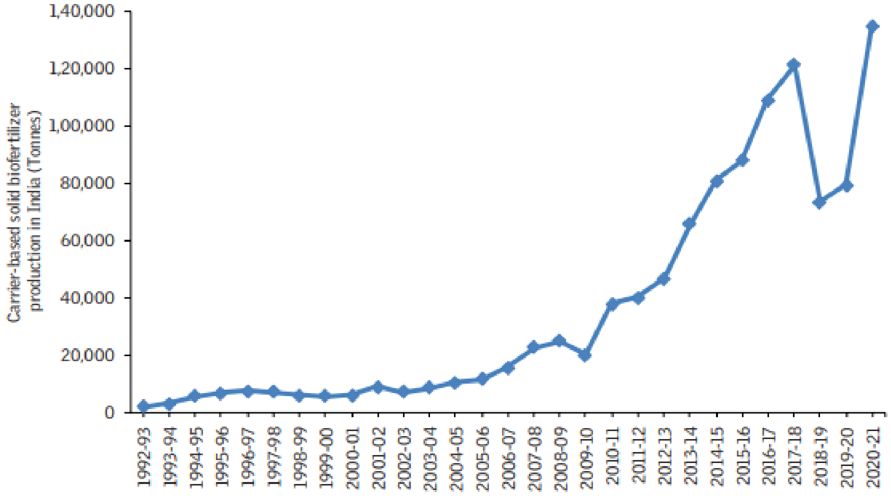

Figure 1- Growth of solid carrier based biofertilizer industry in India from 1992-92 to 2020-21 (Source- Khurana and Kumar 2022)

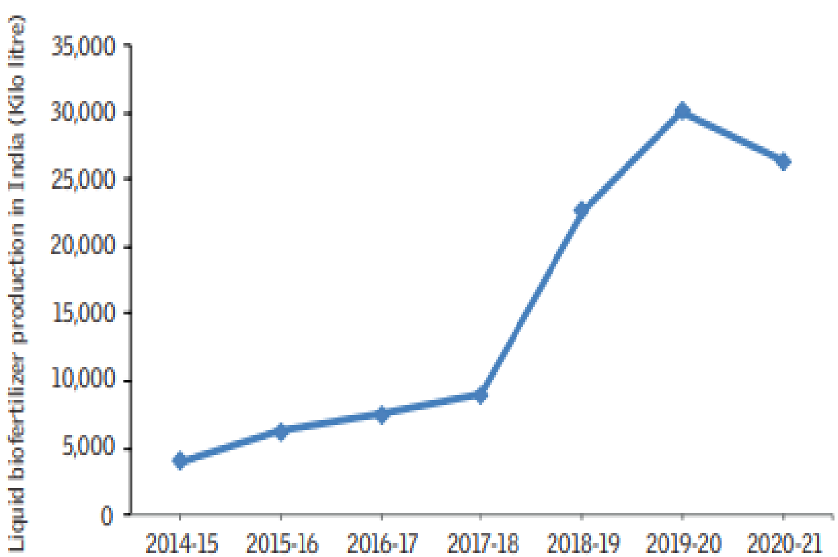

Figure 2- Growth of liquid biofertilizer industry from 1992-93 to 2020-21.
(Source- Khurana and Kumar 2022)

Table 1- Periodic production performance of solid carrier based biofertilizers in India (tonnes).

State/Union Territory	2016-17	2017-18	2018-19	2019-20	2020-21
South Zone					
Andhra Pradesh	3376	4984	264	228	181
Karnataka	31,553	34,493	3254	3607	1866
Kerala	4994	6040	108	91	97
Puducherry	204	298	122	122	76
Tamil Nadu	27,428	28,059	4187	11,611	64,384
Telangana	-	574	2556	1536	320
West Zone					
Chattisgarh	955	969	172	27	56
Gujarat	3910	4248	10,596	20,788	19,108
Goa	822	839	2044	50	30
Madhya Pradesh	5609	6562	7427	1330	1748
Maharashtra	8324	10,025	15,050	15,897	15,591
Rajasthan	711	792	792	2143	1570
North Zone					
Delhi	116	120	394	345	347
Chandigarh	0	-	-	-	-
Haryana	2361	2505	2129	2795	8517
Himachal Pradesh	3	8	135	320	200
Punjab	5534	5645	7167	9252	-
Uttar Pradesh	2836	3441	2452	2143	13,724
Uttarakhand	3721	3942	3360	3119	2692
East Zone					
Bihar	107	129	131	375	162
Jharkhand	19	21	21	5	15
Odisha	516	560	8167	449	1405
West Bengal	3195	3513	2050	2200	2235
North East Zone					
Arunachal Pradesh	120	233	0	-	-
Assam	1259	1743	617	640	-
Mizoram	3	9	3	1	1
Nagaland	51	71	17	19	-
Sikkim	16	33	-	-	-
Tripura	1154	1188	82	340	-
Manipur	25	24	82	13	-
Total	**1,09,020**	**1,21,067**	**73,377**	**79,447**	**1,34,323**

(-) Data not available.
Source: Khurana and Kumar 2022

Table 2- Periodic production performance of liquid biofertilizers in India (kilolitres).

