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Study:

Biofertilizers in China

A Potential Strategy for China's Sustainable Agriculture

Current Status and Further Perspectives

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1. Introduction

In the past 30 years, Chinese famers have applied up to 30 percent of the world's fertilizers and pesticides on 9 percent of global cropland to feed 20 percent of the world's population. The overuse of agricultural chemicals and the low utilization efficiency in agricultural production have led to increasingly serious adverse effects regarding financial losses, food safety, energy consumption and environmental pollution. Acknowledging the urgency, the Chinese government has launched a series of action plans since 2015, such as the action plan to achieve *Zero Growth in the application of Chemical Fertilizers and Pesticides by the year 2020*.

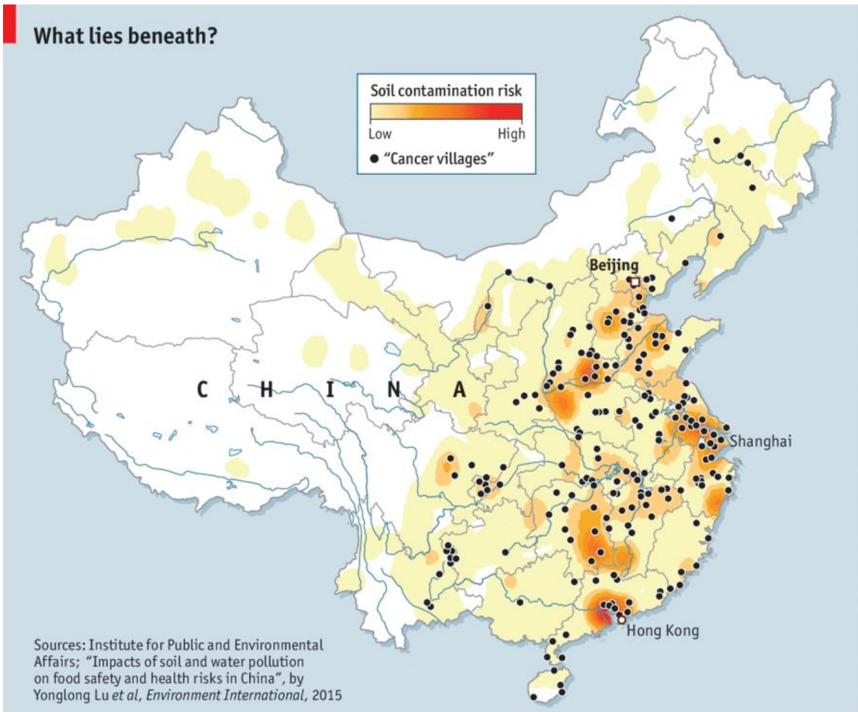
Functional agricultural microorganisms can help plants directly or indirectly by improving nutrient availability in soils, producing plant-growth promoting substances or antibiotic materials. Therefore, they possibly could contribute to promoting the development of sustainable agriculture in China only by reducing the application of agricultural chemicals. **Biofertilizers**, a type of fertilizers prepared from one or more beneficial microorganisms with specific functions, will play a more and more prominent role in China's sustainable agriculture.

The research and application of biofertilizers in China started as early as in the 1950s. By the end of 2018, after a development of nearly 70 years, there are over 6,528 biofertilizer products available, using over 170 functional microbial species/strains, which are registered under 11 generic names by over 2,050 companies (including 28 international companies) [1]. The application of biofertilizers has shown promising results and the potential to reduce chemical fertilizers (by 20% - 50%) without decreasing grains yields [2]. Recently, the promotion of biofertilizers has been implemented as a strategy into the '*National Development Plan for Bioindustry*' in 2013 [3]. This offers great opportunities for the development of a biofertilizer market in China.

Since the implementation of a registration management on biofertilizers in 1996, the Chinese biofertilizer industry started to form up. After nearly 24 years of stable and rapid development in this industry, it has entered a special period where scientific innovation is most desired and extremely urgent. In order to develop strategies for the *National Green Agriculture Development* and *Rural Revitalization*, more and higher requirements have been imposed on the biofertilizer industry. Research and development of new products, new beneficial strains, new fermentation technologies and new functions have become the industrial development goals in the new era. Based on an analysis of the status quo of China's biofertilizer industry in recent years, this report puts forward new industrial development requirements such as new product and technology directions for the next step of industry development, especially around the realization of industrial development goals. It is necessary to accelerate innovation efforts to provide a strong driving force to promote the healthy, stable and sustainable development of the Chinese biofertilizer industry.

2. Background of the study

Over the past 30 years, China has achieved an agricultural miracle by producing enough food to feed the vast majority of its 1.4 billion people. However, this could mainly be achieved with the highest consumption of chemical fertilizers and pesticides in the world. At present, Chinese famers apply about 30 percent of the world's fertilizers and pesticides on 9 percent of global cropland [3]. According to the data from the National Bureau of Statistics, by 2015 China's agricultural chemical fertilizer consumption exceeded 60 million tons, the highest level in history [4]. The use of chemical fertilizers and pesticides greatly contributed to a considerable increase of grain production, but it came at a tremendous cost for the environment [5]. Fertilizers, such as nitrogen fertilizer, helped to increase crop production but have also acidified soil, polluted water and contributed to global warming. The soil health conditions are getting worse and worse, at present, more than 40 percent of China's arable land is degraded.



