Biological nitrogen fixation research and technology assessment for Egypt: II. Training, research, and inoculant production[1]

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ABSTRACT

As part of an assessment of biological nitrogen fixation (BNF) research in Egypt, an interdisciplinary team reviewed training, research, and production. The team has expertise in soil microbiology, soil fertility and management, agronomic practices, and *Rhizobium* inoculant production. Personnel involved in BNF within the Ministry of Agriculture, the Faculties of Agriculture at several universities, and agricultural enterprises within the private sector were interviewed. Facilities were observed and training, research, and inoculant production programs in progress were reviewed. An in-country literature search was conducted to provide information on previous research. Information was obtained for crop acreages, yields, and agronomic practices. Attitudes and recommendations were obtained from scientists, administrators, and farmers. Egypt is not capitalizing on the potential of its BNF scientists to increase farm production. Constraints on the transfer of BNF technology include a lack of Extension agents trained in BNF technology, insufficient applied research, a lack of feedback of field observed problems to research scientists, limited involvement of the private commercial sector, and a lack of effective *Rhizobium* inoculants. Recommendations are made for increasing the effectiveness of research and training programs and for the production of effective *Rhizobium* inoculants.

Additional index words: **Continuing training, B.S. degree training, Postgraduate training, Postdoctoral training, Applied research, Basic research, *Rhizobium Azolla, Frankia,* Blue-green algae, Associative-asymbiotic nitrogen fixation, Lesser developed countries.**

THE first paper in this series inventoried the Egyptian scientists working on biological nitrogen fixation (BNF), their published work, and Egypt's BNF extension efforts (6). Other critical components of a national BNF program are training, research, and inoculant production. Incorporating known BNF technology into production systems is a prevalent problem in most less developed countries (LDCs) (2). Professors in Egyptian universities primarily teach and have insufficient opportunity to conduct research. Conversely, researchers in the Ministry do not teach. Thus, the critical interaction between research and teaching function is preempted. Also, BNF scientists in LDCs often have difficulty in focusing their research on crop production problems. The common result is a proliferation of rather basic research projects and the neglect of applied research (3) or research aimed at solving BNF problems.

Biological nitrogen fixation is the key to greater legume production without substantial inputs of nitrogen. Much is already known about the legume BNF system and can be immediately applied. However, more information is needed to address the problems that limit BNF in Egypt. Non-legumes, in association with other BNF systems, may also benefit from increased emphasis on biologically fixed nitrogen. However, considerably more research is needed on these systems to develop a marketable technology.

The USAID-Cairo recognized the importance of BNF in increasing food and forage production and asked for an assessment of past and present activities. A team of five scientists with diverse backgrounds, experience, and expertise was selected. This paper reports what was learned about past and present BNF training, research, and inoculant production in Egypt and suggests modifications for these programs.

METHODS

The methods employed to assess past and present BNF training and research programs, and inoculant production in Egypt are previously described (6). The team's insight into present BNF training programs was gained primarily from visits to the Egyptian agricultural universities and from theses and lists of theses provided by the universities. Characterization of research programs was based on: 1) first-hand observations of facilities and projects in progress at the Agricultural Research Center (ARC) in Giza and in Sakha and at the universities, 2) interviews with research scientists and administrators, and 3) evaluation of BNF publications including abstracts and title summaries (5, 7, 8). On-site observations of ARC inoculant production facilities at Giza and Sakha, interviews of scientists, private sector agriculturists, and farmers and Roughley's report (4) provided the basis for our evaluation of past and present efforts to produce *Rhizobium* inoculants in Egypt.

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RESULTS AND DISCUSSION

Training

Continuous training and improving of skills are essential for any technical program. The Ministry of Agriculture must continue to provide training opportunities. Several avenues of training are available, four of which are discussed below.

Training at the B.S. level should not be ignored. Certainly Extension agents and students graduating in agronomy or related areas must have a firm knowledge of BNF and how it is applied at the farm level. The training of B.S. students is the responsibility of the universities and new programs to include on-farm experience are to be commended.

The training of current extension agents will partially be performed by the EMCIP (9) and should include BNF technology.

Specific BNF technology training should include:

1. The importance of BNF at the B.S. and extension agent level.
2. The factors limiting BNF.
3. The storage and handling of inoculants.
4. The inoculation of legume crops.
5. The preparation of fields for planting.
6. Checking for field nodulation.
7. The incorporation of demonstration plots.

Well-educated and highly capable people were visited during this evaluation, yet many problems can be corrected with improved and additional training. Some of the opportunities for both current and improved training programs should focus on: 1) known and available technology in both field and laboratory settings; 2) cleanliness and maintenance of research and inoculant production facilities; 3) better organization and execution of field research; 4) cooperation between scientists of disciplines pertinent to BNF, between the universities and the Agricultural Research Center, and between all researchers and extension; 5) development of expertise in the production, storage, distribution, merchandizing, and testing of quality inoculants.

