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FINAL REPORT FOR AID GRANT NO. DAN-5542-G-SS-1087

PROGRAM FOR THE ASSESSMENT OF AZOLLA USE IN TROPICAL LDC's

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4 June 1986

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1. SUMMARY OF PROPOSED WORK.

The following paragraph is the summary of proposed research as stated in the original proposal.

The proposed program is intended to assess the potential for successfully introducing the cultivation of Azolla as a source of organic nitrogen into peasant based rice farming systems of tropical L.D.C.'s. The program will consist of three "hands-on" training workshops; the first in Latin America, the second in Africa, and the third in Asia. The workshops will provide training for key L.D.C. scientists on the practical use of Azolla, based on an improved version of Chinese Azolla technology. They will be coordinated through previously established linkages with international and LDC institutions involved in rice research. The objectives of the program are to: (1) provide L.D.C. scientists with the knowledge to assess the potential of Azolla and to serve as instructors in their home rice regions, (2) produce Azolla handbooks in regional languages which outline an envisioned system and assess the potential of Azolla cultivation under local conditions, and (3) write a comprehensive review of Chinese Azolla technology which will support the preceding objectives.

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2. ACCOMPLISHMENTS UNDER OBJECTIVE 1: TRAINING.

The following information was published in the International Rice Commission Newsletter, vol. 33, no. 1.

WORKSHOPS TO ASSESS THE POTENTIAL FOR AZOLLA USE IN TROPICAL DEVELOPING COUNTRIES. Chiclayo, Peru, 17-23 April 1983; Richard Toll, Senegal, 23-30 October 1983; Bangkhen, Thailand, 22-28 January 1984. The series of three workshops was core funded by USAID and coordinated by Dr. Thomas A. Lumpkin, Washington State University. Collaborative support was provided by the NIFTAL Project of the University of Hawaii, the National Rice Programme of Peru, the West African Rice Development Association, and the BNF Centre of the Thai Ministry of Agriculture. Technical support was provided by Dr. C. Van Hove of the Universite Catholique Louvain-la-Neuve in Belgium, Dr. J. Halliday of the NIFTAL Project, Dr. I. Watanabe of IRRI, Dr. A.W. Moore of CSIRO in Australia, and the Kettering Laboratory in Ohio, USA.

The purpose of the workshops was to assess the potential for Azolla use in various rice-producing regions of the tropics. The workshops began with participant presentations on Azolla research in their respective countries. The presentations were followed by lectures, and laboratory and field exercises on the botany, physiology, and uses of Azolla. The final period was devoted to the preparation of an assessment of Azolla's potential by each participant in relation to their country's rice regions. Books, handbooks, slides, and Azolla varieties were distributed for training and future use in extension. The workshops were attended by 16 participants from 6 countries of Latin America, 20 participants from 11 countries of West Africa, and 34 participants from 10 countries of Asia (see section 7 for names of participants and countries). These workshops were conducted in Spanish, French and English, and English, respectively.

3. ACCOMPLISHMENTS UNDER OBJECTIVE 3: TRAINING MATERIALS.

Three primary training materials were developed and used for the workshops: (1) a book in English, Azolla as a Green Manure: Use and Management in Crop Production, 230 pages; (2) a handbook in French and English, Azolla in West Africa (Azolla en Afrique de l'Ouest), 54 pages; and (3) a slide set, Azolla: Biology and Use, 26 slides. For the workshop in Latin America, few of the attending scientists could speak English so the following chapters from the Azolla book were translated in to Spanish for distribution to the participants: Botany and Ecology, Physiology, Nursery Culture and Multiplication, Field Cultivation, and Pests and Pest Control, totaling 91 pages. These same chapters were translated in to French for the workshop in West Africa. Copies of the training materials are still being requested and being sent to Azolla researchers in L.D.C.s. The training slides are especially popular and have become the standard since IRRI decided not to produce a planned set.

