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PLANNING AN INTERNATIONAL NETWORK OF LEGUME INOCULATION TRIALS

NIFTAL

College of Tropical Agriculture and Human Resources
University of Hawaii
and
U.S. Agency for International Development

1979

PLANNING
AN INTERNATIONAL NETWORK OF
LEGUME INOCULATION TRIALS:

The Proceedings of a Workshop
Held at Kahului, Maui, Hawaii
January 15-19, 1979

Edited by
Susan C. Harris

NifTAL PROJECT

College of Tropical Agriculture and Human Resources
University of Hawaii
and
U.S. Agency for International Development

September, 1979

PREFACE

Farmers inoculate legumes with Rhizobium because they expect to obtain high crop yields more cheaply than by applying nitrogenous fertilizers. Commercial or governmental promotion may encourage adoption of legume inoculation technology initially, but continued use will result only if real benefits are obtained. In the United States of America and in Australia, recognition of the benefits from inoculating certain legumes has created a demand for inoculants that supports substantial commercial inoculant production.

For the majority of tropical legumes, however, no such demand for inoculants exists. Is this because inoculation of these legumes has not been tested? Or is it that inoculation does not benefit tropical legumes?

Scientists worldwide affirm that few studies with tropical legumes have conformed to the criteria considered essential for a definitive inoculation trial. Many projects are thus being initiated to evaluate legume inoculation. Out of recognition that individual trials would be more meaningful if coordinated in an international network, a planning workshop was organized by the NifTAL Project. The aim was to develop an experimental protocol and a strategy for its implementation on a global scale.

Because it was anticipated that scientific expertise alone would not be enough to launch such a complex undertaking, a balance of agricultural and social scientists, researchers, administrators, and management specialists were invited from organizations experienced in related ventures. There were inherent risks in assembling a group from such diverse backgrounds, but fortunately the participants were particularly adept at interdisciplinary communication. The informal program scheduled ample time for discussion, but could not guarantee thatit would be fruitful. Evocative presentations by the speakers and ad hoc leadership assumed by individual participants during the working sessions ensured steady progress over the week of interchange.

The main outputs of the planning workshop were those that had been hoped for: a basic design for an experimental program that will define the value of inoculating tropical legumes with Rhizobium, and a strategy for implementation of an International Network of Legume Inoculation Trials. But the major success of the workshop was the participants' unanimous and generous declaration of support to the NifTAL Project as it undertakes major promotional responsibility for the Network.

This volume has been published because the information communicated by the participants in presentations and working sessions merits wider distribution. That the topics covered are more diverse, and the sequence more disjointed than would normally be encountered in a single volume cannot be denied. However this may be permissable insomuch as these are the actual proceedings of a workshop which, whether by accident or design, successfully achieved its objectives.

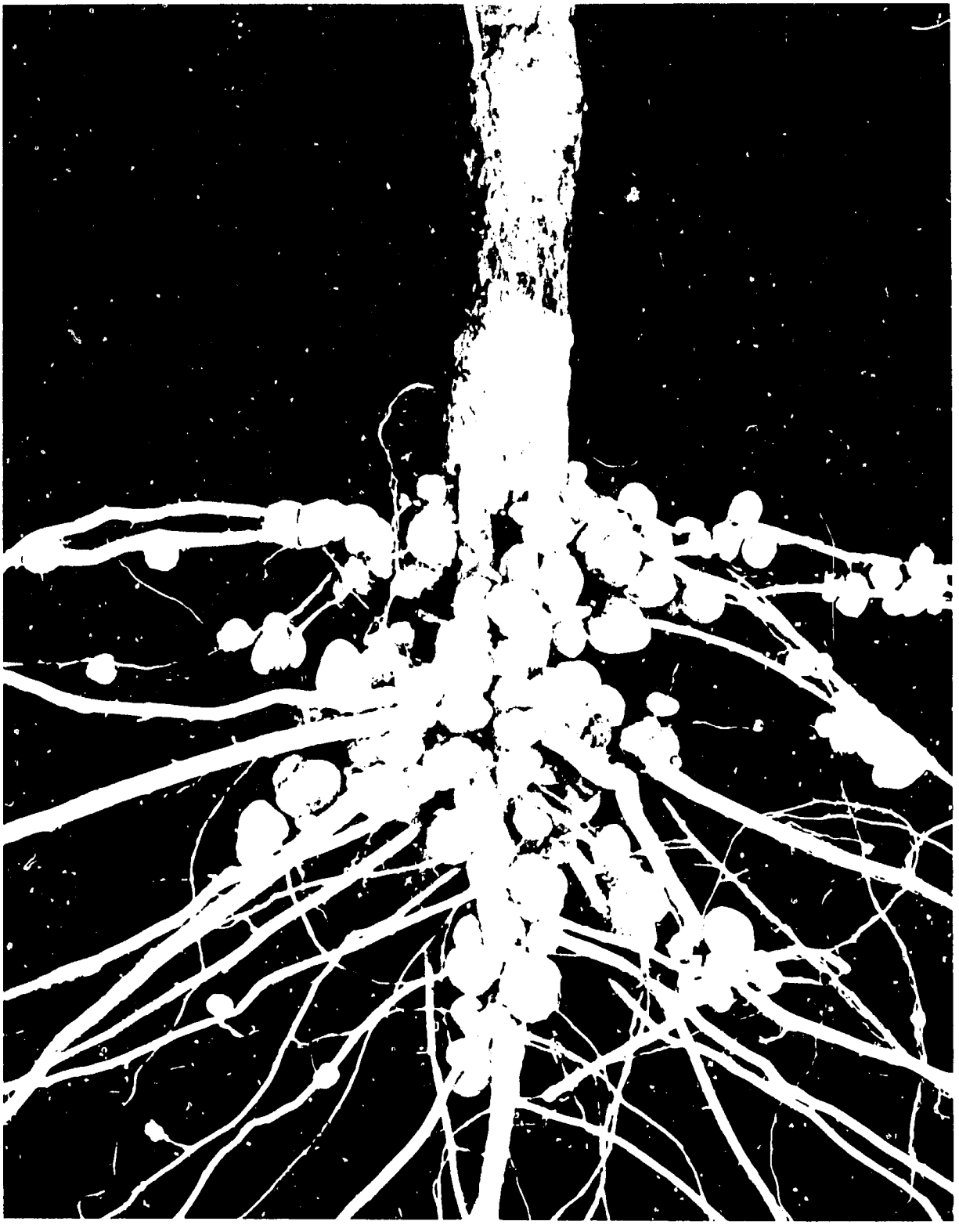

Photo courtesy of Nitragin Co.

Legume root-nodules housing the bacterium Rhizobium can supply the nitrogen required for production of high protein seed without the need for expensive, man-made nitrogen fertilizer. It is seldom possible to obtain abundant nodules unless specially selected types of Rhizobium are introduced to the soil with the seed at planting time.

