DEVELOPMENT AND APPLICATION OF BIOFERTILIZERS IN TAIWAN

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ABSTRACT

Taiwan is a subtropical island characterized by high temperatures and heavy rainfall. Intensive agriculture practices have served as a strong foundation for Taiwan's commercial and industrial "economic miracle." In recent years, agrochemicals (pesticides and fertilizers) have been extensively applied to obtain higher yield. Intensive application of agrochemicals leads to several agricultural problems and poor cropping systems. Farmers use more chemical fertilizers than the recommended levels for many crops. Excessive use of chemical nitrogen fertilizer not only accelerates soil acidification, but also risks contaminating groundwater and the atmosphere. Organic fertilizers offer a safe option for reducing agrochemical inputs. Biofertilizers are being developed in several laboratories in Taiwan over the years. Microorganisms including rhizobium, phosphate-solubilizing bacteria and arbuscular-mycorrhiza (AM) fungi are continuously being isolated from various ecosystems and their performance in the laboratory and field conditions are assessed. The extensive research program over the years on beneficial bacteria and fungi has resulted in the development of a wide range of biofertilizers, which not only fulfills the nutrient requirements of various crop species, but also increases the crop yield and nutrient composition. Many experiments in greenhouses and in field conditions have shown that several crops respond positively to microbial inoculations. In particular, successful rhizobial inoculants were applied to leguminous plants and AM fungi for muskmelons in order to increase the yield and composition. Multifunctional biofertilizers were developed to reduce about 1/3-1/2 of chemical fertilizer application. Enhancement and maintenance of soil fertility through microorganisms will be an important issue in future agriculture. Long-term conservation of soil health is the key benefit of biofertilizers, which in effect is the most sustainable form of agriculture.

Key words: Biofertilizer, N_2 fixing bacteria, VAM fungi, phosphate solubilizing bacteria, rhizobium

INTRODUCTION

This paper reviews briefly the different biofertilizers developed in some Taiwan laboratories over the years with major emphasis on microorganisms, including rhizobium, P-solubilizing bacterium, and mycorrhizal fungi, that were identified as suitable candidates to considerably fulfill the nutrient requirements of various crop species and are known to increase crop yield.

Taiwan experiences a humid, subtropical climate, with a mean temperature of around 20°C (November-April) and above 30°C (June-November). Rainfall is over 3,000 mm in the central region, 1,500-3,000 in the east coast, and 1,500-2,000 mm in the western region adjacent to mountains with frequent typhoons during summer and autumn which affect agriculture. Uncontrolled application of chemical fertilizer is a common practice in those areas. The estimated consumption of chemical fertilizer in Taiwan is about 1,140 thousand tons for 844 thousand hectares (Annual Agriculture Report 2003). However, many upland regions and lowland soils are less fertile and needs greater fertilizer input to sustain yields.

Taiwan agriculture is oriented towards intensive farming practices, and every effort is being made to shorten the growth period of each crop so that more crops can be grown during the following season. Intensive multiple cropping systems have drastically reduced the use of leguminous plants as green manure, since this requires longer growth period. Still, legumes such as soybean, peanut, mungbean, pea, etc. are planted but only as a part of an intensive multiple cropping system (Young and Chao 1983).

It is a well known fact that the crop root zone (rhizosphere) provides a unique microsite for the association of symbiotic and nonsymbiotic microorganisms (Young 1994). N_2-fixing and P-solubilizing bacteria have been well characterized from various soil types and aquatic environments (Seshadri et al. 2000; Garg et al. 2001; Berman-Frank et al. 2001; Young et al. 1982; Young and Cheng 1998; Young et al. 2003 a & b) and many isolates were found to be successful in improving crop yield (Subba Rao 1982; Young et al. 1988a; Young 1994). Hence, several beneficial microorganisms can effectively be used as a chemical fertilizer alternative to minimize the application of inorganic fertilizers.

Biofertilizers, which can be more appropriately called as 'microbial inoculants,' can be generally defined as preparations containing live or latent cells of efficient strain of nitrogen-fixing, phosphate solubilizing (either bacteria, fungi or algae) or any other beneficial activity derived from this process. This can be applied either to the seed and soil or to accelerate microbial processes in soil, thereby augmenting the availability of nutrients which can be easily assimilated by crop plants.