Impacts of environmental pollution on human health [5]. Source: Lu et al., 2015, environment international

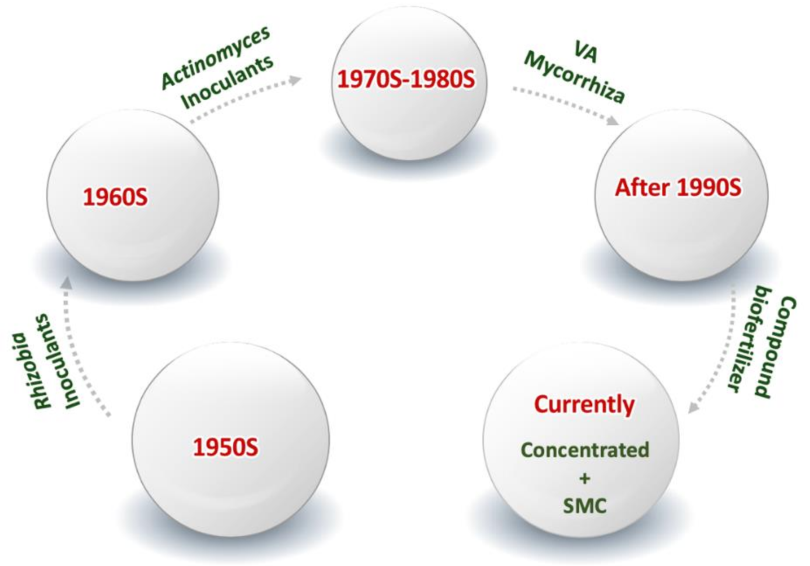
China is currently facing three major soil health obstacles: slow conversion of nutrients, accumulation of pollutants, and soil-borne diseases. This situation determines that China needs to develop, promote and use biofertilizer products more than ever in the new era. What is the current status of biofertilizer industry development in China? What's the future? What opportunities and challenges will the fertilizer industry face?

Crop productivity largely depends not only on the structural and nutritional status of soils, but also on the microbial composition and activities in soils, specifically rhizosphere soils. In 2013, the book "*How microbes can help feed the world*" [2], pointed out that by regulating soil microbial flora, crop yields could be increased by 20 percent and at the same the use of fertilizers and pesticides could be reduced by 20 percent. Biofertilizers have attracted widespread attention in China due to their special characteristics, including the ability to improve soil fertility, save costs, enhance the utilization efficiency of chemical fertilizers and by this promote green environmental protection. According to the standards for biofertilizer products (NY/T 1847-210), there are six functions of biofertilizers: to provide or activate nutrients, to develop the ability to promote active substances in crops, to promote the decomposition of organic materials, to improve the function of agricultural products, to enhance the resistance of crops, and to improve and restore soil functions. It has become one of the irreplaceable magic weapons for the development of green ecological agriculture. At present, microbial fertilizers have already become preferred fertilizers on cash crops such as vegetables, fruit trees, tea, Chinese herbal medicine, etc., and the annual application area in the country exceeds 1.8 million ha, which has obtained huge economic, social and ecological benefits.

In recent years, the Chinese government has promoted the development of biofertilizers by various effective measures. In 2012, the *'Bioindustry Development Plan'* was promulgated and implemented; in 2015, biofertilizers were included as well in the '*Agricultural Biological Products Development Action Plan*'; the former Ministry of Agriculture formulated the *'Zero Growth Action Plan for Chemical Fertilizer Use by 2020'* which specified the technical path of '*organic fertilizer replacement for chemical fertilizers'*. The plan further proposed the *'one control, two reductions, and three basics'* goal, and strives to achieve zero growth in the application of chemical pesticides and fertilizers [6]. The role of microbial fertilizers will become more and more prominent, and it is of great significance to realize the strategy of *"food crop production strategy based on farmland management and technological application"*, which is a strategy of sustainable farmland use and innovative application of agricultural technology to increase farmland productivity. It was proposed by Chinese President XI Jinping in 2015 [7] to ensure national food security, agricultural product quality security, and agricultural ecological security.