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FIRST PLENARY SESSION

Keynote and Introductory Addresses

TECHNOLOGICAL CHANGE, FOOD AND WORLD SECURITY

Harrison Brown
Director, Resource Systems Institute
East West Center

As a young man during World War II, I worked on the development of atomic bombs, and there was a natural tendency for most of us who were engaged in such activity to ask ourselves where mankind might be heading. In 1946, I wrote a book dealing with the dangers of nuclear war. However, by the early 1950's I had come to appreciate that, although nuclear war is indeed a serious danger, other problems are, in a very real sense, even more dangerous. Such problems as rapid population growth, the growing affluence and complexity of industrial society, rapid technological change, and decreasing availability of resources can, by themselves, result in the collapse of our civilization, even in the absence of nuclear weapons. The massive deployment of ICBMs equipped with hydrogen warheads, coupled with the proliferation of nuclear capabilities in the world, serve only to make these basic problems more acute.

In 1954 I wrote a book, The Challenge of Man's Future, in which I attempted to look into the future from the point of view of these other problems. Now, more than two decades later, I find the forecasts in that book to be both surprisingly and depressingly accurate. Although at the time of publication I was criticized by some as being overly pessimistic in outlook, the forecasts, where they err, were more often than not based upon overly optimistic assumptions. The most glaring piece of optimism was the tacit assumption that environmental problems would be solved as quickly as they appeared, with the result that they would present no serious threat.

For many years I have been apprehensive about a number of developments, most of which are rooted in rapid technological change. In recent years my apprehensions have been amplified by the fact that those developments are rapidly converging--with consequences for mankind which are difficult to comprehend; yet which are potentially disastrous.

For the greater part of the history of modern industrial civilization, the distribution of income and consumption among the world's people appears to have been a continuum with most persons being very poor, a few being very rich, and the rest, numbering more than the rich but fewer than the poor, being somewhere in between. Since World War II, however, a striking pattern has evolved amounting to no less than a fissioning of human society

into two quite separate and distinct cultures--the culture of the rich and the culture of the poor, with very few people living in between these two extremes.

The evolution of this process is clearly illustrated by the changing patterns of per capita energy consumption, steel consumption and gross national product since 1950. The data show that with little doubt the world is destined, in the absence of catastrophe, to remain divided into two cultures for a very long time in the future. If present trends continue for the next 50 years, per capita consumption of energy in the rich countries will be 40 times greater than in the poor. By that time the population of human beings in the world will be more than ten billion persons, some 85 percent of whom will be poor.

Growing affluence in the rich countries is the counterpart of growing population in the poor. When we think of "population" it is misleading to think simply in terms of numbers of people. We must also think in terms of the materials which are associated with an individual as well as the energy that is required for the individual to function. For example in a peasant-village society a typical person might have associated with him a part of a wooden or stone dwelling unit and a few simple tools. He and his possessions will be powered for a year by perhaps 150 kilograms of cereal each year. A person in an industrialized society, by contrast, requires the energy equivalent to burning more than 10 tons of coal.

Clearly something is bound to give long before 2020 A.D. is reached. Current growth rates simply cannot persist much longer. Of consuming interest is the manner in which growth rates will change. Will rates of population growth and per capita consumption change as the result of premeditated, willful, constructive actions on the part of the world's people? Will they change as the result of such factors as malnutrition and disease, environmental degradation and decreasing resource availability? Will they change as a result of continuing conflict between rich and rich, between poor and poor, and between rich and poor? Or will growth rates change as the result of a major catastrophic world upheaval?

The rich nations are characterized by low death rates and by low and decreasing birth rates. Collectively the 950 million inhabitants of the rich countries are increasing their numbers at the rate of but 0.8 percent per year, a factor of three smaller than the rate of population growth in the poor countries. High and increasing levels of agricultural production per man-hour worked have

resulted from mechanization (using fossil fuels for energy), liberal application of fertilizers and pesticides, irrigation and the genetic selection of plant varieties best suited for particular environments.

As agricultural productivity has increased and as industries have been developed, people have migrated from rural to urban areas. Most people now live in or near cities and their proportion appears likely to increase.

As affluence has increased, diets have changed. Generally, rich people eat more animal products than do poor ones, and on the average, about ten plant calories are required to produce an animal calorie in the form of meat, milk or eggs. Per capita cereal consumption in the United States now exceeds 700 kilograms per person, most of which is fed to animals. This is about 4.5 times larger than per capita cereal consumption in India, where most of the grains are eaten directly by people.

There is some evidence that per capita consumption of cereals has stopped increasing in the United States. But in other regions of the rich part of the world, notably Europe, the USSR and Japan, per capita cereal demands are increasing rapidly and might eventually approach that in the United States. In view of the fact that cereal demands in the rich countries already represent a substantial proportion of the total world demand, it is important that we attempt to estimate the future demands for cereals on the part of the rich countries, viewed in terms of growing affluence and changing food technologies.

As the rich countries have become more affluent, individual demands for material possessions and services have grown as well. In large parts of the United States automobile ownership is approaching one car for every person of driving age. Per capita ownership of refrigerators, telephones, radios and television sets, at one time luxuries, is increasing rapidly in the rich part of the world. Education to the highest levels seems destined to be available eventually to all who desire it and who can absorb and make use of it. Resources being allocated to medical care are increasing with extraordinary rapidity. As society has become more complex governments have become larger and more pervasive with the result that increasing numbers of persons are required for government service.

The rich countries are investing tremendous resources in developing increasingly effective means to kill and to destroy, and in deploying the new weapons. Between 1961 and 1971 the world spent some $2000 billion on military

establishments. Such expenditures in the United States alone nearly equal combined expenditures for public education and public health. The rich have armed themselves to fight each other as well as the poor; they have armed the poor to fight each other; and they have armed the poor to fight the rich.

As affluence has increased, demands for raw materials have also increased. Demand for steel in the rich countries is increasing at the rate of 5.8 percent annually, and demand for other metals is increasing proportionately. Total energy demands in the rich countries are increasing at the rate of 5.2 percent annually. Per capita consumption of energy in the United States has now reached the equivalent of burning about 10 metric tons of coal each year per person and is increasing at a rate of about 15 percent per decade.

The trend in per capita steel consumption offers the only evidence for a lessening of the growth rate of metal consumption in a rich country. During the first half of this century steel production in the United States increased extremely rapidly. For the past quarter century, however, although total steel production has continued to rise, per capita consumption has remained at about 0.55 metric tons per person per year. The reasons for the flattening of this growth curve are not clear, but studies suggest that, for complex reasons, this might represent the maximum rate at which new steel can be effectively absorbed by a highly industrialized society.

Industrial man has become a major geological as well as ecological force. The waste products of industrial civilization are polluting the atmosphere, oceans and land areas. As demands for raw materials increase still further and man is forced to process ores of decreasing grade, consumption of materials, and particularly energy, will increase still further, and problems of environmental degradation will become even more serious than they are today.