4. ACCOMPLISHMENTS UNDER OBJECTIVE 3: REVIEW OF CHINESE TECHNOLOGY.

Over 400 Chinese articles published from 1949 to 1982 were reviewed to help in the writing of the book, Azolla as a Green Manure: Use and Management in Crop Production. Also on pages 122 to 135 in the book, a series of 7 Chinese training posters were copied and English translations were provided. One year was required to read the Chinese Azolla articles and to prepare English abstracts which were used in preparing the book. Much of this work was done by student assistants hired under the grant. During the final stages of the grant duration, a follow-up article on Chinese Azolla research was prepared and published: Advances in Chinese research on Azolla, Proceedings of the Royal Society of Edinburgh, 86B:161-167, 1985.

5. ASSESSMENT OF THE POTENTIAL FOR AZOLLA USE IN TROPICAL LDC's.

The following information was published in the International Rice Commission Newsletter, vol. 33, no. 1. This assessment is basically a summary of information extracted from the individual country assessments prepared by participants at the three regional workshops.

ASSESSING THE POTENTIAL FOR AZOLLA USE IN THE HUMID TROPICS. The aquatic fern Azolla has potential as a green manure because of it's high relative growth rate and symbiotic relationship with a nitrogen-fixing endophytic cyanobacteria called **Anabaena azollae**. This symbiotic relationship gives Azolla a competitive advantage over other floating hydrophytes in environments such as rice fields which are relatively low in available nitrogen. Incorporation and decomposition of an Azolla crop in a rice field soil results in an increase of available nitrogen to a companion or succeeding rice crop. Azolla has the potential of supplying the entire nitrogen requirement for a high yielding rice crop since it can accumulate more than 10 kg of nitrogen/ha/day (25 tons/ha x 6% dry wt. x 4% N x RGR 0.17 ton/ton/day). Under proper management and conditions, this growth rate can be sustained because the growth of Azolla more closely resembles the growth of single-cell organisms than terrestial plants. Azolla can also be used to suppress paddy weeds (Moody, 1981), and is an excellent food for pigs, ducks, and fish (Cassani, 1981).

Azolla was regularly cultivated on a large scale only in southeastern China and northern Vietnam. In these areas, Azolla was primarily used as a green manure for rice and was viewed as a crop of rather low economic value. Only short periods, before or with the spring rice crop were allocated for its cultivation. Azolla can use short cool periods in the cropping sequence because some varieties have both (a) the ability to sustain a relatively high growth rate under cool temperatures (10-20° C) and (b) have a potential for doubling their biomass in as little as two days (0.35 g/g/day) under more optimal conditions (Peters **et al**, 1980; Lumpkin, 1983; Watanabe and Berja, 1983).

Cool weather tolerance was the key to successful cultivation in Vietnam and China. A high growth rate in cool seasons made Azolla a good economic competitor against alternative crops grown for food and a good biological competitor against other hydrophytes and algae. In addition, cultivation during cool seasons allowed Azolla to avoid devastation by

it's thermophyllic insect pests.

The cool season (winter-spring) cultivation of **Azolla pinnata** var. **imbricata** in Vietnam's Red River Delta and irrigation system reached an area exceeding 500,000 hectares during the late 1960's and has continued to be an important crop because of insufficient nitrogen fertilizer. In China, cool season cultivation of **A. pinnata** var. **imbricata** and **Azolla filiculoides** peaked in the late 1970's at over 1,000,000 hectares and has since declined dramatically in the face of improved supplies of nitrogen fertilizer and increasing pressure for food through population growth and rising expectations.

INTEREST IN THE TROPICS

Cultivation of Azolla in China and Vietnam was generally unnoticed by scientists in other countries until the mid-1970's. An upsurge of interest in Azolla began with a literature review by Moore (1969), followed by a series of articles by Peters (1977), Rains and Talley (1979), Watanabe **et al.** (1981), and by Lumpkin and Plucknett (1980, 1982). These reports helped to stimulate substantial research in developing countries that produce rice (Kannaiyan, 1982; Kulasooriya **et al.**, 1980; Partodardjono **et al.**, 1983; Swatdee and Seetanum, 1979; Van Hove **et al.**, 1983). Awareness and demand also brought Azolla into the INSFFER fertilizer trials of the International Rice Research Institute.