SELECTION AND DEVELOPMENT OF BIOFERTILIZERS

Rhizobial Inoculants

In Taiwan, research work on the selection of efficient rhizobial strains for inoculation started in 1958. Collection, isolation, and subsequent selection of effective rhizobial strains and its uses in agriculture have yielded fruitful results. Since marked variations were observed among rhizobial strains (Young and Chao 1983), Wu (1958) selected a number of pure rhizobial strains from lupin, alfalfa, peanut, crotalaria and soybean, and conducted a wide range of field experiments to select the most effective inoculants. Yield was significantly increased when lupin, alfalfa, peanut, and soybean were inoculated with selected rhizobial strains compared to those with non-inoculated plants.

After the 1980s, fast- and slow-growing soybean rhizobial strains were isolated and selected from Taiwan soils for inoculation (Young et al. 1982; Young and Chao 1983), and several effective isolates were deposited in the Culture Collection and Research Center (CCRC) of the Food Industry Research and Development Institute in Taiwan (CCRC 1991).

Few field experiments were conducted to determine the effects of single and mixed inoculations with rhizobium and Arbuscular-Mycorrhiza (AM) in six different tropical Taiwan soils (Young et al. 1988b). The results indicated that inoculation with rhizobial strains alone increased N_2 fixation and soybean yield in three out of six fields. Inoculations with rhizobial strain singly, or in combination with AM, without any N_2 fertilizer applications, significantly increased soybean yield from 5 percent to 134 percent in the field experiments. Results from the other experimental sites also showed that a mixed inoculum of rhizobium and AM can be an efficient biological fertilizer that maximizes soybean yields. The combined effect of the mixed inoculum was a striking finding in the field of biofertilization. AM might have provided the essential P for the growth of soybean plants.

P-solubilizing Microbial Inoculants

P-solubilizing bacteria (PSB) were isolated from various tropical soils in Taiwan. Aliquots of soil diluted in sterile water (1:10 soil/water) were plated on calcium phosphate medium (modified from Subba Rao 1982) for the isolation of P-solubilizing bacteria.

The basic research on P-solubilizing biofertilizers was successfully established during the 1990s in Taiwan (Young 1990; Chang and Young 1992; Young et al., 1998a & b; Young and Chen 1999; Chang and Young 1999; Young et al. 2000a & b; Liu and Young 2001; Young et al. 2003). Crop plants such as peanut, various horticultural plants, and vegetables were successfully inoculated with PSB to obtain higher yields. Several field experiments concluded that P-solubilizing bacteria not only improved the growth and quality of crops but also drastically reduced (1/3-1/2) the usage of chemical or organic fertilizers.

A-Mycorrhizal Inoculants

The major VAM fungi used as inoculant were *Glomus* spp. isolated from tropical soil of Taiwan (Young 1986). Chlamydospores were borne terminally on single undifferentiated hyphae in soil. The mature spores were separated from the attached hyphae by a septum. The AM fungal inoculant was placed in pots containing sterilized mineral attapulgite $[(Mg.Al)_5Si_8O_{22}(OH)_4.4H_2O]$ with *Zea mays* as the host plant. The VAM fungal inoculant used in pot experiments contained approximately 50 spores/g soil together with infected roots (Young et al. 1988).

Young et al. (1986) used two species of AM in a pot experiment to observe the effect of inoculation of AM fungi on the yield and mineral P utilization in soybean. The results showed that the AM fungi inoculation increased soybean yields over the non-inoculated treatments to a certain extent depending on the soil type. Moreover, the P uptake by soybean was significantly improved in the inoculated treatments. In a similar experiment, rhizosphere soil was used to assess the difference in P uptake by the soybean plants. Soybean in non-inoculated treatments took up minimum Al-P from acidic soils and less Ca-P from calcareous soil, and failed to absorb Fe-P from any soil types. Inoculation with either of the two mycorrhizal fungi improved the uptake of Al-P by soybean in acidic soils, and also increased the uptake of Ca-P in calcareous soils and significant amount of Fe-P uptake was found. These results suggest that AM can enhance uptake of fixed soil P. The efficiency rate and utilization of various forms of mineral P by mycorrhizal plants depends on the species of mycorrhizal fungi inoculated, and on the soil type. Further, Chang and Young (1992b) showed that inoculation of tea cuttings (cv. TTES No. 12) inoculated with A-mycorrhiza or P-solubilizing bacteria significantly enhanced the growth of tea seedlings.

APPLICATION OF BIOFERTILIZERS IN TAIWAN

In order to promote sustainable agriculture, both central and local government agencies in Taiwan are supporting extensive application of biofertilizers. Major programs for the application of biofertilizer include production of rhizobial, P-solubilizing microbial inoculants for soybeans that can be used as vegetables, for some crops, and production of AM-inoculants for melons and other horticultural crops. The project also aims at improving biological nitrogen fixation in soybeans that are consumed as vegetables, peanuts, and in red bean. Similarly, emphasis is also laid on attaining higher yield and better quality horticultural crops through three major programs: (1) Production of inoculants; (2) Extension programs so that farmers can apply inoculants to their farms; and (3) Demonstration and awareness programs to show farmers the benefits of inoculated plots.