State/Union Territory	2016-17	2017-18	2018-19	2019-20	2020-21
South Zone					
Andhra Pradesh	365	370	-	-	99
Karnataka	993	1353	758	1218	9713
Kerala	60	83	2	5512	2112
Puducherry	11	28	6	8	2
Tamil Nadu	875	984	537	1482	732
Telangana	-	44	12712	175	150
West Zone					
Chattisgarh	10	17	134	190	163
Gujarat	2858	3519	431	94444	8056
Goa	0	-	-	-	-
Madhya Pradesh	238	290	327	316	262
Maharashtra	398	427	4194	237	2141
Rajasthan	0	1	1	-	-
North Zone					
Haryana	70	76	247	-	108
Himachal Pradesh	195	210	12	138	0
Punjab	210	236	221	192	157
Uttar Pradesh	461	744	2445	2540	593
Uttarakhand	697	534	281	4980	1151
Jammu & Kashmir	0	0	0	-	-
East Zone					
Bihar	0	0	-	1900	2
Jharkhand	0	0	-	-	-
Odisha	32	46	150	1719	860
West Bengal	26	38	38	-	34
North East Zone					
Arunachal Pradesh	0	0	0	-	-
Assam	26	33	-	5	35
Manipur	0	-	100	12	4
Sikkim	0	-	52	-	69
Tripura	0	0	-	40	-
Lakshadweep	0	0	-	-	-
Total	**7526**	**9033**	**22,646**	**30,106**	**26,442**

(-) Data not available.
Source: Khurana and Kumar 2022

KRIBHCO, Krishak Bharati Cooperative Limited, a Government of India undertaking produces and sells 10 types of liquid biofertilizers. These include phosphate solubilizing biofertilizer (PSB), which has phosphate solubilizing bacteria who also produce growth hormones. This product solubilizes two bags of Single Super Phosphate (SSP) in medium/high phosphorus soils. NPK biofertilizer increase availability of applied NPK/DAP/SSP/MoP, aid in early root development and disease resistance. NPK biofertilizer is of three sub-types- NPK-1 which contains *Azotobacter*, PSB and Potassium Mobilizing Bacteria (KMB); NPK-2 contains *Azospirillum*, PSB and KMB; NPK-3 contains *Rhizobium*, PSB and KMB. NPK biofertilizer restricts leaching of Potassium (K) and Nitrogen (N) in the soil and reduce immobilization of Phosphorus (P) by 70-80%. They make available 10-12 kg N/acre, 8-10 kg P/acre and 6-8 kg K/acre. Other liquid biofertilizer produced by KRIBHCO include *Acetobacter* biofertilizer, *Azospirillum* biofertilizer, *Azotobacter* biofertilizer, *Rhizobium* biofertilizer, potash mobilizing biofertilizer (KMB) and Zinc biofertilizer. Each liquid biofertilizer of 500 ml contains 5×10^{10} viable bacteria. Acetobacter is recommended for use in Sugarcane. It provides nitrogen equivalent to 2-3 bags of urea. *Azospirillim* is recommended for use in rice and jute, *Rhizobium* for legumes and *Azotobacter* for use in fruit and vegetable crops. Both of them fix nitrogen equivalent of one bag of urea. KMB biofertilizer makes available 6-8 kg K/acre and growth hormones. It increases yield by 20-30%. Zinc solubilizing biofertilizer makes available 1-2 kg Zinc per acre. KRIBHCO has sold 8.3 lakh litres of liquid bioferilizers in 2021-2022 (Krishak Bharati Cooperative Limited 2021). They were awarded for their leadership in production and promotion and marketing of biofertilizers by Fertilizer Association of India (FAI) (Krishak Bharati Cooperative Limited 2021). KRIBHCO has taken initiatives for farmer mass connect through mass media (Krishi Darshan) and social media, participation in farmer fairs/expo, distribution of materials, association with village level cooperative societies) (Krishak Bharati Cooperative Limited 2021).

Public sector biofertilizer producing company, National Fertilizers Limited (NFL) sells biofertilizers under brand name ‘KISAN”. Its Vijaipur, Madhya Pradesh based plant has installed capacity of 600 tonnes of solid and liquid biofertilizer for four strains- PSB, ZSB, *Rhizobium* and *Azotobacter*. NFL sold 528 MT of biofertlizers in 2020-2021 of both solid carrier based and liquid biofertilizers. It undertakes orientation program for farmers, dealers to sensitize them towards soil health and importance of use of biofertilizers. It also conducts biofertilizer trials on farmer fields (National Fertilizers Limited 2021).