Unfortunately environmental constraints, primarily associated with year-round high temperatures and humidity, prevented research in the tropics from progressing beyond the laboratory or an occasional field experiment. This research situation continued until the unexpected success of an IRRI out-reach program in an area of the southern Philippines called South Cotabato on the island of Mindanao.

South Cotabato has a long rainy season (9-11 months) and a high level of available soil P, and is without a native Azolla. In 1979, researchers introduced a strain of **Azolla pinnata** var. **imbricata** from Bangkok. With some trepidation, they watched it spread across 5,000 hectares of rice fields with virtually little assistance from man, other than initial dispersion.

After it was realized that there were no important negative consequences, the Philippines government and fraternal societies initiated a massive extension program. The South Catabato success and the extension program generated high expectations, but these were soon displaced by frustration when the difficulties of replacing an industrial product -- nitrogen fertilizer -- with a sensitive biological product became apparent. Bureaucratic foul-ups compounded problems of maintaining, multiplying, and distributing Azolla, while insects and drought devastated the Azolla population in South Cotabato. Fortunately, the crop in South Cotabato has partially recovered with the end of the drought and the use of **Azolla microphylla**.

THE CONTROL AND AVAILABILITY OF WATER

The primary constraint to Azolla cultivation is its requirement for an aquatic habitat. An individual plant can survive for only a few moments on a dry surface under a tropical sun. It can survive for only a few days or a week on paddy soil that dries during intermissions between rains. Some varieties can survive indefinitely on moist shaded mud, but these

will not multiply to any useful extent. Thus, without good water control, the success of Azolla cultivation will be at least as unpredictable as the rains.

The fact that Azolla is produced vegetatively from whole plants compounds this problem. Some plant material must be maintained all year round and multiplied in nurseries prior to large scale field cultivation. With the present system a certain amount of water must be available all year for maintenance and multiplication. Water availability for these nurseries is especially critical if Azolla is to be cultivated as an intercrop with rice at the start of a monsoon season. For full cultivation, an area of Azolla equal to 20% of the rice area has to be produced before the rice is transplanted.

The year round maintenance requirement might be avoided if Azolla could be propagated from spores. Azolla is capable of producing spores, but no methods are known for inducing spore formation, harvesting them, nor utilizing them in cropping systems.

Once an Azolla crop is grown as a green manure, it must be incorporated into the soil in order to recover a significant portion of its nitrogen. Since the rhizome and leaves of Azolla are hydrophobic, water must be completely drained from the field or Azolla will be washed aside in the effort to incorporate. Farmers are reluctant to drain rainfed and even irrigated rice fields to incorporate an Azolla crop. Incorporation of an Azolla monocrop is possible with existing implements, but water is not usually available for monoculture. Incorporation of an intercrop is presently impractical because no efficient methods or implements are known.

THE TROPICAL CLIMATE

Although the need for water control greatly reduces the area under which Azolla could be cultivated, it is the indirect effects of a humid tropical climate which most threaten the possibility of any cultivation. Many researchers suggest that high water or air temperature is the most important factor preventing Azolla use. Growth rate is depressed at temperatures above 35°C and even the most heat tolerant varieties are killed at prolonged temperatures above 45°C. The temperature of shallow water standing over dark soil may exceeding 40°C in the tropics, however it is also possible to avoid high temperatures by draining, shading or flushing. Thus high temperature itself will not prevent cultivation, though it will certainly make it more difficult.

The worst threat from the climate comes from the stimulating effects of high temperature and humidity on the population dynamics of insects and fungi that attack Azolla. Insects and fungi can be controlled by a comprehensive program of Azolla management and frequent pesticide applications, but the environmental and economic consequences of frequent pesticide applications would make Azolla cultivation unrealistic by any method of cost accounting. Azolla cultivation is often promoted as a means of reducing the importation of nitrogen fertilizers or of the fossil fuel needed for their manufacture, however, any savings on nitrogen fertilizers would be quickly negated by imports to support additional pumping of irrigation water and the application of pesticides and phosphorus usually required for Azolla's cultivation.

