AGRICULTURE AND BIOMASS PRODUCTION

As the members of the Indo/US Senior Scientific Panel focus on the world's food, forage and wood needs for the next half century, we are apprehensive.

In 1975, when world population reached four billion, the world produced an all-time record harvest of 3.3 billion tons of all kinds of foods, e.g., grains, pulses, tubers, vegetables, fruits, nuts, sugar, oilseeds, eggs, milk, cheese, meat and fish. It took from the beginning of agriculture and animal husbandry, some 12,000 years ago, up until 1975 to gradually increase production to the aforementioned record level. If human population growth continues to increase at the 1975 level, population will double to eight billion by 2015 A.D. Consequently food production must at least be doubled by then. Even if we assume that the present reduced rate of population growth will prevail, the population will double by 2035, and will require staggering increases in food, forage and wood production. These projections mean that within 40 to 60 years world food production must be increased by as much as was achieved during the 12,000 years from the beginning of agriculture to 1975 level. This will maintain per capita food production only at the inadequte 1975 level.

Until 50 years ago as more food was needed increased production was achieved primarily by opening more land to cultivation. But in the future increased food production will need to come from increased yields per hectare on land now under cultivation, for there is little additional suitable land.

During the past 50 years, large increases in yields of crops have been achieved by the widespread application of new technology based on research. This has involved the use of high yielding crop varieties, heavy applications of chemical fertilizers, chemicals to control weeds, insects and diseases, and improved machinery for tillage, planting and harvest. These achievements have prevented widespread starvation. For example, the application of high yield technology to the production of the 17 most important food and forage crops in the USA has increased production 2.5 fold between 1930 and 1980 with an increase of only 3 percent in cultivated area. Indian wheat production increased from an average production of about 11 million tons in the 1959-66 period to 37.8 million tons in 1982, an increase of about 3.5 fold in the 16 year period. More than half of this increase resulted from increases in yields per hectare. However, in some countries menacing clouds on the horizon threaten our ability to maintain the rhythm of expanding food, forage and wood production fast enough to cope with increasing demands.

Among the many obstacles that threaten our ability to increase production fast enough to meet growing demands is the fact that as the maximum genetic yield potential is approached it becomes increasingly difficult to increase yields further. Moreover, shortages and increasing costs of fossil fuels that directly affect the availability and price of fertilizers, especially nitrogenous fertilizers, also will restrict production.

Confronted by these problems, the members of the Indo/US Senior Scientific Panel have targeted two inter-related areas of mutual interest that are of paramount importance. Both bear on the future availability and cost of nitrogenous fertilizer and consequently on the production of food, forage and wood. It is proposed that cooperative research programs be initiated in the following project areas:

1. Improving nitrogen utilization in the biosphere through:

    A - Improving biological fixation of nitrogen

    B - Improving the biological utilization of nitrogenous fertilizers.

2. Increasing biomass production for ~~food~~ fodder, fuel and soil improvement.

These proposed areas of collaborative research are of great interest to both India and the USA because:

1) Both increased biological fixation of nitrogen and improved effectiveness of utilization of nitrogenous fertilizers can contribute to increased crop yields at lower cost.

2) Research on wood production can improve availability and reduce the cost of firewood. An effort should be made to achieve this on poor soils unsuitable for agriculture. Moreover, growth of trees on some water-logged sodic soils may increase soil permeability, water percolation and leaching of sodium. This improvement in land quality may permit its use both for tree and later for crop production. In other cases, badly eroded soils may be reclaimed for silviculture and perhaps for crop production.

The following section presents the rationale for these projects, and subsequently in this report a more detailed description of the projects is presented.

Project - 1A - Research designed to increase the biological fixation of nitrogen and to improve its utilization. Rationale: With increasing prices for chemically fixed nitrogenous fertilizer, it becomes more important to exploit biological nitrogen fixation fully. Agronomic research must be expanded to determine how the biologically fixed nitrogen can be utilized most effectively.

Project - 1B - Research designed to improve the efficiency of utilization of fertilizer nitrogen.
Rationale: With greatly increased cost of nitrogenous fertilizers it is urgent to increase the efficiency of their use.