The trends, as exemplified by the case histories of the development of Western Europe, the United States, the Soviet Union and Japan, raise many questions. How will they continue to provide for their needs for raw materials? How will they provide for their food? What technological developments are likely to change their future direction? How will they come to grips with their expanding environmental problems? Collectively, can they avoid nuclear conflict? As their internal systems of extraction, production and distribution become increasingly complex,

will they be able to control the numerous disruptive forces which, in one form or another, will always be present? Finally, in what ways will the rich countries interact with the poor ones?

The poor nations are characterized by high death rates and by high birth rates. Collectively the 2440 million inhabitants of the poor countries are increasing their numbers at the rate of 2.5 percent per year. For the most part, birth rates hover around 40-50 births per 1000 persons per year, although a few areas have experienced substantial reductions in recent years (e.g. Taiwan, South Korea, Singapore, Hong Kong). Death rates are highly variable, ranging from about 5 (Taiwan, Singapore, Hong Kong) to highs of 25-30 in large parts of tropical Africa. There is, thus, considerable variation in the annual rate of population growth, ranging from a high of 3.4 percent per year (Morocco, Rhodesia, Iraq, Colombia, Ecuador, Venezuela) to a low of about 1.5 percent per year (Jamaica, Argentina, Uruguay).

The vast majority of the inhabitants of developing countries live within the framework of peasant-village culture. Although most persons live on or close to the land growing their own food, the proportion of persons living in the cities is increasing. The rapid growth of cities in most of the poor countries stems from a combination of rapid population growth, limited availability of land, and increasing farm productivity--all coupled with the lure of jobs and money. Unfortunately, however, people are migrating to the cities more rapidly than jobs can be created, or for that matter more rapidly than services such as housing, water and sewage can be provided. Large parts of the huge cities of India such as Calcutta and Bombay have become vast slums, disease ridden and teaming with hungry unemployed.

The future of the poor nations depends in large measure upon how rapidly population growth can be slowed, agriculture can be modernized and industries can be created (both in the urban and rural areas). Although fertility rates have decreased in certain areas, quite possibly as a result of the introduction of substantial family planning programs, it is nevertheless possible that the poor countries collectively have not yet reached their peak rate of population growth. Further, there is as yet no clear indication that the rate of population growth in the poor countries will be lowered soon by conscious human action. It seems more likely at present that the rate of growth will lessen as the result of increased mortality stemming from malnutrition brought about by massive shortages of

food.

The food situation in the world today is alarming, aggravated by a combination of growing population, growing affluence, shortages of fertilizers, sharp increases in petroleum prices, and unfavorable weather. Modernization of agriculture depends upon the availability of water and fertilizer. Petroleum is needed tc run pumps and for fertilizer manufacture. A four-fold increase in the price of crude oil can have a devastating effect upon the agricultural production of a number of populous countries which lack their own supplies, for example, India, Pakistan, Bangladesh, the Philippines, and Egypt.

The modernization of agriculture cannot be divorced from industrialization. Fertilizers and pesticides are produced in factories which require steel for their construction, plus a variety of equipment, as well as energy. Transportation to and from farms requires trains, trucks and roads.

Total energy and steel consumption in the poor countries are increasing about as rapidly as in the rich ones. But so rapid are the rates of population growth, per capita consumption of energy and steel is increasing extremely slowly. The vacuum to be filled is enormous. If by some magic the per capita inventory of metals in use in the world as a whole were to be brought up to the average level of the ten richest nations, all the present mines and factories in the world would have to operate for more than 60 years just to produce the capital, assuming no losses.

Case histories of the trends in poor countries such as India, Egypt, The People's Republic of China and Brazil raise numerous questions. How large are the populations of the poor countries likely to become? How will they cope with the numerous consequences of rapid population growth? How will they provide for their food? Where will they obtain their raw materials? How will they cope with their tremendous problems of urbanization? How large will their military expenditures become? Can they avoid conflict among themselves? Can they avoid conflict with the rich?

Rich and poor nations are coupled by a variety of mechanisms, the most important of which are trade and communications. Most rich nations are heavy importers of raw materials, primarily from the developing countries. The Middle Eastern countries, North Africa, Nigeria, Venezuela, and Indonesia, export oil. Morocco and Tunisia export phosphates; Bolivia and Malaysia export tin; Jamaica exports bauxite; Peru, Chile and Zaire export copper. All

together, about 20 developing countries, inhabited by some 450 million persons, are benefiting or will soon benefit from significant exports of non-renewable raw materials. Clearly the money obtained from the sale of these resources, if invested wisely, can accelerate development.

An additional 900 million persons in the developing world live in countries which are reasonably self-sufficient with respect to non-renewable resources, including energy. These nations, which include China, Colombia, Mexico and Peru, for example, were not appreciably harmed by the sudden increase in the price of crude oil, which took place in 1973.

Another 60 million persons live in countries including South Korea, Taiwan, Hong Kong and Singapore which, like Japan are closely integrated with the world economy, almost entirely through the manufacture of goods.

About 925 million people inhabit countries which are in serious trouble with respect to raw materials and in particular energy. These include the entire Indian sub-continent, the Philippines and Egypt. These nations require fertilizers if they are to increase food production and they require energy if they are to increase fertilizer production.

Renewable resources such as foodstuffs also flow between the rich and poor nations. Grain flows from North America to Asia, Africa and Latin America. Coffee flows out of Latin America. Fruits, vegetables and flowers flow out of a number of developing countries. Hardwoods flow from many tropical countries to Japan, Europe and America.

But many changes are taking place in the flows of renewable and non-renewable raw materials between the rich and the poor countries. For example, Venezuela intends to discontinue exports of iron ore to the United States and develop her own integrated steel industry using coke purchased from Colombia. She wants to decrease her exports of crude oil and develop her own petrochemical industry. Chile wants to decrease her exports of copper ingots and build plants to manufacture finished copper products. Taiwan is building a fertilizer plant in Saudi Arabia. Ghana is producing metallic aluminum from her own bauxite. How rapidly will such developments take place and what will be their cumulative effect upon the rich countries?

With respect to the flow of foodgrains, three rich countries--the United States, Canada, Australia--remain the only substantial exporters. The greater part of their shipments are made to other rich nations which can afford

to pay, and to a few poor countries, notably China, which can also afford to pay. As affluence grows in the rich countries and population grows in the poor ones competition for exportable surpluses will become increasingly severe, with the poor nations standing every chance of being the losers.

Rich and poor countries are also linked by arms shipments. By 1970, military expenditures in the developing countries were approaching 30 billion dollars annually, and most of the arms were imported from rich countries, notably the US, the USSR, the UK, France and Sweden. Military expenditures in the poor countries are small when compared with those of the rich; they are nevertheless important elements of their budgets. In the poor countries, collectively, military expenditures exceed combined expenditures on public education and public health.

Technological skills and knowledge link rich and poor nations in many ways ranging from peaceful to warlike. Transfers of technical knowledge from the rich countries to India made possible the "Green Revolution." Such transfers also made possible the detonation by the Indians of a nuclear device. It is probable that quite a few of the Chinese scientists responsible for the development of their nuclear devices and guided missles received training in the laboratories of the rich countries.