The Fertilizers and Chemicals Travancore Limited (FACT). It produces and sells solid carrier based biofertilizers. BIOFACT-*Azospirillum*is recommended for use in all crops. It fixes 20-25 kg nitrogen/hectare over a period of two years. Sustained application of this biofertilizer can reduce dependency on nitrogen chemicals by 20-25%. BIOFACT-*Rhizobium*is recommended for use in legumes. BIOFACT-Phosphate Solubilizing Bacteria solubilizes the immobilized phosphorus and makes it available to the plants in a usable way (www.fact.co.in).

Indian Council for Agricultural Research`s (ICAR) state agricultural universities, (SAUs) produce solid carrier and liquid biofertilizers and make it available to the farmers through ICAR`s Krishi Vigyan Kendras (KVKs) and Farmer Advisory Service Centres (FASCs) (www.icar.org)

Other public and private sector biofertilizer producers having market presence include Indore Biotech Inputs and Research Pvt Ltd, Jaipur Biofertilizers Ltd, KCP Sugar and Industries Cooperative Ltd, Multiplex Biotech Karnataka, Agro Biotech Research Centre Kerala, TN Cooperative Sugar Fed, Gujarat Agro Industries Corporation, KAN Biosys Pune. Biofertilizers produced and sold by these units are both bacterial and mycorrhizal biofertilizers for macro and micro nutrient acquisition (nitrogen, phosphorus, potassium, zinc), plant growth promotion (PGPR) and drought stress. Consortium and single culture biofertilizers contain organisms as *Azotobacter, Acetobacter*, *Azospirillum*, *Pseudomonas*, *Thiobacillus*, *Bacillus*, *Gluconacetobacter*, *Herbaspirillum*, *Burkholderia*, *Glomus*, etc. These products are available in both solid granular form as well as liquid form. In addition, the culture of these bio-inoculants can be used to bio-priming the seeds of crops. They are recommended for use in cereals and cash crops, vegetables, fruits, legumes and flowering plants. Biofertilizer application of these is claimed to reduce chemical fertilizer application by as much as 25% (Khurana and Kumar 2022).

4) Entrepreneurship hurdles and remedies-

Biofertilizers are products which contain viable or living beneficial micro-organisms. These products are mandated to contain a threshold number of these living beneficial organisms which then extend the intended benefit. Their being biological in nature makes transport, marketing and storage cumbersome. This problem is compounded by the lack of logistics and supply chain for biofertilizers in India. Infrastructure development and development of a supply chain can facilitate consistent and easy availability of biofertilizers to farmers. Further, consumer confidence in biofertilizers is inspired by robust microbial strains which extend visible and significant benefit to the farmer. But microbial strains do not work across terrains. Instead, they work in native soils only. Remedy to this lies in quick and smooth technology transfer of select strains from laboratories to field. Slow technology transfer impedes the growth of this industry (Bharati and Suryavanshi 2021).

Bacterial biofertilizers form symbiotic association with the host plant as in *Rhizobium*-legume association or they may be free living as *Azotobacter* in cereals and vegetables or they may be non-symbiotic associative as *Azospirillum* in cereals. These crops are seasonal and so is the demand for their biofertilizers. This seasonal nature of biofertilizer demand discourages entrepreneurship. Also, mycorrhizal biofertilizers though promising, present a technical challenge. These fungi cannot be grown *in vitro* or laboratories conditions because they are obligate symbionts which thrive in the root tissue of the host plant. As a result, their mass production is difficult to undertake. Mycorrhizal fungi produced by crushing roots of host plant may possibly contain unwanted or even potentially pathogenic fungi (Vosátka et al 2012).

Largely, mycorrhizal *Glomus* strains is used. It helps in nutrient acquisition and drought stress tolerance. Other mycorrhizal inoculants contain spores of *Rhizofagus irregularis*, *Funneliformis mossae*, and *Claroideoglomus etunicatum* for improved fruit production (Amir et al 2020).

Biofertilizer products and their sale market are highly unorganized and unregulated. It poses a major obstruction in the form of lack of quality assurance of biofertilizer products. Lack of quality check laboratories facilitates passage of spurious products into the market. These products do not extend said benefit which eventually erodes farmer confidence. To counter this, Government of India has formulated quality control specifications for 11 biofertilizers through its Fertilizer Control Order (FCO) which was revised in 2015 (Aamir et al 2020; Khurana and Kumar 2022).

Quality control of biofertilizers can also be developed by setting up quality assurance labs and regulating quality of the product being sold in the market. Monitoring and rigorous inspection of biofertilizer manufacturing units for frequent sampling and quality checks, mandatory quality assurance certification can encourage farmer confidence in the biofertilizer product. Government owned quality assurance labs with trained and qualified personnel should be set up and made functional in all states and prominent cities for easy and quick testing of the biofertilizer product. Non compliance to quality standards should be made a punishable offence.