3. Development of biofertilizers in China

The commercial history of biofertilizer in the world started with the launch of 'Nitragin', a laboratory culture of Rhizobia by Nobbe and Hiltner in 1895[8]. The research and application of microbial fertilizer in China is similar to that in the world. It also started from the application of *Rhizobium* inoculants on leguminous plants. During the 1950s and 1960s, under the leadership of soil microbiologist Professor ZHANG Xianwu from Chinese Academy of Sciences rhizobium inoculants became the most widely used microbial fertilizer products. The inoculation area was very large, and the soybean rhizobium inoculation technology increased the average yield of soybeans by more than 10 percent. When China introduced autogenous nitrogen-fixing bacteria, phosphorous bacteria, and silicate bacterial agents (commonly known as bacterial fertilizers) from the former Soviet Union in the 1950s, Chinese biofertilizer industry started to enter a new period of bacterial fertilizers. In the 1960s, Professor YIN Xinyun from Chinese Academy of Agricultural Sciences isolated an *Actinomycete* strain '5406' from the rhizosphere of alfalfa in Shanxi province to make a widely used bacterial fertilizer '5406' with antibiotic and nitrogen-fixing function, which promoted the further development of microbial fertilizer in China. In the mid-1970s and mid-1980s, a kind of biofertilizer with Vesicular-Arbuscular Mycorrhiza (VAM) was first studied and applied, resulting in significant effects in improving plant phosphorus nutritional conditions and increasing water use efficiency. From the mid-1980s to 1990s, associate nitrogen-fixing bacteria and compound bacteria agents have been successively used as seed dressing agents in agricultural production.



The different stages of the Chinese biofertilizer industry development. Source: own illustration, 2020. (VA: Vesicalar Arbuscular; SMC: Synthetic microbial community)

In recent decades, with the advancement of technology, China's biofertilizer industry developed rapidly. By the end of 2019, the number of registered biofertilizer products has reached 7,000 with a total production amount of 30 million tons. As biofertilizers have attracted more and more attention, they are now becoming the most important fertilizers for agricultural production in national ecological demonstration zones, green and organic agricultural production bases at various level, where the annual application amount accounts for about 50 percent of the annual output of biofertilizers, i.e. more than 15 million tons[1,9].

The first definition of biofertilizer in Chinese has been provided by Professor CHEN Huakui, a famous soil microbiologist from Huazhong Agricultural University [10]. It refers to a specific type of fertilizer product containing live microorganisms, which can be used in agricultural production to obtain a specific fertilizer effect. In the production of this effect, liv microorganisms in the product play a key role. Products meeting the above definitions should be classified as microorganism fertilizer. The National Standard (GB20287-2006, *Microbial Inoculants in Agriculture*) and the Agricultural Industry Standard (NY/T 1113-2006, *Terms of Microbial Fertilizer*) define biofertilizers as products containing specific microbial living organisms, which are used in agricultural production in order to increase the supply of plant nutrients or promote plant growth, increase yield, improve agricultural product quality and agro-ecological environment.

4. Current status of the biofertilizer industry in China

In recent years biofertilizer production has increased significantly, fertilizer quality has been improved, and especially the impact for the protection of the ecological environment is increasingly recognized. At the same time, the government has also supported policies and funds, and formulated a series of industry standards to regulate and monitor production. In 1994, China issued the *'Biofertilizer Standard'* by the Ministry of Agriculture, which puts forward specific requirements for the technical requirements and testing methods of biofertilizers. This has been the first standard for China's biofertilizer industry, and over the years has been subject to a series of changes. It played a positive role in supervising and guiding the market, guiding scientific research, and improving quality and safety of biofertilizer products. In recent years, benefiting from national policies and industrialization projects, the biofertilizer industry has developed rapidly. It has formed a scale of more than 3000 producing enterprises with an annual output of 30 million tons and an output value exceeding 40 billion RMB Yuan. Thus, becoming an important contributor to China's agricultural biological industry. The application of microbial fertilizers in China ranges from legumes and other vegetables to tobacco, trees, flowers, and other economic and ornamental plants, and therefore occupies an increasingly important position in agricultural production.

Compared to the international microbial fertilizer industry, China's microbial fertilizer industry has several major characteristics:

1. There are many types of products. Compared with other countries, China has many types of microbial fertilizers and many types of bacterial products, especially in the development of microorganisms. China is leading in terms of new products that are compounded with organic nutrients, microorganisms and inorganic nutrients.
2. The application area is large. The cumulative application area of biofertilizers has reached 13.3 million ha, covering almost all agricultural crops [11]. Good results have been achieved in terms of improving the utilization rate of chemical fertilizers, reducing the amount of chemical fertilizers and reducing environmental pollution caused by excessive use of chemical fertilizers.
3. The production scale is large. At present, China has developed a large production scale with a production capacity of more than 30 million tons [11].
4. Technological innovation urgently needs to be improved. Research and development therefore have broad prospects. The problems of finding new functional strains, promoting scientific and reasonable processes, improving product quality, reducing production costs, and stablizing application effects are still issues that China's microbial fertilizer industry is facing and urgently need to be solved.

5. Description of different kinds of biofertilizer

Biofertilizers enrich soils with nutrients for plant growth through natural processes such as fixing atmospheric nitrogen, solubilizing phosphorus, and stimulating plant growth through the synthesis of growth-promoting substances. Chinese biofertilizers have many different product types which can be categorized in different ways according to their nature and function. At present, the types of biofertilizer products registered in the Ministry of Agriculture and Rural Affairs (MARA) include agricultural microbial inoculants, microbial organic fertilizers, and compound microbial fertilizers according to the nature and complexity of nutrient content.