Generally only 20-40% of nitrogen applied as fertilizer is actually utilized by the crop plants.

Project - 2 - Increasing biomass production for use as fuel, forage, and soil improvement.
Rationale: The primary reason for this research effort is to produce firewood on land unsuitable for agriculture. It also may reduce the need for burning animal dung as fuel and thus permit its use for production of bio-gas or for organic fertilizer. Some woody trees and shrubs also fix nitrogen in association with rhizobia or actinomycetes. These may be valuable for intercoping or crop rotation with non-nitrogen fixing crop species.

Some trees and shrubs in intensive coppice rotation may produce "forage" for livestock.

TECHNICAL PROGRAM

Project 1: "Improving the utilization of nitrogen in the biosphere"

Problems in nitrogen availability and utilization can be approached by: (a) enhancement of the process of biological N_2-fixation, and (b) development of better on-field fertilizer management practices to minimize losses and to improve its uptake.

A. Improving the use of biological N_2-fixation

Objectives:

(1) To identify and evaluate superior strains of rhizobia.

(2) To identify and improve free-living and associative N_2-fixing microorganisms.

(3) To evolve improved systems for N_2-fixation through genetic manipulation.

(4) To identify and improve new systems for N_2-fixation through genetic manipulation.

Scientific basis for the research:

In many soils the symbiotic fixation of N_2 by legume-Rhizobium associations is a major source of fixed nitrogen. The grain and fodder legumes can obtain virtually all their needed nitrogen in this way. Free-living, N_2-fixing bacteria may contribute small amounts of fixed nitrogen to plants, and there is evidence that Azospirillum species may form a loose association with the roots of cereal plants and contribute a significant portion of the plants' needed nitrogen in certain soils. Certain blue-green algae also are important contributors of fixed nitrogen. Improvement of these and other potential associations and greater exploitation of their potential can be of almost immediate benefit to agricultural production.

Long term:

Members of the bacterial genus Rhizobium are unique in their abilities to induce nodules on the roots of leguminous plants and to fix nitrogen in the nodules. A complex series of steps is involved in infection of host-root tissues and establishment of an effective symbiosis. Identification of the bacterial and host genes involved in each step is necessary to devise strategies to manipulate the symbiosis to improve its range and effectiveness. Rhizobium-legume associations are the most significant source of biologically fixed nitrogen in agriculture. Also organization and expression of genes in Rhizobium seems different from that in Klebsiella pneumoniae, whose nitrogen fixation genes have been analyzed. For these reasons symbiotic and nitrogen fixation genes of rhizobia must be studied before they can be manipulated for increasing the efficiency of the legume-Rhizobium symbiosis and for enlarging their host range.

Institutional arrangements:

The research programme with microbial systems is designed to aid in achieving both the short and long-term objectives stated. The programme will be initiated at a "Center for Research on N_2-Fixation" in the Indian Agricultural Research Institute. It will complement ongoing applied research under the coordinated programmes of I.C.A.R.; and the following Indian institutions and others may be associated with the work.

Tamil Nadu Agricultural University;

University of Agricultural Sciences, Bangalore;

Haryana Agricultural University;

Madurai Kamaras University, Madurai;

Indian Institute of Sciences, Bangalore;

Bhabha Atomic Research Centre, Bombay;

University of Baroda;

Cooperation will be sought with a number of laboratories in the U.S.A. with common interests--U.S.D.A-A.R.S., universities, and private non-profit institutes.

Proposed program structure:

(1) Collection, evaluation and application of effective N_2-fixing microorganisms.

Collections of Rhizobium sp., Azospirillum sp. and N_2-fixing blue-green algae will be built as a resource. Native strains collected from the wild should supplement those acquired from other collections. The organisms in the collections will be screened for their effectiveness in

N_2-fixation under controlled and field conditions in the presence and absence of exogenous fixed nitrogen and with attention to responses to stress and ability to use hydrogen. This work should be aimed at identification of improved strains directly applicable in crop production. The collections also will serve as a base for genetic studies of the N_2-fixing system.

(2) Molecular genetics of the N_2-fixing system.