In view of these constraints and the lack of progress in applying

Azolla technology, three workshops were held to assess the potential for Azolla use in the humid tropics. The final workshop was convened in Bangkhen, Thailand from 22-28 Feb. 1984. The Asian workshop was supported by USAID's NIFTAL project, the Thai Ministry of Agriculture and the International Rice Research Institute and was attended by 34 Azolla researchers from 12 countries. Participants assessed the potential of Azolla and discussed the assessments prepared at the previous two workshops in Peru and Senegal. Discussions covered constraints and outlined the areas of research that might yield breakthroughs. The discussion of constraints and important research areas can be summarized into three broad subject areas.

1. **Fundamental**
   - Induction of sporogenesis and germination of spores for applied use, breeding material, and for pest and stress avoidance.
   - Plant resistance and inexpensive non-polluting methods to control insects, disease and competitors.
   - Importance of available phosphorus in soil and water, and ways to improve uptake of applied phosphorus.
   - Implements for incorporation of Azolla into soil under different rice planting systems and methods for improving the availability and uptake of nitrogen from Azolla by rice.
   - Greenhouse and growth chamber methods to characterize agronomic traits of Azolla accessions.
   - Management procedures to allow water transportation of planting material, avoid flushing of Azolla during typhoons and rain storms, and avoid draining of water for incorporation of Azolla.
   - Characterization of rice producing areas for potential Azolla use.

2. **Organizational**
   - International coordination of research programs with defined objectives and priorities.
   - Distribution of mini-grants (U.S. $5,000-10,000) to support coordinated research.
   - Education of administrators on potential and limitations of Azolla use.
   - On-site technical advice and assistance for regional researchers.
   - Newsletter of aquatic nitrogen fixation containing annotated references and communication announcements.
   - Standardization of research procedures.

3. **Social, Cultural, and Political**
   - Fertilizer uses and policies, especially influence of subsidized nitrogen on use of Azolla.
   - Attitude of farmers, bureaucrats, industrial organizations, and politicians to Azolla promotion and use.
   - Government extension programs for Azolla, which often fail because of excessive propaganda, untrained personnel, and

inconsistent support.

- Detailed economic analysis and description of national Azolla programs in China and Vietnam and relevance of their structure and methods to programs in other countries.
- Year-round production of Azolla as a fodder and forage for pigs, ducks, and fish combined with the sale of Azolla to rice growers.

CONCLUSIONS

The nitrogen fixing Azolla is an excellent green manure, suppressor of certain paddy weeds, and fodder for pigs, ducks, and fish. Despite its cultivation and use in China and northern Vietnam, it has not been successful in the humid tropics, including southern Vietnam, because of problems with insects and disease, availability of water and phosphorus, and an intensive labor requirement. If cultivation in the tropics is ever to be successful on a large scale, a number of scientific breakthroughs are necessary, and these will only be accomplished by a well focused and well financed internationally coordinated research program.

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7. PHOTOGRAPHS OF THE WORKSHOPS AND ADDRESS LIST OF PARTICIPANTS.

Figure 1. Participants and instructors at the first Azolla workshop conducted at National Rice Institute of Peru, Chiclayo, Peru, 17 - 23 April 1983. Participants represented Brazil, Colombia, Costa Rice, Dominican Republic, Peru and Uruguay.

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Figure 2. A field plot at the Peru workshop used for the multiplication of Azolla filiculoides. This Azolla was used as an incorporated green manure in an adjacent rice-Azolla experiment. Participants in the field are demostrating a method for measuring biomass

Figure 3. Participants and instructors at the second Azolla workshop conducted at the WARDA station at Richard Toll, Senegal, 23 - 30 October 1983. Participants represented Benin, Cote D'Ivoire, Guinee Bissau, Haute Volta, Liberia, Mali, Mauritania, Nigeria, Senegal, Sierra Leone, Togo

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Figure 4. A field plot at the Senegal workshop used for the multiplication of Azolla pinnata. As in the previous, Azolla was used as an incorporated green manure in an adjacent rice-Azolla experiment established by the participants. Participants in the field are demostrating a method for mass collection of [illegible]

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Figure 5. The classroom for lectures at the Senegal workshop. In this photo Dr. I. Watanabe of IRRI is seen delivering a lecture on IRRI's program for nitrogen fixation in paddy fields. Microscopes were also used during training so that participants could observe the cyanobacteria Anabaena azollae growing in the leaf cavities of Azolla.