1. **Microbial inoculants (GB 20287-2006)**
    - *Rhizobium inoculant*
    - *Azotobacteria inoculant*
    - *Inoculant of phosphate-solubilizing microorganism*
    - *Silicate bacteria inoculant*
    - *Inoculant of Photosynthetic Bacteria*
    - *Organic matter-decomposing inoculant*
    - *Inoculant of plant growth-promoting rhizosphere microorganism*
    - *Multiple species inoculant*
    - *Mycorrhizal fungi inoculant*
    - *Bioremediating inoculant*
2. **Compound microbial fertilizer (NY/T 798-2015)**
3. **Microbial organic fertilizers (NY 884-2012)**

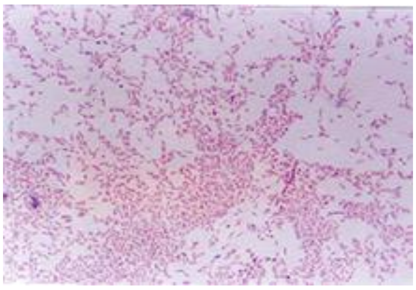
Among the registered products, various functional microbial inoculant products accounted for about 40 percent of the total number of registrations, and compound microbial fertilizers and microbial organic fertilizer products each accounted for about 30%, whereas more than 170 strains were used, covering bacteria, actinomycetes, and Fungi categories.

Different kinds of biofertilizers. Source: Deng Zuke from Beijing AMMS Company.

A. *Rhizobium inoculant*

Rhizobium sp. are symbiotic nitrogen-fixing bacteria which assimilate and fix atmospheric nitrogen in root nodules, formed in the roots of leguminous plants. These bacteria infect the roots of leguminous plants, leading to the formation of “lumps” or “nodules” where the nitrogen fixation takes place. The bacterium also produces enzymes (nitrogenase) that supply a constant source of reduced nitrogen to the host plant. The *Rhizobium* inoculants are available as in carrier-based powder formulation and also in liquid formulation.

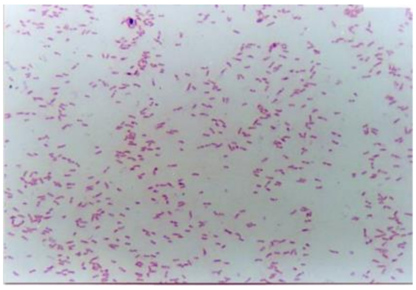
Peanut



Rhizobium arachis

Source: Deng Zuke from Beijing AMMS Company

Soybean



Bradyrhizobium japonicum

Source: Dr. Jiang Xu from Chinese Academy of Agricultural Sciences

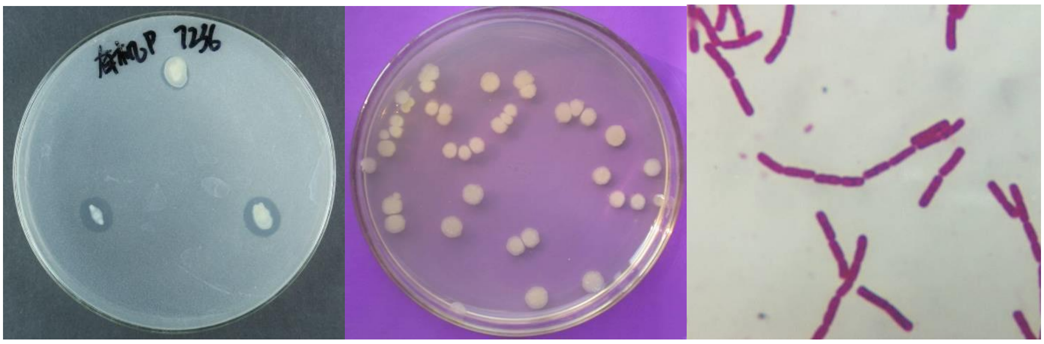
B. *Azotobacterial inoculant*

Azotobater strain bacteria produce growth promoting substances which improve seed germination and the growth of an extended root system. They produce polysaccharides which improve soil aggregation. *Azotobacter* suppress the growth of saprophytic and pathogenic microorganism near the root system of crop plants.

Azotobacter chroococcum. Source: Zhou Yiqing from CAAS.

C. ***Inoculant of phosphate-solubilizing microorganisms***

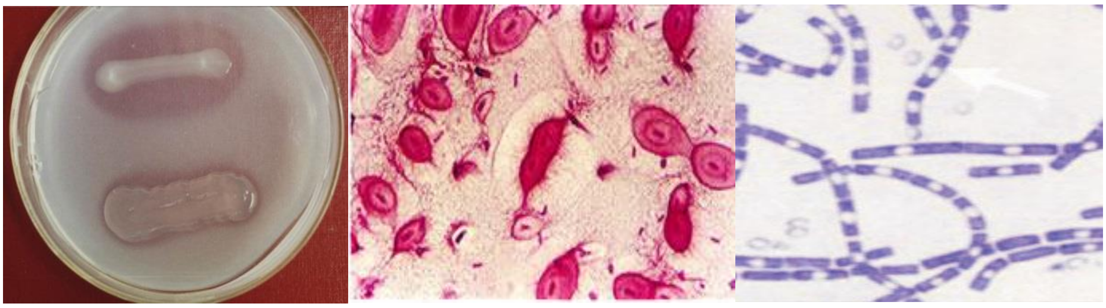
In the rhizosphere of crops***, inoculants of phosphate-solubilizing microorganisms*** make insoluble soil phosphate available to plants by producing and secreting organic acids. The use of this kind of biofertilizer will also increase the availability of phosphate from rock phosphate when applied directly even to neutral to alkaline soil or when used for preparation of phosphor compost. Phosphate solubilizing microorganisms include efficient strains of bacteria and fungi, like *Bacillus megaterium* and *Penicillium* sp.