Genetic manipulation of the nitrogenase system has been directed primarily at the free-living N_2-fixers, particularly Klebsiella pneumoniae. It has been possible to transfer the nitrogen fixation (nif) genes to Escherichia coli and other bacteria where they have proved functional. Transfer to yeast has not yielded a functioning nitrogenase, and the more difficult transfer to higher plants has not been successful. Although such a transfer will be difficult, the much more demanding task will be to build a system to protect nitrogenase against inactivation by oxygen and to provide the added energy that N_2-fixation will require from the plant. Initial work will focus on the genetics of N_2-fixation in free-living N_2-fixers with the expectation that information gained from these systems will aid in transferring a functional nitrogenase system to higher plants such as the major cereal plants that now are incapable of N_2-fixation.

Some progress already has been made in the dissection of genes determining the symbiotic ability of Rhizobium meliloti. In several different Rhizobium species at least some of the symbiotic genes have been found to reside on plasmids. Most rhizobia that have been studied seem amenable to the techniques of molecular genetics developed for Escherichia coli and Klebsiella pneumoniae. Following is the list of experiments that should be considered;

(i) A few strains each of the fast and slow-growing groups of rhizobia will be employed to genetically mark and locate Nod, Nif and Fix genes. Labelled probes will also be used for this purpose, whenever possible. R primes carrying some or all of these genes will be constructed and characterized using homologous or heterologous bacteria as the hosts.

(ii) Nod, Nif and Fix genes will be cloned from the R primes and the genes carried on the clones will be identified using complementation tests with mutants. DNA-clones themselves will be used to carry out site-directed mutagenesis to isolate new mutants.

(iii) Agrobacterium strains carrying specific gene clones will be employed to define the blocks in the development of symbiosis and associate them with specific gene products.

(iv) The question will be asked whether any direct interaction occurs between the DNA's of plant and Rhizobium.

(v) Experiments will be done to answer the question why *Rhizobium* genes fail to express in non-Rhizobiaceae bacteria such as *Escherichia coli* and *vice versa*. Markers concerned with one or more building block molecules and with drug resistance will be employed for this purpose.

(vi) *Rhizobium* strains carrying the hydrogen uptake genes (Hup) will be identified. Their Hup genes will be defined and located. Hup genes will be incorporated in the vicinity of Nod, Nif, and Fix genes on the plasmids, if possible.

(vii) The relationship between Nif and denitrification genes will be worked out in suitable rhizobia.

Although long-term, the above research programme is based on the fundamental recognition that information and material to be generated is essential for genetical manipulation of the nitrogen fixation process on a continuing basis, and thus is needed for attainment of the important objectives recognized both in India and the USA. The potential applications will include: (1) improvement of effectiveness of *Rhizobium* strains that are competitive and adapted to specific soil and environmental factors such as pH, salt concentration, toxic substances and water limitation and are effective on locally grown varieties of specific legumes, (2) similar improvement in the effectiveness of associative symbioses, (3) extension of the range of symbioses, and (4) transfer of the nitrogen fixation capability to new systems.

Visit:

A maximum of 20 visits each way on the N_2-fixation project is visualized with a maximum of 2 person-years each way annually.

Revision of the program:

The program may be altered by mutual consent of the Indian and U.S. participants.

Project 1B

Improving the Biological Utilization of Fertilizer Nitrogen.

1. Rationale:

Many years of cheap fuel and resultant cheap nitrogenous fertilizers resulted in a failure to develop methods for efficient use of these fertilizers. Because of greatly increased costs, resulting largely from the dramatic increases in prices for petroleum and natural gas, it is urgent to increase the biological utilization of nitrogenous fertilizers if the momentum of expansion in food production is to keep pace with increased demand for food.

It is estimated that only about 20-40% of the nitrogen applied to the soil as fertilizer is actually utilized by the crop plants. The remainder is lost in a number of ways, and this demands more research to identify loss mechanisms under different agro-production systems and to devise ways to minimize these losses.

Low effectiveness of utilization of nitrogenous fertilizers may result from volatilization, inefficient metabolic processes within the plant, or leaching below the root zone.

This collaborative research will determine the causes of low biological utilization and suggest ways to improve the uptake of nitrogenous fertilizers in both rain-fed, and irrigated crops, including lowland rice crops.