Soybeans for vegetable purpose are extensively produced in Taiwan and exported to Japan. Superior and constant maintenance of quality will be an important factor governing the export value of soybeans in the international market. But earlier, farmers were applying more chemical fertilizer than the recommended levels leading to inferior quality of beans. Since 1988, the Department of Soil and Environmental Sciences at the National Chung-Hsing University in Taiwan actively started the production of efficient inoculum (liquid and solid biofertilizers) that can maintain yield and superior quality soybeans, which were exported and consumed presently as vegetables in several countries. Figures 1-3 show the increase in the area/ha of inoculated crops over the years. During the last 18 years (from 1987 to 2004), enough inoculants were produced to inoculate approximately 65,091 ha of farm land. Over the year, farmers' economic gain also increased significantly (US$27 million) by using rhizobial inoculants. Moreover, a great deal of chemical fertilizer was saved and further groundwater pollution caused by N leaching was significantly reduced.

Healthy seedlings are one of the essential factors affecting the growth and yield of crops. Over the past decade, mycorrhizal inoculants have been produced in Taiwan and applied to

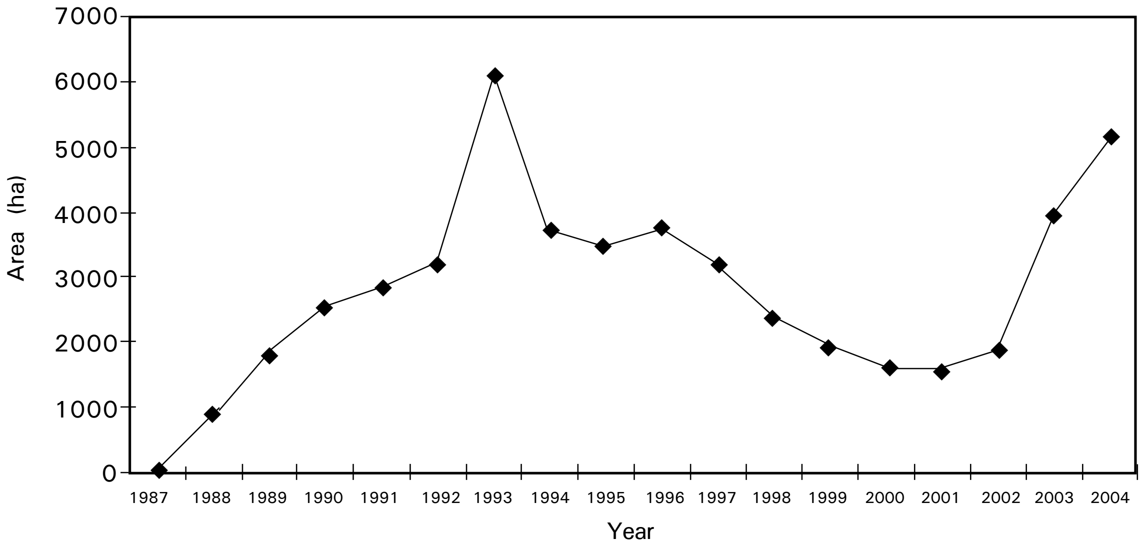

Fig. 1. Area of vegetable soybean inoculant in Taiwan.