Bacillus megatherium. Source: Xu Biao from Shandong Tumuqi Company.

D. ***Silicate bacteria inoculant***

Silicate bacteria is a beneficial bacterium capable of mobilizing potassium in the soil root zone of plants. It works well in all types of soil. Using such bacteria in powder form can increase the availability of potash in usable form to the plants, which stimulates flowering and fruiting, improves soil properties and sustains soil fertility.



Paenibacillus mucilaginosus. Source: Zhiyong Ruan.

Biofertilizers are subject to stringent safety evaluation including microbial species/strain identification and toxicological tests of functional microorganism and final products. By the end of 2018, more than 170 functional microbial strains were used in over 6,500 biofertilizer products. In all safe strains allowed to be used in biofertilizer manufacturing, strain *Bacillus subtilis* is the most popular one, followed by strain *Paenibacillus* ***mucilaginosus*** and strain ***Bacillus amyloliquefaciens*** (table 1).

Table 1: The top 5 most used strains in Chinese biofertilizer products [12] , own translation.

Name of strains	Percentage（%）
Bacillus subtilis	65.9
Paenibacillus mucilaginosus	23.2
Bacillus amyloliquefaciens	18.5
Bacillus licheniformis	17.9
Bacillus megaterium	9.0

To ensure product quality, China has accelerated the selection of technical parameters and the development of testing methods and compiled them in product executive standards such as national or industrial standards. Only biofertilizers which meet the technical criteria of the standards can be registered under the corresponding generic name.

Table 2: Technical criteria to the product quality standard for Chinese biofertilizers [13]
GB 20287-2006, Microbial Inoculants in Agriculture [S]
Contaminants refer to any those non-target effective living microbes found in the products.

Parameters		**Form**		
		Liquid	**Powder**	**Granule**
Effective living microbes 100 million CFU/g(mL)	≥	2.0	2.0	1.0
Number of mold CFU/g(mL)	≤	3.0×10^6	3.0×10^6	3.0×10^6
Contaminants rate (%)	≤	10.0	20.0	30.0
Water Content (%)	≤	-	35.0	20.0
Fineness	≥	-	80	80

(%)				
pH Value		5.0~8.0	5.5~8.5	5.5~8.5
Shelf life （Month）	≥	3	6	

6. Application

Biofertilizers are ready-to-use of such beneficial microorganisms, which upon application to seeds, roots or soil, mobilize nutrients by their biological activity in particular, and help to improve microflora and, in turn, soil health in general, which consequently benefits crops. Biofertilizers are designed to improve soil fertility with regard to nutrients such as nitrogen, phosphate and potassium. They also provide growth promoting substances, leading to an average increase in crop yields by 20 to 37 percent[10,14]. Algae-based fertilizers enhance rice yields at rates ranging from 10 to 45 percent [15]. Different types of biofertilizers can be used in different ways:

1. How to use liquid biofertilizers

(1) Used on seeds

i. *Seed dressing: Immerse the seed in a 10-20 times diluted microbial inoculant solution or spray the seed wet with the diluted solution before sowing, so that the seed is in full contact with the liquid biological bacterial agents before sowing.*
ii. *Seed soaking: soak the seeds with a suitable amount of fungus agent, remove them to dry, and sow the seeds when they are exposed.*

(2) Used on seedlings

i. *Dip the root: Dilute the liquid fungus 10-20 times. Before transplanting the seedlings, immerse the roots in the liquid and take it out immediately.*
ii. *Root spraying: When there are a lot of seedlings, put the 10-20 times dilution into the spray barrel to spray the roots.*

(3) Used during the growing period

i. *Spraying: Foliar topdressing can be carried out during the crop growth period. After the liquid fungicide is diluted by the required multiples, it should be sprayed on the back and front of the leaves evenly on a cloudy day without rain or after a sunny afternoon.*
ii. *Irrigate roots: stir the roots or irrigate the roots of fruit trees according to the dilution ratio of 1: 40-100.*

2. How to use solid biofertilizers

(1) Use on seeds

i. *Seed dressing: spray seeds with water or millet soup before sowing, mix with solid bacteria and mix thoroughly, so that all seeds can be sown when covered with a layer of solid biological fertilizer.*
ii. *Seed soaking: After soaking the solid bacteria for 1 to 2 hours, soak the seeds with the leaching solution.*