2. Objectives:

(a) Identify, determine and quantify all the different ways by which nitrogen is lost by lowland rice grown in semi-tropical and tropical conditions.

(b) Identify, determine and quantify all the different ways by which nitrogen is lost by wheat in irrigated fields.

(c) Develop methodology for application and use of nitrogenous fertilizers for various cropping systems at different sites and under different soil conditions to enhance their utilization.

3. Research Program Outline:

The sources of loss of nitrogen from flooded rice and irrigated wheat will be determined utilizing appropriate experimental techniques; e.g., ^{15}N-isotope labelling of fertilizer nitrogen, denitrification inhibitors and other techniques aimed at quantifying both gaseous and leaching losses. Quantification of these losses will be related to soil characteristics and water use.

There are numerous management options available to the farmers. This variety of management options include such variables as chemical and physical form of fertilizer, crop variety, planting methods, planting dates, fertilizer application methods, timing of application and many others. Since the package of practices used by the farmer are applied on specific crops at specific sites, research must be conducted to determine what package of practices result in the most effective utilization of nitrogenous fertilizers for major crop and soil situations.

4. Duration:

   (a) Short Range:

   6 months (take off period)

   2 years data collection and analysis

   (b) Long Range:

   5 to 10 years to include all major soil and crop conditions.

5. Expected Funding Sources

   (a) India

   Indian Council of Agricultural Research

   (b) U.S.

   U.S.D.A. - Special Foreign Currency Program in India

   U.S.A.I.D. - Agricultural Research Program

   U.S.A.I.D. - Soil Management Support Services Project

   U.S.D.A.-A.R.S.

6. Collaborating Institutions in India

   Central Rice Research Institute - Cuttack

   Tamil Nadu Agricultural University - Coimbatore

   University Agricultural Sciences - Bangalore

   Punjab Agricultural University - Ludhiana

   Indian Agricultural Research Institute - New Delhi

   Dry Land Agricultural Project - Hyderabad

7. Collaborating Institutions in USA

   University of Nebraska

   USDA-ARS, Beltsville, Maryland

   University of Minnesota

   University of California (Riverside)

Project - 2 - Increasing biomass for food and fodder, and for soil improvement.

FORESTRY PROBLEMS IN INDIA

There are two distinctly different forestry needs in India. The first is concerned with the reforestation and proper management of the vast areas of forest land in the mountaneous areas of the Himalayas. These forests produce most of the wood that is available for use as lumber, paper and pulp. These forests are also of great value because of their indirect effects on the watershed. When properly managed, such forests control run-off, reduce erosion, reduce siltation of reservoirs, and flooding on the plains below. They also are valuable as habitats for many species of wildlife and provide opportunities for outdoor recreation.

These vast mountaneous forest land areas have been, in many areas, denuded and need reforestation and improved management practices. However, commensurate with the tasks substantial resources are needed.

The second forestry need is Agro Forestry to re-establish forest plantings primarily for the production of firewood on waste land around villages, along highways, roads, railroads, canals and on eroded or waterlogged saline soils unsuitable for the production of agricultural crops. These are sometimes known as social forestry plantings, for they are primarily established to provide firewood for local villagers. During the last several years, a number of Indian organizations have initiated social forestry planting programs. There is, however, a dearth of research information to support them. The research program proposed by the Indo-USA Senior Scientific Panel is aimed at providing this essential knowledge.

The problem: To produce wood for fuel and thereby return more animal waste to the soil as manure.

1. Objectives. The objectives of this project are as follows:

   (a) To evaluate fast-growing firewood tree and shrub species for their potential as biomass producers for fuel and fodder and for soil improvement, at four different latitudes and on at least one semi-arid site.

   (b) To evolve agrotechniques for silviculture and biomass farming on marginal lands. Spacing, intercropping, rotation, fertilization, coppicing responses, etc., will be evaluated.

   (c) Improvement and rapid multiplication of the most promising selections from the best adapted species by tissue culture techniques and/or cuttings.

   (d) Biomass utilization and processing for energy.