Adequate training in agronomic field research is rare among microbiologists. Adequate training in BNF technology is rare among agronomists and soil scientists. There appears to be little organized effort between institutions to improve training or transfer information. The exchange of scientists between institutions and countries should be expanded. Travel by Egyptian scientists to the USA or other developed countries may provide training in the following areas:

1. Technological areas for which inadequate opportunity exists in Egypt.
2. Implementation of current technology at the farm level.
3. Organization of and participation in cooperative research.
4. Improvement of BNF technology transfer from the research lab through the extension service and the private sector to the farmer.

Travel by U.S. scientists to Egypt should be part of the scientific exchange for similar reasons.

In-country scientific exchange is needed to:

1. Organize a national BNF program.
2. Transfer technology between institutions.
3. Develop cooperation between institutions.
4. Identify areas where concentrated research effort is needed.
5. Organize uniform field trials of BNF technology.
6. Compare results in similar experiments.
7. Change emphasis on BNF research when appropriate.
8. Insure the knowledge is transferred to extension and is implemented at the farm level.

Postdoctoral training of Egyptian educated Ph.D.s is essential. A well-managed and clean microbiology laboratory with an organized research effort could be encouraged by proper budgetary support and postdoctoral training opportunities. Additional training and a chance to work with a research team may help develop BNF laboratories equal to the best in the world. Further training should include:

1. Field plot technique and maintenance.
2. Equipment maintenance.
3. Laboratory maintenance and cleanliness.
4. Organization of a research program including cooperation with other disciplines.

Additionally the student should be well-trained in the traditional postdoctoral pursuits.

Postgraduate training in the USA and other countries in active BNF laboratories can be valuable for the same reasons as listed above. Graduate training in both the theoretical and applied aspects of BNF is required. However, the main deficiency in expertise presently is in the applied aspects of BNF, including field research.

Students in the basic research areas must interact with those in the applied areas and include some course work in agronomically related fields to gain some understanding of practical problems. Field research must directly involve both the professor and the student from the experimental design and implementation stages through data summarization, including active student participation in all phases of machinery and plot maintenance.

Research

The research programs in BNF in Egypt appear to be carried out by well-trained scientists with careful attention to detailed observations and measurements. The problems researched appear to be more related to the current scientific literature than to problems observed in the field. The techniques used are standard, but sometimes opportunities to adapt them in innovative ways to solve problems are overlooked. Much of the research adds to the data available on microbiology and BNF, but the usefulness of such data to Egyptian agriculture is difficult to assess or put into practice. The research activities appear to be fragmented because each investigator follows a special interest, or because funding support is sporadic and inadequate. Cooperation and coordination are lacking.

Biological nitrogen fixation research in Egypt can be categorized into five systems: 1) *Rhizobium*-legume, 2) *Azolla*, 3) associative N_2-fixing bacteria, 4) blue-green algae, and 5) *Frankia*. Field research is needed to test the BNF technology developed in the laboratory and greenhouse. Some basic research conducted in the laboratory and greenhouse is needed to develop scientific understanding and to provide the basic information for improving BNF technology. Most research should be related to problems that have been identified in the field, and the methodology should be no more sophisticated than needed to solve the problem.

The total scientific effort in BNF research should be apportioned as shown in Table 1.

Table 1. Recommended apportionment for BNF research in Egypt.

N_2 fixing system	BNF effort	Research activity within each system: Field	Research activity within each system: Laboratory and greenhouse
	%	%	%
1. *Rhizobium*-legume (grains, forages)	60 to 80	60 to 80	20 to 40
2. *Azolla* (flooded soils only)	10 to 20	40 to 60	40 to 60
3. Associative N_2 fixing bacteria (cereals, cotton, other)	5 to 10	20 to 40	60 to 80
4. Blue-green algae (flooded soils only)	3 to 10	30 to 50	50 to 70
5. *Frankia*-nonlegume and others (*Casuarina*, other)	2 to 5	10 to 30	70 to 90

Rhizobium-legume System

This system is well-known and the technology for applied field use has been developed and is functioning in other countries, but has not been adapted and transferred adequately in Egypt. A current summary of the *Rhizobium*-legume technology has been presented by Halliday (2).