(2) Use on seedlings

i. *Dilute the solid fungus agent 10-20 times. Immerse the roots in the diluent before transplanting the seedlings and take them out immediately.*

(3) Mix fertilizer

i. *Every 1000 grams of solid bactericide is mixed with 40-60 kg of fully decomposed organic fertilizer before use. It can be used as base fertilizer, top dressing and seedling fertilizer.*

(4) Mix the soil

i. *It can be mixed with nutrient soil to make a nutrient bowl when seedlings are cultivated. It can also be mixed with thin mud to dip roots into the substrate before transplanting seedlings such as fruit trees.*

3． Application of microbial organic fertilizer

(1) As base fertilizer

i. *For field crops, the microbial organic fertilizer could be used as base fertilizer with the usual amount of about 500-1800 kg per ha according to the nutrition requirement of different crops; the farm manure could be applied at the same time for the base fertilizer. For cash crops or greenhouse crops, the application amount could be increased to a higher level in accordance with local planting habits.*

(2) As topdressing

i. *Compared with chemical fertilizers, microbial organic fertilizers are more nutritious and have a longer but slower fertility efficiency. Therefore, microbial organic fertilizer should be applied as topdressing 7-10 days earlier than chemical fertilizer, using the equivalent amount compared to chemical fertilizer.*

Application of biofertilizer products in agricultural production. Source: Deng Zuke.

7. Case studies from China

The use of biofertilizer products in crops is becoming more and more widespread, most widely used with cereals, followed by oilseeds, vegetables and fiber crops. Due to differences in physiological characteristics, growth environment, and management methods of different crops, the effects of biofertilizers on the yield of different crops vary greatly. A lot of case studies on biofertilizers have been carried out in China in the past years. As biofertilizer products have been widely used in crops like rice, wheat, corn, and on vegetables like cabbage, cucumber, corn, tomato, soybean, pepper, bitter gourd, cabbage and fruit trees like apple, orange, grapes, a lot of good results have been obtained in these studies.

1. Application of biofertilizer product on grapes has achieved great success

The application of the biofertilizer Duoweiwang, manufactured by Century AMMS company (Beijing), on grape in Linwei District of Weinan City, Shaanxi Province resulted in high yield, high sugar content, good fruit shape and increased commodity rate. The farmers had a reward of increased 3,306 RMB (about 430 Euro)/mu (unpublished data).

Treat	Color	Single fruit weight (g)	Average sugar content (%)	Production (kg)	Production of commodity fruit (kg)	Commodity rate %
Biofertilizer*	Good	13.1	16.1	3360	3090	91.96
CK*	Slightly worse	11.6	14.5	3090	2710	87.70
Increasing	—	+1.5	+1.6	+9%	+14%	+4.26

Biofertilizer: A biofertilizer named Duoweiwang manufactured by Century AMMS Company (Beijing)*
CK: A traditional organic fertilizer*

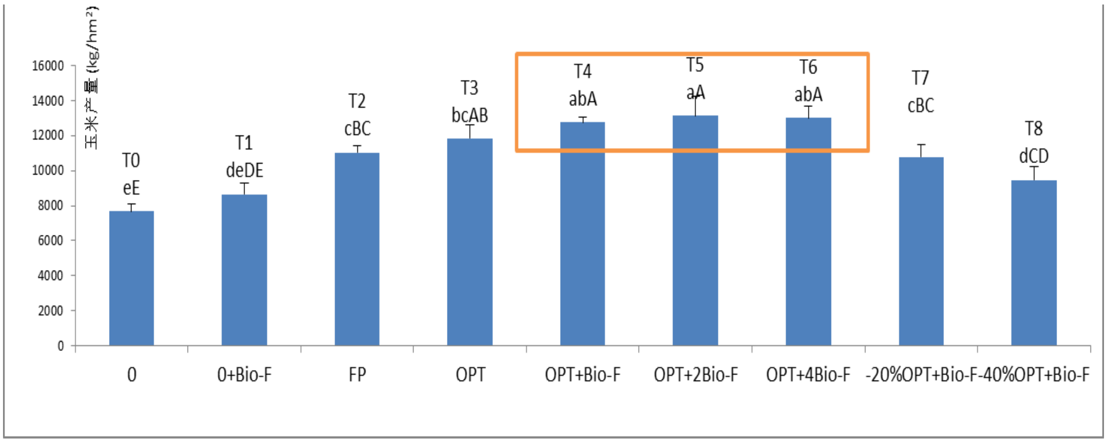
Biofertilizer product applied on grape trees (data and photos courtesy of Mr. DENG Zuke from Beijing AMMS Company)

The biofertilizer and traditional organic fertilizer with the amount of 160 kg had been used respectively in this experiment per mu (equal to 1/15 ha), 230 kg chemical fertilizer also had been used in this experiment.