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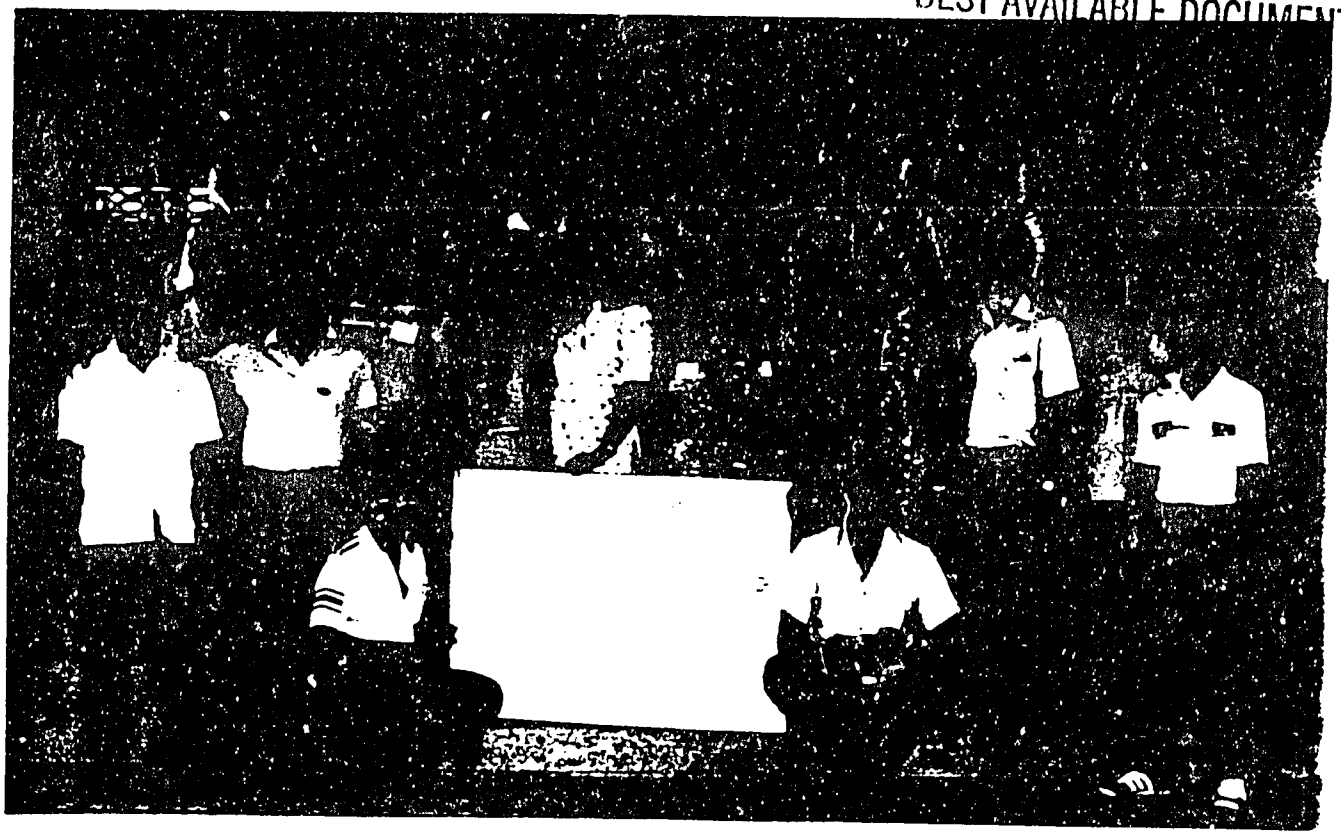

Figure 6. Participants and instructors at the third Azolla workshop conducted at the BNF Center of the Thai Ministry at Bangkhen, Thailand. 22 - 28 January 1984. Participants represented Australia, Bangladesh, Burma, India, Indonesia, Laos, Pakistan, Philippines, Sri Lanka, and Thailand.

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