Finally the rich and poor nations are coupled by rapid communications. Prior to a few decades ago, the people in the poor nations knew vaguely how the people in the rich nations lived, but it was little more than rumor. Today they can see it on television and in motion pictures, they can hear about it on transistor radios and read about it in diverse publications. With the rapid growth of education in the poor countries coupled with high rates of unemployment and inequitable income distribution, rapid communication breeds discontent which often evolves into hatred.

From the time of the invention of agriculture man has had profound effects upon his environment. Deforestation has changed patterns of water run-off and altered the carbon-dioxide balance of the atmosphere. Consumption of coal and petroleum have increased the carbon-dioxide content of the atmosphere appreciably, thus altering the radiation balance. Industrial activity has increased the concentration of particulate matter in the atmosphere, also affecting the radiation balance. Our increasing energy consumption is changing the patterns of atmospheric heating. Large-scale use of fertilizers and pesticides can give rise to critical environmental alterations. As nuclear power comes into

widespread use, contamination by radioactive substances will be a matter of major concern. As mining operations increase in size, the destruction of soil and scenery on a large scale will be inevitable.

The probability is high that world climate is changing and it is quite possible that such factors as carbon-dioxide, particulate matter and energy generation will affect climate in varying ways. Were climate to change in the years ahead in such a way as to affect adversely agricultural production in the rich countries, the poor countries, or both, the consequences could be disastrous.

How stable is the rich country-poor country system? We all realize that rich countries can destroy each other with nuclear weapons. But can poor countries do much harm to rich ones?

Few studies have been made of this problem, but it seems likely that rich countries are far more vulnerable to disruption than are poor ones. A highly industrialized country consists of vast networks of mines, factories, communication and distribution facilities. If certain elements are destroyed, the entire system might stop functioning. By contrast a peasant village society as India with 500,000 villages, only loosely coupled to each other, is relatively immune to disruption.

Given a substantial potential for conflict, the question of the vulnerability of industrial society to disruption takes on a very serious dimension indeed. Quite apart from all-out warfare, rich countries have already experienced extreme difficulties when confronted by high-jackers, kidnappers, and other forms of terrorism. Even lawful actions, such as strikes of garbage collectors and transportation workers, have emphasized our vulnerability. Once nuclear power generation becomes truly widespread in the world, as it probably will, what are the prospects for major terrorism? The potential is probably considerable. Even in the absence of nuclear explosives the situation would be serious. But, given a continuing possibility for division of nuclear materials, it should be possible for a few persons to paralyze large elements of our society.

As we attempt to formulate possible U.S. policies, it is important that we recognize that the "food-population-resource problem" is itself a vast system composed of a large number of interrelated parts. Once we understand this we appreciate that there is no such thing as a "solution" to the over-all problem. Rather, if the broad problem is to be brought under control, the resolution of

a number of component problems must be pursued simultaneously. Many choices and combinations of choices are possible.

An over-all resolution of the world problem clearly would involve in varying degrees the following very broad long-range interrelated goals:

1. Increasing world food production in such a way that each major area of the world becomes self-sufficient;

2. Increasing the efficiency of food utilization and distribution;

3. Decreasing the rate of growth of affluence;

4. Decreasing the rate of growth of population;

5. Establishment of a carefully controlled international food reservoir which can be drawn upon in years of poor crop yields and replenished during years of relative abundance;

6. Establishment of an efficient world system for estimating harvests in all regions of the world in time to make the necessary adjustments in world cereal distribution;

7. Shifting to coal and nuclear powered economies in such a way as to minimize the harm to the environment;

8. Learning how to make maximum use of solar energy for heat and power;

9. Accelerating the economic development of the poor countries;

10. Creation of new international institutions which will enable nations to dispense with their tremendous weapons systems and greatly decrease their wasteful expenditure on arms.

Given these ten developments it is hoped that a stable world in which men can live at peace with nature and with each other will evolve. The accomplishment of these goals will be an enormous task requiring the dedicated efforts of all of us.

Speaking as a member of the scientific community of the richest of the rich countries, I suggest that scientific

and technological inputs are critical to the solution of these problems. I also suggest that from a scientific and technological point of view, hunger and poverty in the world are inexcusable.

Confronted as we are by a complex of problems, all of which are difficult; all of which are interrelated, we clearly need a great amount of research if we are to understand them--let alone solve them. Our survival depends upon their identification and their solution.

I am confident that we in the United States have the technological competence to survive. The real question is: Do we have the intelligence to recognize this, and the political competence to put that technological competence to work? If we don't, I fear the worst.

THE SCIENTIFIC METHOD AND RESEARCH MANAGEMENT--PARTNERS IN PROBLEM SOLVING

N. P. Kefford

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First, I should establish credentials for speaking to a workshop on biological nitrogen fixation, other than as administrator of the unit to which the Project on Nitrogen Fixation by Tropical Agricultural Legumes (NifTAL) belongs. So you must excuse an extended reference to some personal experiences. About 20 years ago, I published a paper on the nodulation process. But that barely qualifies as a credential, because I was really interested in the process only as a means of probing the hormonal regulation of plant development. On the other hand, every Australian, at least in my generation, learned at school that "Australia rides on a sheep's back." As our knowledge increased, we learned that the sheep, upon which we all rode, was walking in a clover pasture--that is, if it was a fortunate sheep. The Division of the Australian, Commonwealth Scientific and Industrial Research Organization (CSIRO) for which I worked, Plant Industry in Canberra, was preoccupied with clover-pasture research, and in the early 1950's a group from that Division moved north to Brisbane to investigate agricultural legumes for increasingly tropical ecosystems.

The Australians were, of course, concerned with converting gaseous nitrogen, through plants, into the nitrogen of the protein fibers of high-quality wool. My early observation of this plant-animal system was that the communication between the plant scientists and animal scientists was not optimal. For instance, the sheep physiologists complained that the agronomists turned up at the field station on the first, fine, warm day of spring to set out their plots, whereas the real problems in meeting the feed needs of the sheep had occurred in the previous three months of winter. So I made a move which was personally fateful. I organized symposia on topics such as "Plant lignification in relation to ruminant nutrition," in which plant and animal scientists had to interact. I did not recognize it at the time, but this was my first move into research management, an activity in which I now find myself totally absorbed. It is critical to the progress of the current workshop that we recognize the reality of and the necessity for research management in the complex system we are studying. It is equally critical that we distinguish clearly between management and the scientific method. They

are, in my opinion, essential but distinct components of an effectively-organized, research attack upon the problems of a system containing many interrelated components.

The system we are studying is even more complex than the Australian system described earlier. We are concerned with getting the atoms from gaseous nitrogen into the proteins, nucleic acids and other essential nitrogenous components of the cells of a healthy, mentally alert, human being who is able to achieve his or her potential as a citizen of the world. I content that the more complex the system, the greater the need for effective management. But we must be fully aware that research management, including administration and organization, can do nothing more than create the conditions in which individuals or groups of individuals can generate, test and propagate ideas. While ideas are the sparks of the scientific method, these ideas are the least tangible and the most mysterious aspect of the research process. So if management exists to foster idea generation, it clearly must involve much more than concrete support services such as getting scientists paid, assuring that laboratory and field facilities work, and arranging travel.