2. Technical Research Program

(a) Collection of germ plasm. Germ plasm will be collected over ecologically similar regions of the world and across four latitudes. The most promising species will be selected for different types of environments and marginal lands. Ecological criteria, biomass yield potential, amenability to high density planting and short rotation, nitrogen fixing potential, tolerance to soil salinity, biomass fuel value, and suitability for combustion and potential use as forage will be applied in evaluation.

(b) Seed Origin, Procurement and Maintenance

Genetic control will be effected through seed origin and maintenance of vegetative germ plasm. Genetically superior clones will be selected. A seed collection will be developed based on such criteria as optimal characteristics of the plant to ensure high survival and rapid initial growth. Seed storage methodologies and optional breeding systems will be developed.

(c) Mass Multiplication Through Tissue Culture and Population Improvement

Techniques for mass multiplication will be applied to intractable species and also to elite clones. Techniques will be standardized for clonal propagation and for mass production of saplings for firewood and afforestestation. Tissue culture techniques will be used in production of disease-free stocks and in selection of variants at the cellular level; large numbers of cells can be tested against the physical and chemical stresses encountered on marginal lands in an attempt to isolate cell lines with superior characteristics.

(d) Insect Pest and Disease Management. Potential animal, insect and disease problems in biomass plantations will be examined in relation to species, soil, climate, intercroping and other agronomic practices.

(e) Population Improvement for Disease Resistance.

3. Potential Collaborating Institutions in India

1. National Botanical Research Institute, Lucknow
2. Biomass Research Centre, Kamraj University, Madurai
3. Forest Department, Uttar Pradesh, Lucknow
4. Forest Department, Tamil Nadu, Madras
5. Centre for Energy in Agriculture, Punjab Agricultural University, Ludhiana
6. Central Drug Research Institute, Lucknow
7. Botany Department, Calcutta University, Calcutta
8. University of Agricultural Sciences, Bangalore
9. Central Arid Zone Research Institute at Jodhpur, Rajasthan
10. Indian Grassland and Fodder Research Institute, Jhansi, U.P.
11. Bharatiya Agro Industries Foundation, Urli Kanchan, Maharashtra
12. Central Soil and Water Conservation Research and Training Institute, Dehra Dun
13. Central Soil Salinity Research Institute, Karnal.
14. Andhra Pradesh Agricultural University, Hyderabad
15. Birsa Agricultural University, Ranchi, Bihar
16. Forest Research Institute, Dehra Dun
17. G.B. Pant University of Agriculture and Technology, Pantnagar

18. Indian Agricultural Research Institute, New Delhi

19. Central Plantation Crops Research Institute, Kasargod

20. Indian Institute of Horticultural Research, Bangalore

21. National Chemical Laboratories, Poona

4. Potential Collaborating Institutions in USA

1. Forest Products Laboratory, University of California, Richmond, California

2. Laboratory of Renewable Resources, Purdue University

3. Chemical Technology Division, Oak Ridge National Laboratory, Tennessee

4. Forest Products Laboratory, USDA, Wisconsin

5. Eastern Regional Laboratory, USDA, Philadelphia, Pennsylvania

6. North Carolina State University

7. U.S. Forest Service

8. Texas Tech University

9. New Mexico State University

Other Considerations

1. It is recommended that the scientists selected to participate in each of the areas of agriculture and forestry identified by the Senior Scientific Panel meet to develop detailed plans for specific collaborative research projects.

2. The mandate for the Indo-US Senior Scientific Panel required that only a few of the highest priority areas regarding research be identified for this initiative. The panel has recommended collaborative research to (I) improve nitrogen utilization in the biosphere through enhanced nitrogen fixation and efficient fertilizer use, and (II) increase efficiency of production of woody tree and shrub species for fuel and fodder and for soil improvement.

Discussions during the panel's deliberations and visits reaffirmed the areas identified by the joint Indo-US Subcommission on Agriculture and Science and Technology in June 1982 as being high priority areas for collaborative research.

This Senior Scientific Panel wishes to indicate its strong opinion that early attention should be given to the following areas:

1. Integrated plant nutrient management systems
2. Water Management
3. Post-harvest management of agricultural products
4. Improvement of safflower.