Government of India offers heavy subsidy for chemical fertilizers which discourages the farmer from looking for alternatives to the chemical fertilizers. However, this may be thing of the past considering recent measure of phased withdrawal of subsidy and also the resultant paucity of chemical fertilizers in the market. This scenario can be manoeuvred to provide much needed impetus to biofertilizer market. In addition, Government of India and also various State Governments have been taking steps to promote biofertilizer market both at the level of the user-farmers and at the producer-investor level by taking certain measures- (i) farm level outreach and extension programs to promote biofertilizers (ii) financial aid to investors in setting up manufacturing units (iii) subsidies on biofertilizer sales (iv) direct biofertilizer production in public sector units, cooperative organizations and in national, state universities and research institutions.

Also, Government of India is taking steps to formulate a targeted and funded national program to promote organic and natural farming both of which revolve around biofertilizers. As part of this, biofertilizer production units have been extended government aid. Factually, biofertilizers production units located in different Indian states can be categorized in two groups; (i) units financed by Government of India (GoI) (ii) units financed by other sources. Sixty-four biofertilizers production units have been established with the GoI support. They have over 900 tonnes of total installed production capacity and over 600 tons of the total biofertilizers production. Thiry-eight of these biofertilizers production units have low total installed production capacity in the face of potential demand of 235 thousand tons for bacterial biofertilizers (Khurana and Kumar 2022).

During the Ninth Plan, Government of India formulated and implemented a central scheme National Project on Development and use of Biofertilizers (NPDB) for the production, distribution and promotion of biofertilizers. A National Biofertilizers Development Centre (NBDC) was established at Ghaziabad as a subordinate office named National Centre of Organic farming (NCOF), of the Department of Agriculture and Cooperation, Government of India. NCOF has seven regional centres named Regional Centres of Organic Farming (RCOF). Soil health management scheme should be enforced nationally to guide farmers on the status of their soil health parameters and suggest interventions for optimizing soil health parameters. However, better monitoring of government funded schemes is desired.

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5) Future prospects-

The most important factors which can influence biofertilizer market footprint is farmer awareness and technology adoption. Farmer outreach programs conducted at village level can sensitize them towards benefits of using biofertilizers and share information about the adverse environmental effects of using chemical fertilizers. All stake-holders primarily central and state governments, agricultural scientists and farmers and civil society must play a role in popularizing biofertilizers.

Consistent availability of good quality biofertilizer compliant to FCO standards can provide the essential NPK to the crops without leaving any adverse environmental footprint. Biofertilizers are cheap and easy to use. In addition to nutrient acquisition, they play a role in replenishing soil health and restoring soil physical properties. Better crop health translates into higher yield which is often under-emphasized because of farmer dependency on chemical fertilizer. In addition, an interplay of subsidies and incentives by the government to farmers can go a long way to promote organic farming with PGPR bacterial and mycorrhizal biofertilizers. With this multi-pronged strategy, biofertilizer use can be increased in India.

Alongside, biofertilizer production can be sold as a small scale business idea to attract potential entrepreneurs. Technology incubation centres set up by public sector institutes and educational institutes can be made available to for production by new start ups. Many studies have been conducted on use of natural media for biofertilizer production. Many natural media like extract of agricultural residues, molasses, vegetable-fruit waste, whey, high organic waste water as dairy waste water, etc have proven to support the growth of bacterial biofertilizers. Using these wastes can economize the production process, solve the waste disposal problem and generate a useful product.

6) Conclusions-

The projections show that to feed world population of 9.1 billion in 2050, the world food production would have to increase by 50% from the current level. Developing countries would need to double their production. Annual cereal production world have to increase by one billion tonnes and meat production by 200 million tonnes.

The high yield of newly bred varieties is sustained by high chemical application. Consequently, the world consumption of the three main fertilizer nutrients, nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), is increasing. Rampant use and often overuse of these chemical fertilizers compromises the soil fertility and productivity. Alternatives to this intensive agriculture are natural and organic farming. These terms are often used inter-changeably as both of them advocate the use of biological tools as biofertilizer to sustain yield and environment.

Biofertilizer are environment friendly and easy to use products. They increase soil health and crop yield. Their effect is subtle and not immediately visible after application. This is possibly a road block in their adoption by the farmer. Also, biofertilizer production and market is relatively unorganized compared to the chemical fertilizer sector. Therefore, it does not receive the amount of attention which it deserves. Central and state governments must make concerted efforts to educate and promote biofertilizers and to support the production units. Biofertilizer adoption and their consistent available at village level can be the much required catalyst for enhancing production and application of biofertilizers.

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