I am proposing the scientific method and management as complementary partners in the overall research process, and to make my point of view clearer, we must look at their individual roles in detail.

The crux of the research process is the scientific method, and the steps in the method are assumed to be well known. In the scientific method, existing data and existing hypotheses constitute the known. From this base, we analyze the frontier of the known and define a testable hypothesis for extending the frontier. The aim of the testing is to disprove the hypothesis and we do that by validating testing methods, collecting data, and analyzing the new data and relating it to old data. Then we ask, critically, whether the hypothesis has been disproven. We must recognize the wholeness of the scientific method and the interdependence of its components. The method works ... but only as a unit. What is the extent of this unit that we call the scientific method? A lead may be sought by asking when research is completed. Research is not completed until it has been independently, directly or indirectly corroborated, which means the work has been published in a form that permits its precise repetition. Delivery to some level of clientele, and accountability, are parts of the scientific method. We are accountable to our peers and to nature, however, nature and our peers serve as stimuli as well as judges in our scientific

endeavors.

If we are realistic about the functioning of the scientific method, we see that no individual alone can embrace all aspects of the method. There is the need for intellectual unity, interdependence and interlocking of many individuals. Scientific management must provide opportunities for this unity.

Research management exists for scientists, and, in my experience, it must be created by and operated by scientists. As the scientific method is the core of the research process, I believe that management of the process requires experience with the scientific method. It is not enough to have read the rules--one must have played the game to the finish and taken the knocks. The rule book cannot describe the most important element of the game: the genesis and painful elimination of ideas.

Research management cannot function only through the introverted process of individuals or groups producing ideas, it must also provide links with society. Western culture generated the scientific method and the scientific method generated modern society. But this society using the results of research has a confused and highly variable concept of research. Attitudes toward research change, and there is an increasing clamor for accountability in research. More commonly than before, institutions and individuals of all types and descriptions are saying, "I need research!" In so saying, everyone means and indeed actually needs something different. But the research process--a combination of management and the scientific method--can cope. It can sort the apples from the oranges and, hopefully, can avoid getting the raspberry.

When we receive appeals for research, we sort them into the "unknown," or the "known." To the known, we can respond directly or through adaptation. Within the unknown, problem analysis and definition helps us distinguish between "real" and "unreal" problems, and among the "real," to decide which are researchable. We proceed with the researchable problems through the steps of the scientific method, and a response in terms of the research can be delivered. However, we must recognize realistically that at any step in the scientific method we can hit a barrier that blocks the process. In such circumstances, we must make the honest response that the scientific method has limitations and does not produce miracles. Research management provides a means for all facets of society to appeal for research and to tap the scientific method. It can also produce in society a realistic understanding of research and its limitations,

thus avoiding frustrations and unhappiness.

In Hawaii, we believe we have developed and tested a research management system that produces a good melding of the research sector with other sectors of society. Hawaii's society is a microcosm which provides conditions for testing a system that has a chance of general applicability. Our management process provides the means for analyzing complex systems into interrelated components of manageable size. It defines problems and sets them in order of priority, and proposes the actions and resources needed to overcome the problems. It provides the data needed for accountability and indicates the impact of taking or not taking actions to overcome problems. What is more, it involves all those in society who can contribute positively, so that the system is now generating overall State policy and practice for agriculture. I mention our successful system to encourage you in the faith that you can do likewise.

For research, the management system provides problems in an order of priority that all elements of society have accepted as a consequence of a systematic and rational assessment of a total agricultural system. Thus, the management system hands over to the scientific method those problems, the solutions of which have the potential to make optimal impacts. But it is up to the scientists, working within the scientific method, to develop the hypotheses and objectives relevant to the problems. A management system cannot create ideas, nor can it dictate that individuals shall have ideas--it can only provide the conditions for ideas to arise.

That is what this workshop is about. If it is successful, it will create unique conditions causing the generation of ideas and the means of testing them. Overall, we are considering nitrogen economics in tropical ecological systems. As the consequence of a broad hypothesis, we have focused our attention on a portion of the problem: the potential contribution of the inoculation of tropical legumes with rhizobia to plant productivity. We will be developing subhypotheses and means of testing them. But we must keep the loci of your attention in perspective, coordinated, and on track. The development of an effective research system can do this, at the same time as assuring the maintenance of the highest academic standards and a creative atmosphere that is spontaneously generated.

GOALS AND METHODOLOGY FOR THE WORKSHOP

A. Sheldon Whitney
Principal Investigator, NifTAL Project

Dr. Harrison Brown has painted a mural for us--a large and intricate one--and has pointed out gaps within the mural, blank wall if you please, and other spaces that are sketched in but not yet painted. Some of these spaces look familiar enough that we might be able to fill in the blank gaps or give some color to the sketched scenes.

How do we go about it? Within this mural of complex problems and technological change, how can we best achieve an appropriate impact that will improve the well-being of small farmers and under-nourished people in developing countries? Our starting point is the legume, with its tremendous potential for providing high yields of protein and for improving the nitrogen economy of cropping systems. Our goal is to achieve even higher legume yields and in some cases at least, more residual nitrogen for the next crop.

Opposing these goals, we find that in a number of places the area devoted to legume crops is actually declining, and further, that legumes are being displaced to less-fertile, rainfed, upland soils by higher-yielding cereals. This is doubtless due to one or more interrelated factors, including:

1. That alternative crops have a higher yield potential than legume crops;

2. That legumes are more susceptible to insects, nematodes, diseases, and weed invasion, and are thus less reliable than alternative crops, unless high management inputs are applied;

3. That legumes demand greater amounts of phosphorus, lime, etc., than alternative crops;

4. That increasing population pressures increase the demand for cereals more than for legumes.

These factors have overshadowed the two big advantages of legumes: they do not need nitrogen fertilizer, and they provide high-protein products. At this workshop we cannot hope to deal with all questions associated with the growing of legumes, but we can address a very important part of the problem--that of ensuring that the legume has the best possible *Rhizobium* strain in order to maximize nitrogen fixation under both prevailing and improved management systems.

About 2½ years ago, some of us met on this island to consider the potential for more fully exploiting the legume-*Rhizobium* symbiosis in tropical agriculture. It was a very useful and valuable workshop. The proceedings are a valuable contribution to the literature and are in great demand. The focus of this workshop is somewhat different. We have enlisted people with relevant program planning experience, at the same time limiting the group to a manageable size. Also, we have allocated more time to issue-oriented discussion and planning and less to strictly scientific pursuits.

We have thus invited you, requesting that you join in a cooperative venture to develop a program of work that will make a significant impact on low and moderate technology agriculture in developing countries. By working together as a network of cooperating institutions and scientists we have the potential to provide answers to questions concerning *Rhizobium* performance that would be virtually impossible to obtain if each worker approached the problem individually.