Numerous field trials should be initiated to help develop inoculation recommendations for various legume crops in different Egyptian soils. Also, research is essential before a *Rhizobium* inoculant production system for Egypt can be formulated. Decisions based on research need to be made concerning the following:

1. Need-to-inoculate: Determine, on an individual basis, the need to inoculate for each legume beginning with recently introduced legumes, but including all pulse and forage legumes.
2. Inoculant methodology: Develop field methods that reliably nodulate field legumes.
3. Inoculant carrier evaluation: Research needs to be continued on the evaluation of possible carriers to be used for inoculant production in Egypt. The effectiveness of sterile versus non-sterile carriers should be evaluated.
4. Field testing of *Rhizobium* strains: Collect and maintain local and foreign strains of rhizobia for the legumes produced in Egypt and evaluation of strains for nodulating ability, nitrogen fixation, and effect on yield.
5. Limiting factors: Evaluate factors limiting BNF in Egypt. Such trials should include factors inhibiting *Rhizobium* as well as the plant, etc.

Azolla-flooded Crop System

Azolla has been used as a green manure to provide nitrogen under flooded conditions for rice and taro. Each crop of *Azolla* can provide significant quantities of nitrogen for following or companion crops. Current research at the International Rice Institute in the Phillipines and elsewhere in Southeast Asia have shown potential for the *Azolla* system.

Research needed includes the following:

1. Methods of culturing *Azolla* in nurseries and managing *Azolla* in the fields.
2. Selection of productive species or strains for Egyptian conditions; southern Egypt may have different requirements from northern Egypt. Also Southeast Asian strains may not be adapted to Egypt.
3. Determine the contribution of *Azolla* fixed N.
4. Land requirements for nurseries.
5. Information exchange with IRRI and research centers in China.

Associative or Non-symbiotic N_2-fixing Bacterial Systems

Many N_2-fixing bacteria exist in Egyptian soils. *Azotobacter* is plentiful in Egyptian soils, and recent studies indicate that many other bacteria in the root zone of grasses fix N_2 only under low oxygen tension. These include *Azospirillum, Klebsiella,* and some bacilli.

Research needs on the associative nitrogen fixing bacteria include the following:

1. Repetition of field trials of *Azospirillum* inoculation of wheat, barley, and maize to determine the consistency of yield increases and the relation to N fertilizer response. Trials on other cereal grains and possibly other non-legume crops.
2. Effective methods of inoculation and the need to reinoculate.
3. Determine the ability of N_2-fixing bacteria to colonize roots. Determine whether differences exist between cereal species and cultivars.

Blue-Green Algae System

Considerable work has been done with this system using rice grown on flooded soils. Favorable results have been reported that indicate the use of blue-green algae can reduce the need for nitrogen by one-half. This system is also used to some extent in India, the Phillipines, and China, but does not appear to be widely used by farmers.

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1. Confirmation of yield increases by agronomists trained to use the blue-green algae technology and with appropriate fertilizer nitrogen controls.
2. Surveys to determine why farmers are reluctant to adopt the blue-green algae technology.
3. Nitrogen balance studies on greenhouse and field systems to determine the contribution of each component of the nitrogen supply (and losses).
4. Basic studies on strain selection, nutrition, culturing, pest protection, and harvesting of blue-green algae.
5. Land requirements for nurseries.
6. Large scale production technology.

Frankia-root Nodulated Non-legume System

At present, only perennial, woody plants are known to have this N_2 fixing system. The most common genus in Egypt with this system is *Casuarina*. Little is known of the vlaue of these plants in farming systems, but obvious uses include providing windbreaks, firewood, and building material.

Research needs include:

1. Surveys to determine plants that have this system with observations to indicate their potential value in farming systems.
2. Studies and selection of both host plant and endophyte to improve and broaden the utility of the plants and to select types that fit different needs.
3. Studies to determine ways to culture the endophyte and to produce inoculants for tree nurseries.

All of the systems have intriguing research problems. The greatest and most rapid increase in total agricultural production is likely to result from maximizing the use of the *Rhizobium*-legume system. The greatest potential benefit would derive from a nitrogen-fixing system that could provide the major portion of the N needs of cereals. The *Azolla* and blue-green algae systems provide N only for flooded crops and the cost in labor, management, space (land), and time is considerable. The associative bacterial system has not been developed such that it is reliable and consistent.

RHIZOBIUM INOCULANTS

The inoculant production system in Egypt has evolved to utilize two Jiffy peat discs in an autoclavable plastic cup. Two discs are sterilized in the cup before the *Rhizobium* culture is added to the cup. The Jiffy peat discs adsorb the culture to provide the material which is to be used as a seed-applied inoculant. The user must remove a plastic net from around each disc, crumble the inoculant into particles as small as possible, and attempt to adhere this inoculum to the legume seed. The BNF assessment team and the Egyptian Ministry of Agriculture consider this inoculant to be unsatisfactory and production in this form should be discontinued. This assessment is supported by the lack of adequate nodulation with this method in field experiments. Extensive contamination and insufficient *Rhizobium* survival in the acid peat discs, poor inoculant adherence to seeds, and the absence of a quality control program appear to be the main reasons for ineffectiveness.