2. *Application of biofertilizer product on corn has achieved great success*

A biofertilizer named ‘woke’ manufactured by Century AMMS company (Beijing) has been applied on corn in Heilongjiang province in different treatments collaborated with Heilongjiang Academy of Agricultural Sciences. The output of treatment 4 (T4, optimized fertilization + biofertilizer with recommended amount), T5 (optimized fertilization + biofertilizer with 2 times of recommended amount), and T6 (optimized fertilization + biofertilizer with 4 times of recommended amount) were 12746.32 kg/ha, 13123.64 kg/ha, 13003.92 kg/ha. Compared with the optimized fertilization without using biofertilizer, the yield increases were 13.49 %, 15.97 %, and 15.20%, respectively. The recommended amount of biofertilizer (30 kg/ha) + optimized fertilization increased the number of soil bacteria. At the same time, the results of high-throughput sequencing showed that the number of beneficial microbes in the soil also increased.

Biofertilizer applied on corn. Source: Deng Zuke from Beijing AMMS Company.



Biofertilizer applied on corn. Source: Deng Zuke from Beijing AMMS Company.

8. Observed impacts

Biofertilizers have become an important alternative to chemical fertilizers and are also representing the majority of new varieties of fertilizers. They have an irreplaceable role in improving nutrient transformation and utilization, maintaining soil and plant health, increasing yield and efficiency, reducing the application amount and improving the efficiency of chemicals, while ensuring sustainable agricultural production capacity and green development.

The unique function of biofertilizers is determined by the characteristics and multifunctional effects of microorganisms. The impacts of biofertilizers on Chinese agriculture can be summarized in the following five aspects:

1. *Microorganisms help to maintain and improve soil fertility, eliminate problems such as soil degradation, unhealthy microbial community, low-quality aggregate, chemicals pollution in the soil, restore soil productivity, and maintain health and quality of soils;*
2. *Microorganisms in straw and other organic materials promote the effective utilization of organic materials;*
3. *Microorganisms in nitrogen fixation and activation of soil nutrients, provide nutrient supply and improve fertilizer utilization, to achieve the effects of reduced fertilization, efficient fertilization and economic fertilization;*
4. *Microorganisms help to overcome the obstacles such as over-use of chemical pesticides, poor growth of crops, hazardous materials accumulation and imbalance of microbial community during continuous cropping and improve the quality of crop products;*
5. *Application of microorganisms improves functions such as drought resistance, flood resistance, cold resistance, and disease resistance of crops.*

In order to achieve a higher demand for Chinese biofertilizer industry, technological innovation based on the “safe, high-quality, sustainable” features of green agriculture and the functional characteristics of microbial fertilizers are the key, especially the core work such as selection, evaluation and intellectual property protection of new functional strains. It can be concluded that with the beneficial impacts from biofertilizers, they are becoming the preferred inputs for China ’s green agriculture, and the development of green agriculture cannot go without biofertilizers in the future.

9. Potential ecological risks

With the rapid development of the biofertilizer industry, some risks have occurred. In addition to the potential pollutants such as heavy metals, antibiotics, and toxic and harmful substances in the raw materials, the biological safety of strains for manufacturing cannot be ignored. As the core ingredient of biofertilizer products, the safety of bacteria is the primary guarantee for product quality and safety. Currently, more than 170 species of microbes are used, but the classification status of many production strains is not clear or even confusing, and it is difficult to assess the preliminary security risks.

1. The potential risks from the microbes in the biofertilizer products

Although the current biofertilizer products are required to use plant growth-promoting rhizobacteria, the results from many studies in recent years have found that some strains from genus Bacillus also could produce toxins. Hemolysin genes have been detected in some popular strains for manufacturing, such as *Bacillus subtilis*, *Bacillus polymyxa*, and *Bacillus licheniformis*, even though they are listed in the strain safety classification list at the first safety level exempt from toxicological tests. A potential hazard cannot be ignored [12].

2. The potential risks from the raw materials for biofertilizer products

At present, the raw materials for the production of biofertilizers are mainly derived from agricultural waste such as livestock and poultry manure, and some companies use industrial waste, urban sludge, and domestic waste in violation of regulations. These raw materials may contain toxic and hazardous substances, and may also contain miscellaneous bacteria, viruses, and pests which will seriously endanger human health. The potential risks from the raw materials for biofertilizers production cannot be ignored [12].

Therefore, carrying out a biosafety risk assessment of the strains in biofertilizer products, clarifying the pollution status of harmful microorganisms in agricultural products, and keeping the strains safe from the source are not only the basic requirement for the quality and safety of biofertilizer products, but also an inevitable choice for the development of sustainable agriculture.

10. Economic risks

Compared with chemical and traditional organic fertilizers, the functions of biofertilizers are based on the inherent characteristics of the microorganisms. Biofertilizers are affected by viable number, metabolism, temperature, soil acidity and nutritional condition, interaction of microbial species, etc., thus the short term of ROI (Return-Over-Investment) of biofertilizers is inferior to chemical fertilizers and traditional organic fertilizers. The nutrition content in biofertilizer products usually has a relatively low level, therefore a larger amount will be required to satisfy the need for the growth of most crops, which will increase the cost of agricultural production.