We face three questions:

1. Do legumes of economic importance in the tropics respond to inoculation under two or more levels of agronomic inputs?

2. Are certain *Rhizobium* strains better than others with a given legume?

3. Are there interactions among inoculum strains, legume varieties and environment?

Beyond these questions we are also asking the question "Why?" Why does a legume respond as it does? Can we predict with reasonable certainty how it will respond under slightly different conditions? It would be patently impossible to sample every legume variety, every soil situation, and every stress in a series of field experiments. How then can we design a program that will provide the most important data and give us a firm basis for better legume production in the tropics? The answer is "very carefully." And that is why we have proposed spending 4½ days of intensive work here on this beautiful island in the middle of the Pacific.

The program of work needed to answer these three questions will require the combined resources of many individual programs and the expertise of many workers. Where will the resources (labor, equipment, supplies) come from? Who will manage the experiments? How do we ensure

good communication among workers, with truly complementary (rather than duplicative) programming both within and among countries? A strong and well-defined program will be required in order to command the support of those who allocate resources and scientists in developing countries.

We at the NifTAL Project view our role as facilitators. Our goal is to provide the kind of assistance that will permit such a program to function effectively. The label is not important; the task before us is both important and urgent. The time has come for us to pool talents and resources in order to test the potential benefits of Rhizobium inoculation in a truly comprehensive way.

I propose one possible way of viewing such a collaborative program in Figure 1. Of course, this is somewhat incomplete. For example, some groups within the "support group" will also be actively engaged in research, and grants and support services will naturally be channelled through the institutions involved. However, this model may be helpful in thinking through the ways in which a program can be expedited so that it is truly both collaborative and comprehensive.

At the conclusion of this workshop, we expect to have a publishable document reflecting the consensus of this group regarding a strategy for a testing program which will, in a reasonable period of time, tell us whether there is a need for inoculation of the major legumes grown in the tropics, (e.g. grain legumes, pasture legumes, vegetable legumes, cover-crop legumes, and other under-exploited legumes), and whether certain strains of rhizobia are superior to other strains for inoculating those legumes which do respond. This document should provide a firm basis for enlisting broad international support for the proposed program of work.

We have asked some of you to prepare issue papers which will provide the basis for one or more hours of discussion immediately following each paper. We have asked some of you to serve as chairmen of a working session. The chairman has the relatively easy task of introducing the topic and the speaker, and the far more difficult task of directing the ensuing discussion in such a way that the issues are not only discussed in depth but that, if possible, a consensus is reached on each issue. We have asked others of you to serve as rapporteurs. Your task will be to record the major points which emerge from the discussion, hopefully, as a consensus, as well as those details which may be significant in the formulation of a working strategy for action.

You will notice from the program that we have allocated the remainder of this day to an exploration of where we stand in the area of Rhizobium strain testing. This will provide a common understanding of the present state of affairs which should stand us in good stead in our subsequent deliberations. Tomorrow will be a very busy day, as we plan to discuss three important topics which form the essential basis for cooperative action. First, the strengths and constraints of BNF research programs; second, institutional networking; and third, problem solving and communication. On Wednesday we will discuss the nuts-and-bolts aspects of the proposed experimental network, and on Thursday morning we will attempt to reach a consensus on the activities which will be needed to get the network actually underway.

Some of you may be concerned about how the discussion topics interrelate to each other and how they overlap. I don't believe we should worry about overlap in our discussions, because they represent important interfaces between program and institutions or individuals. The more we address these interfaces in depth, from different perspectives, the better.

I'd like to suggest one way of viewing the interrelationships between our discussion topics (Figure 2). In this perspective the involvement of the individual scientist is the key element. All other aspects of our planning impinge on his or her involvement. Institutions are involved both in capability strengthening and in the definition of goals and standards as they relate to national priorities. This involvement, in turn, affects the research procedures to be employed, again with the involvement of the scientists concerned.

So let us discuss the issues of each individual topic, but pay particular emphasis to the interrelationships among the topics, as they may be more important to the success of the program than the issues or topics, taken singly.

Following the conclusion of the workshop, NifTAL will arrange for the necessary editing to eliminate duplication, and compile the documents into a single cohesive report. These then will be returned for review and any further revision, prior to publication by April or May, 1979.

We anticipate that the output from this workshop will be a document which each of us will be proud to claim as part owners and which each of us will want to actively promote in developing countries throughout the tropics.