Recommended *Rhizobium* Inoculant Program

Based on these conditions and results, the following BNF Program concerning *Rhizobium* inoculants is recommended.

1. *Import quality legume inoculants*—It is essential that high quality inoculants capable of producing satisfactory nodulation on soybeans be imported immediately. With 60 to 90 kg/fd of nitrogen fertilizer currently used on soybeans, a large economic savings for the Egyptian government would be realized by utilizing a soil inoculant in place of the nitrogen fertilizer, even if no yield advantage was achieved. The cost of nitrogen fertilizer is considerably more than the cost of inoculation. The use of inoculants on other legumes would also be required when planted on new land. Importation of high quality legume inoculants can meet the immediate need for inoculants and also help develop the market demand. Current restrictions on the importation of inoculants should be eliminated by the Egyptian government.
2. *Develop inoculant production capability in Egypt*—As the market demand develops through use of imported quality inoculants, and research provides answers to allow the production of a reliable inoculant in Egypt, an improved inoculant production capability should be developed.
3. *Evaluate the potential for increasing legume yields and minimizing the nitrogen fertilizer needs for all legumes in Egypt*—A field survey should be conducted to investigate the amount of nodulation and effectiveness of nitrogen fixation for all legumes presently grown in Egypt.

Inoculant Production Alternatives in Egypt

Local production of legume inoculants in Egypt should be economical. Egyptian production would eliminate the concern for quality deterioration during shipping and customs clearance of imported inoculants.

Inoculant production would best be served by a joint venture between the Egyptian Government (or company within the government) and an experienced foreign private company. An alternate approach would be for an Egyptian private company to develop the inoculant production capability either independently or in cooperation with an existing foreign inoculant producer.

Quality Assurance

An effective quality assurance program for all inoculants used in Egypt (either produced within Egypt or im-

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ported) is very important to a successful inoculant program. It is recommended that the quality evaluation be conducted by the soil microbiology section of the Ministry of Agriculture.

Inoculant Storage and Distribution

Inoculum is a perishable product and care must be exercised in maintaining the best storage and handling conditions. Inoculant quality is best maintained under refrigeration. A cold room at the inoculant storage facility is essential. Ambient temperatures in Egypt are too high for successful inoculant storage without refrigeration.

Care should be exercised in expediting inoculant shipments to regional distribution points and to the farmer. A system by which the farmer must come to the inoculant production site to obtain his inoculant supply is not feasible in an improved BNF program designed to reach the Egyptian farmers. A network of regional and local inoculant distribution points must be established to meet these needs. This is a major constraint in the rapid development of an improved inoculant program in Egypt. Additionally, expiration dates should be placed on the inoculant packages.

SUMMARY AND CONCLUSIONS

Egyptian universities should provide all undergraduate training for BNF scientists and agriculturalists. Graduate training should continue at universities in several countries, but more training in field work is necessary. Postgraduate training and scientist exchange with the USA and other foreign institutions is essential for professional enhancement and interchange of ideas and techniques.

A coordinated research program in BNF for Egyptian agriculture should be established and should utilize the Agricultural Research Center, the National Research Center, and those universities with capable staff trained and interested in BNF research. A small committee of BNF scientists could provide guidance for Egyptian research in BNF. Field research on the *Rhizobium*-legume system should be emphasized with smaller, but significant, efforts on the Associative N_2-fixing bacteria system for cereals, the *Azolla* and blue-green algae systems for rice, and the *Frankia*-root nodulated system for *Casuarina*. Research activities should include the determination of the best method of inoculation, especially for introduced legumes such as soybeans and all legumes in new lands, need-to-inoculate trials for each legume grown in Egypt, and the evaluation of new cultivars for efficiency with selected strains of *Rhizobium*.

High quality inoculant should be imported immediately. Inoculants presently produced in the Jiffy peat pellets are ineffective and production should be discontinued. Extension agents and farmers should be trained in proper handling and application of legume inoculants. An urgent need exists to use proper inoculation for soybeans to get optimum yields with the use of little or no nitrogen fertilizer. A commercial company should be established to provide high quality inoculant produced in Egypt. The Ministry should also provide quality assurance for inoculants sold and used in Egypt. Development of an Egyptian Inoculant Research and Control Service based on the Australian model should be considered.

When a comprehensive, coordinated Egyptian BNF program is designed and supported by Egyptian scientists and authorities, support of the program would be a worthwhile project for an outside agency.

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