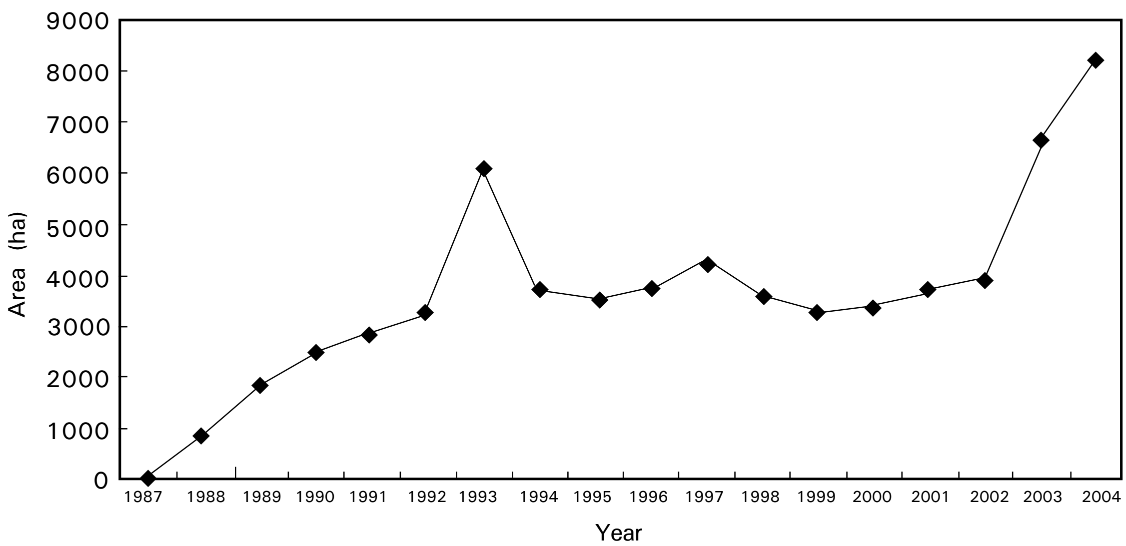

Fig. 2. Total area of biofertilizers used for extension programs in Taiwan.

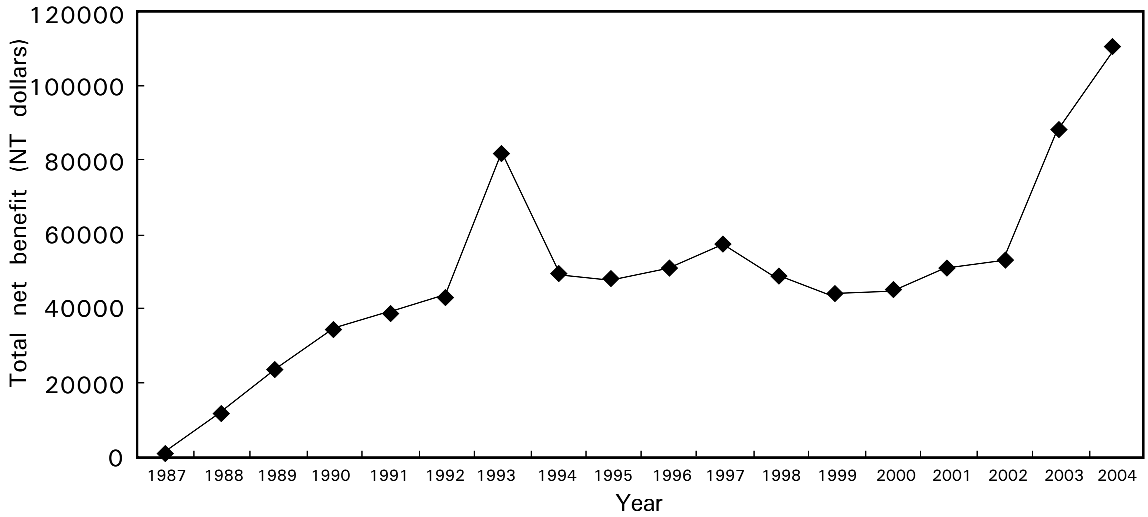

Fig. 3. Total net benefit to the farmers from the extension programs on biofertilizer.

many crops, particularly horticultural and ornamental plants such as muskmelon, citrus, strawberry, lily, tomato, chrysanthemum, gerbera, tea, and fruit trees (Chang 1987, 1993, 1994; Chang and Young 1992a & b; Cheng and Chung 1991; Chen and Hung 1994; Young 1990).

FUTURE OUTLOOK

An excess of nutrients is accumulated in Taiwan soils, particularly P as a result of over application of chemical fertilizers by farmers during intensive agricultural practices. Hence, major research focus should be on the production of efficient and sustainable biofertilizers for crop plants wherein, inorganic fertilizer application can be reduced significantly to avoid further pollution problems. In view of overcoming this bottleneck, it will be necessary to undertake short-, medium-, and long-term research, in which soil microbiologists, agronomists, plant breeders, plant pathologists, and even nutritionists and economists must work together.

The most important and specific research needs should highlight the following points:

(1) Selection of effective and competitive multifunctional biofertilizers for a variety of crops.
(2) Quality control system for the production of inoculants and their application in the field, to ensure and explore the benefits of plant-microorganism symbiosis.
(3) Study of microbial persistence of biofertilizers in soil environments under stressful conditions.
(4) Agronomic, soil, and economic evaluation of biofertilizers for diverse agricultural production systems.
(5) Transferring technological knowhow for the biofertilizer production at industrial level and optimum formulation.
(6) Establishment of Biofertilizer Act and strict regulation for quality control in markets and application.

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