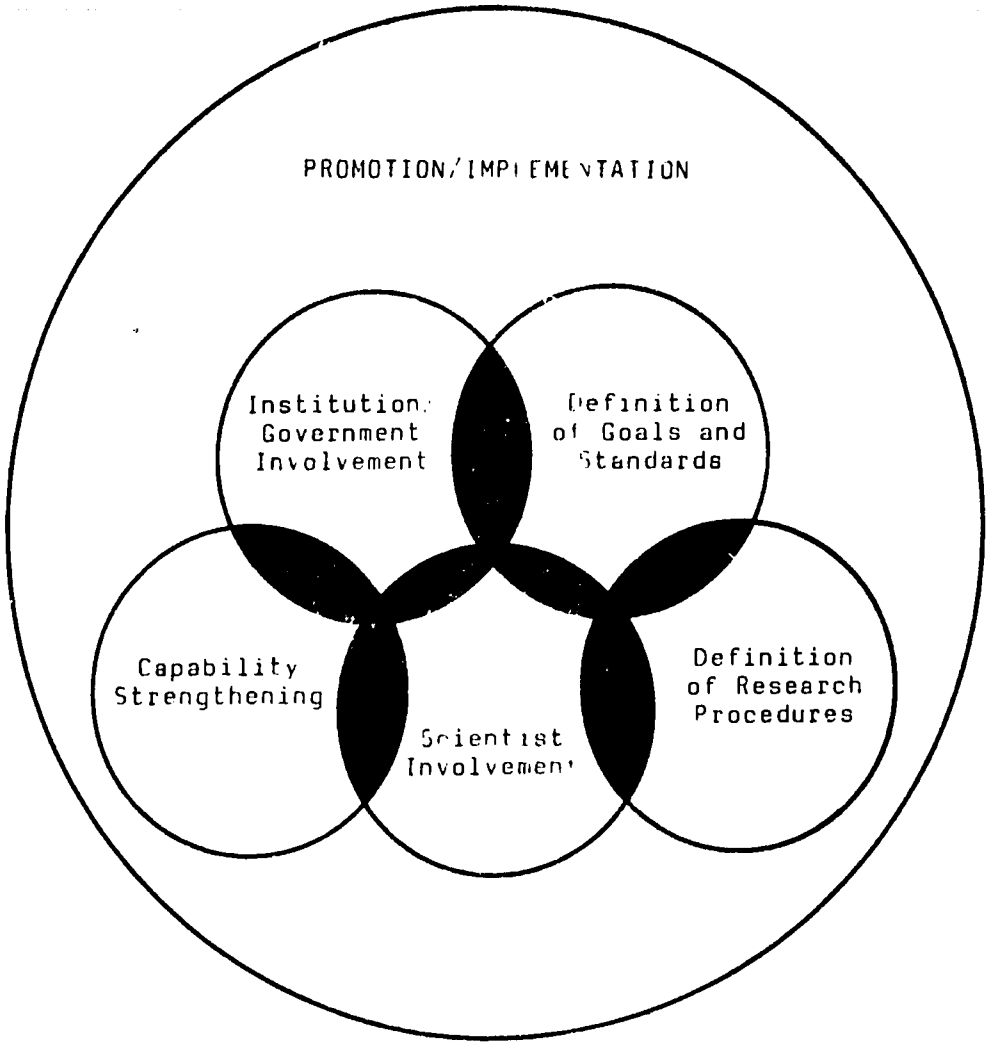
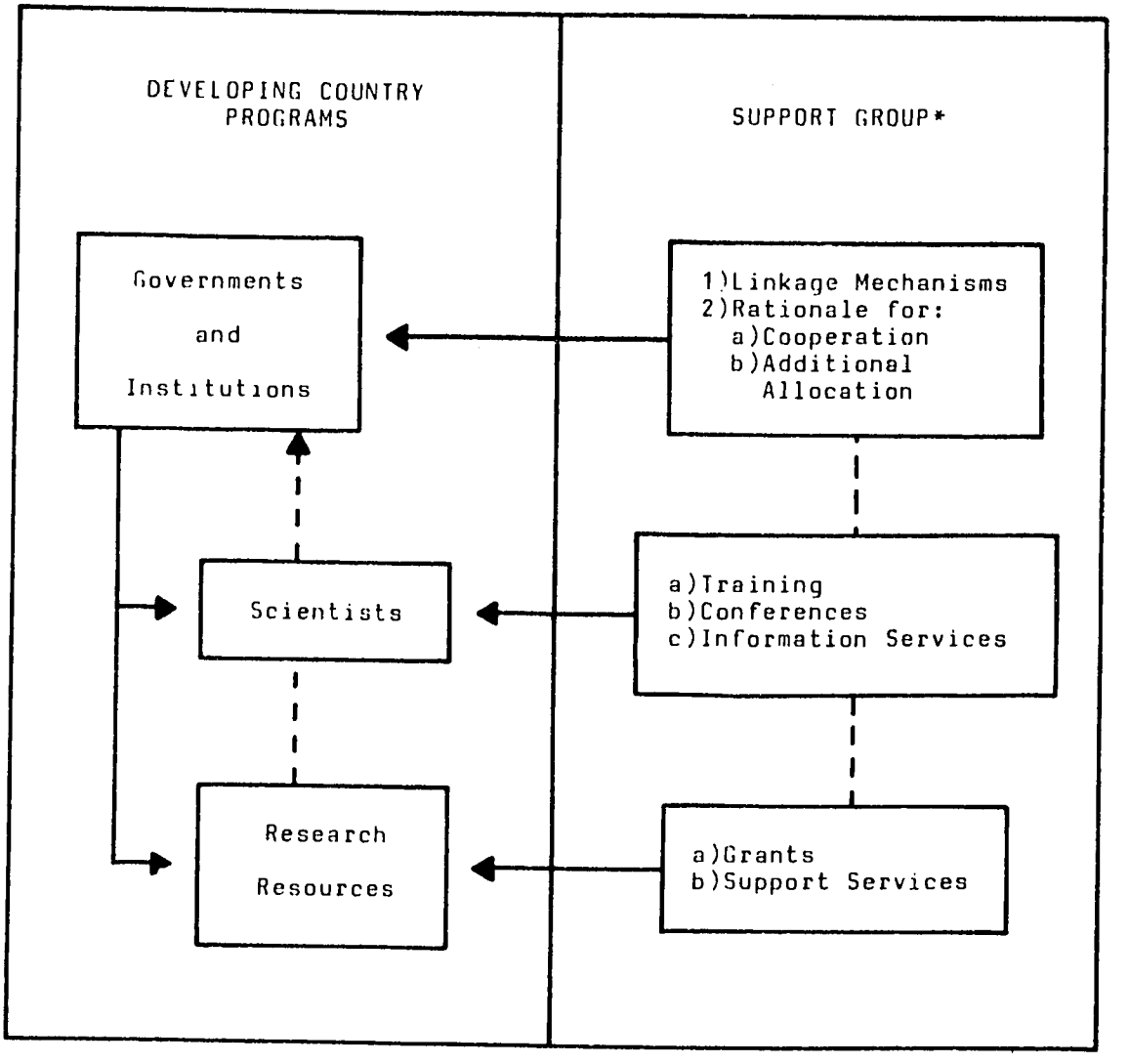


Figure 1. Interrelationships implicit in the proposed Rhizobium Testing Network.



* FAO, USAID, UNESCO, etc.

Figure 2. Schematic of potential collaborative relationships for coordinated Rhizobium Testing Network.

SECOND PLENARY SESSION

Current BNF Research in the Tropics: Short Reports by the Participants

LEGUME RESEARCH AT THE UNIVERSITY OF NAIROBI IN RELATION TO BIOLOGICAL NITROGEN FIXATION IN AFRICA

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LEGUME RESEARCH IN THE UNIVERSITY OF NAIROBI

In East Africa, the main form of protein readily available to the bulk of the population is plant protein. As the population has increased, pastures have decreased, and the costs of producing animal protein have soared. Hence, animal protein, although preferred, is economically out of reach for the bulk of the population in both rural and urban areas.

The most viable alternative to this expensive animal protein is plant protein which is derived mainly from the leguminous crops. In Kenya, where the majority of the population are subsistence farmers, legumes such as beans (*Phaseolus vulgaris*) in the relatively high rainfall areas and cowpeas (*Vigna unguiculata*) in the marginal areas have traditionally been grown. Acceptability of plant protein, therefore, is not the main problem.

The problem is to increase plant protein yield so that the subsistence farmer will have enough for his family's needs, and some extra yield to meet the rising demand in the urban areas. This increase in yield can be realized through better management of the local legumes and through introduction of improved varieties suitable for various agro-climatic regions.

The University of Nairobi has recognized this problem, and to date there are four programs in the University with the aim of improving legumes. These are:

1. Cowpea Improvement Program
2. Pigeon Pea Project
3. Integrated Grain Legume Program (IGLEP)
4. Rhizobium MIRCEN (Microbial Resources Centers) Project

These programs employ an interdisciplinary approach, and the staff involved work hand-in-hand in cooperation with the Kenya Ministry of Agriculture toward the common objective of increasing yields of leguminous crops and maximizing their role in the improvement of soil fertility. The Rhizobium MIRCEN Project, although based at the

University of Nairobi, is a regional project for Eastern Africa. In addition to the above four programs, there is a Plant Protection Program (PPP) at the University. The PPP is split into four major disciplines: (a) Entomology, (b) Plant Diseases, (c) Virology and Nematology, and (d) Cropping Systems and Weeds. The PPP's basic aims are to investigate and devise scientific pest management techniques for small scale, mixed cropping farms, and to provide data that can be used as a basis for developing a training program based on integrated pest management.