For a long time, the basic research on bio-organic fertilizers has been weak, showing a low level of technology in production, simple production processes, and low technology content of products. The quality of some of the products cannot be guaranteed, mainly regarding the product's effective live bacteria. Due to the short retention time and shelf life of bacterial activity, the high cost and unstable quality of biofertilizers have severely affected the development of biofertilizer industry in China.

The poor acceptability of the biofertilizers among farmers may be attributed to:

- ✓ Inconsistent responses to the production of crops
- ✓ Poor quality of carrier-based products
- ✓ Sensitivity to temperature and short shelf life
- ✓ Non-compatibility with chemical seed dressers/fertilizers
- ✓ Poor organic carbon in soils
- ✓ Dependence for supply on government system

11. Current policies and standards in China

China now realizes the consequence of excessive use of chemical pesticides and fertilizers. In terms of industrial policy and industry orientation, the State Council released the '*Bio-industry Development Plan*' in 2013 to list biofertilizers as high-tech industries and strategic emerging industries. The National Development and Reform Commission has listed microbial fertilizers as one of the priorities for the development of modern agriculture and an '*Action Plan for Zero Growth in the Application of Chemical Pesticides and Fertilizers*' was launched in 2015. In the '*National Development Plan for Bioindustry*', biofertilizers have been included into the development action plan for agricultural biological product. The Chinese government will support and develop the biofertilizer industry in the 14th Five-Year Plan and beyond. All these policies and actions offer great opportunities for biofertilizers, and they are expected to account for about 15 percent of the total amount of fertilizers to be applied on an area of over 26.7 million hectares.

Since the implementation of registration management on biofertilizers in 1996, the regulatory framework for biofertilizers has been basically formed, consisting of a primary overarching standard, microbial species safety standard, product standard, method and technical specification. China has compiled a series of national standards on strain safety, product specification, terminology, labelling, testing method, technical specifications for inspection and evaluation. These standards form a multi-tiered system (table 3).

Category	Standard
Common Standard	NY 885-2004 Markings of Microbial Product in Agriculture
	NY/T 1113-2006 Terms of Microbial Fertilizer
Strain Safety Standard	NY 882-2004 Silicate-Dissolving Bacteria Culture
	NY 1109-2017 General Biosafety Standard for Microbial Fertilizers
Product Standards	NY 609-2002 Organic Matter-decomposing Inoculant
	NY 527-2002 Inoculant of Photosynthetic Bacteria
	GB 20287-2006 Microbial Inoculants in Agriculture
	NY 884-2012 Microbial Organic Fertilizers
	NY/T 798-2015 Compound Microbial Fertilizers
	NY/T 3083-2017 Concentrated Inoculant of Agriculture Microorganism
Method Standards	GB/T 19524.1-2004 Determination of Fecal Coliforms in Fertilizers
	GB/T 19524.2-2004 Determination of Mortality of Ascarid Egg in Fertilizers
Technical Regulations	NY/T 883—2004 Technical Regulation for Production of Agriculture Microbial Inoculants
	NY/T 1114-2006 Technical Specifications for Culture Medium of Microbial Fertilizers Experiment
	NY/T 1535-2007 Rule for Rational Fertilization-Microbial Fertilizer
	NY/T 1536-2007 Technical Regulation for Field Experiment of Microbial Fertilizer and Directory of Effect Evaluation
	NY/T 1735-2009 Technical Specification of Quality Evaluation for Rhizobial Strains of Inoculant
	NY/T 1736-2009 Technical Standard Specification of Strain Identification for Microbial Fertilizers
	NY/T 1847-2010 General technical requirements for production strain quality of microbial fertilizer
	NY/T 2066-2011 Differentiation for Strain of Microbial Fertilizer Production by PCR Method
	NY/T 2321-2013 Code of Practice for Inspection of Microbial Fertilizers
	NY/T 2722-2015 Technical Specification for the Decomposition Effect Evaluation of Straw-decomposing Inoculant

Table 3: The multi-tiered system of standards for Chinese biofertilizer industry (GB: National standard; NY: Agricultural Industry standard)

12. Outlook – Further perspectives

Although the development and application of biofertilizers in China has lasted for decades and has achieved rapid development in the past 10 years, there is still a lot of work to be done to enhance a continuous development of the biofertilizer industry. As far as the technological innovation of the biofertilizer industry is concerned, the following four aspects must be taken seriously to promote the development of the industry:

1. Isolation, screening, and expansion of new functional strains, and selection of functional strains with good crop compatibility, regional adaptability, and excellent production performance.
2. Optimize the combination of microbes for biofertilizer products, and the maintenance technology for activity of living microorganisms in products, so that different functional strains complement each other; also enhance the combination of strain and carrier function to achieve a stable effect.
3. Establish the system of effect evaluation, ecological effects evaluation, quality and safety supervision and inspection, and market promotion for biofertilizer industry.
4. The formation of awareness and culture of technology innovation in the biofertilizer industry.

It is necessary to accelerate innovation efforts to provide a strong driving force to promote the healthy, stable and sustainable development of the Chinese biofertilizer industry.

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Appendix – List of important publications (Chinese and English)

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