The main leguminous crops in Kenya are beans, cowpeas, and pigeon peas (*Cajanus cajan*). Their provincial distribution is given in Table 1. Legume research at the University of Nairobi is mainly on these three grain legumes.

Table 1: Estimated areas under grain legumes in Kenya by province in the 1969/70 crop year (10^3 ha)*

Province	Common beans	Pigeon peas	Cowpeas	Others	Total
Eastern	130.9	60.0	55.7	13.7	260.3
Central	113.7	0.4	0.2	10.2	124.5
Nyanza	40.0	---	4.4	4.3	48.7
Western	20.4	---	0.9	0.2	21.5
Rift Valley	9.3	0.6	0.2	0.8	10.9
Coast	8.3	0.2	5.2	---	13.7
Total	322.6	61.2	66.6	28.2	479.6

*Source: Kenya Ministry of Agriculture (1970) Statistical Abstract

BEANS

Altitude in Kenya varies from sea level to 2500 m at Mt. Kenya, and the mean annual rainfall varies from 255 to 2030 mm. Hence, leguminous crop production in Kenya depends on both rainfall and temperature (as a function of altitude). In the high, cool and relatively wet areas, the common bean is the number one grain legume. (See Table 1, Central and Eastern Provinces). In a recent survey of Kiambu District (Central Province) by the University's PPP, it was found that out of 52 farms visited, 95% grew beans.

The national average bean yield is estimated at 500

kg/ha, which is miserably low. In an endeavor to improve this situation, the University of Nairobi, under the auspices of IGLEP, Rhizobium MIRCEN, and PPP, and in cooperation with the Ministry of Agriculture, has begun research on beans. About 6000 lines of beans have been collected within and outside the country. These lines are being evaluated for disease and pest resistance, yield, nitrogen-fixation capabilities, etc.

Under this program "Canadian Wonder" variety yields were pushed up from 500 to 800-900 kg/ha. The main problem in bean production in Kenya appears to be disease; especially seed-borne disease. Merely by using clean seed in the program, "Canadian Wonder" yields of 1500-2000 kg/ha have been realized. Hence one of the main problems is going to be producing clean seed for distribution to farmers. The main diseases encountered are haloblight, anthracnose and bean rust.

Of the 6000 lines collected, the following are promising selections:

1. "Canadian Wonder," which is medium-maturing with medium resistance to haloblight and anthracnose;

2. Red harricot, which is resistant to haloblight and bean rust;

3. Rosecoco which, although susceptible to both haloblight and anthracnose, can survive because it is early maturing;

4. Mwezi moja, which is susceptible to haloblight and anthracnose, but is also early maturing;

5. Black bean, which is resistant to haloblight, anthracnose and bean rust.

Both rosecoco and mwezi moja selections are suitable for marginal rainfall areas where the rainy season is relatively short.

The Rhizobium MIRCEN is involved in bean research (and research with other legumes) with the ultimate aim of improving nodulation and nitrogen fixation which will, in turn, minimize use of nitrogen fertilizers to produce maximum bean yields in Kenya.

In addition to the evaluation of various strains of Rhizobium (local and imported), other factors (e.g. nutrient availability) which might affect nitrogen fixation in the

Kenya environment are being investigated. If the need for nodulation is established, the aim is to produce inoculants locally, using local materials as much as possible. Research has been initiated to evaluate local materials as substitutes for peat as an inoculant carrier. Kenya is not endowed with substantial peat deposits. Local materials being evaluated include bagasse, filter mud, charcoal dust, coir dust, sawdust, and diatomite--all of which are readily available in Kenya.

Besides disease, there are other factors which limit bean production in Kenya. Among them is soil acidity. In many high altitude and high rainfall areas soils with a pH range of 3.5 to 4.5 (1:1 soil/water) are found, sometimes with relatively high levels of Al and Mn. Studies have been initiated to attempt to solve this problem.

COWPEAS

The greater part of Kenya lies in marginal rainfall areas (less than 1000 mm annually) and although some lines of beans have been developed for these areas, the main grain legumes in these areas are cowpeas and pigeon peas.

For the last year and half, the University of Nairobi Cowpea Project, in cooperation with other legume programs and the Ministry of Agriculture, has been involved in evaluating local and introduced cowpea varieties in different ecological zones of Kenya. It is hoped that these efforts will produce high yielding, disease and pest resistant varieties for both grain and leaf purposes and suitable for each ecological zone.

In the Eastern Province, which grows 80% of the cowpeas in Kenya (Table 1), average grain yield under subsistence farming is 135 kg/ha (Kenya Ministry of Agriculture, Annual Reports, 1974). Under research conditions the Cowpea Project has recorded yields of over 1000 kg/ha. So far, local varieties have out-yielded new entries from the International Institute of Tropical Agriculture (IITA) in the cool and less humid, or warm and dry environments of the Eastern Province. The IITA cultivars performed better under humid, warm environments. The main problem appears to be insect damage. In the pre-flowering stage, cutworm (*Agrotis ipsilon*) was the most serious pest. *Taeniothrips sjotedti* was the most serious flowering pest while American bollworm (*Heliothis armigere*) was the most serious pod boring pest. Among the diseases recorded was one named "yellow mottle" which had not been recorded in East Africa.

The breeding section has collected 235 cowpea cultivars

from within and outside the country, and these are being evaluated for their suitability for leafy vegetable and seed production in the different ecological zones.

The Rhizobium MIRCEN is observing the nitrogen fixing capabilities of the various cultivars.

PIGEON PEAS

Pigeon pea is the third most important grain legume in Kenya after field beans and cowpea. It is very tolerant to drought and can grow under a great variety of climatic and soil conditions (Landrau and Samuels, 1959; Johnson and Raymond, 1964; Pursglove, 1968). In East Africa pigeon pea is grown primarily as a pulse crop. However, the unripe green seeds are also an excellent fresh vegetable or they may be canned. Protein content in dry seeds generally varies from 20-28½ with a good amino acid balance and very low antinutritional factors (Tawde and Cama, 1962; Johnson and Raymond, 1964). Because pigeon pea is a very important grain legume in marginal rainfall areas of Kenya and has a good potential for alleviating protein deficiency, research for its improvement was started in the Department of Crop Science in 1975. Progress which has been made in its research at this University includes:

1. Germplasm Collection

Any crop improvement program requires a wide genetic variability on which improvement can be based. With this in mind, a number of both local and exotic pigeon pea genetic resources have been assembled. These have been grown and screened for a number of agronomic characteristics. Of the 840 entries in the pigeon pea germplasm bank, 236 were collected from Kenya. The Kenya cultivars are late and require 10 months to mature while most of the exotic entries, mainly from India, but also from the Caribbean, South America, Australia, and the Sudan, mature within 4 months. A number of promising cultivars have been identified and are undergoing further improvement. This germplasm bank has supplied seed to research workers in other countries, including Sri Lanka, India, Zambia and Botswana.

2. Outcrossing in pigeon pea and its insect-pollinators

According to reports from various parts of the world, pigeon pea outcrosses between 0.09-80½ (Ariyanagam, 1976; Khan, 1973). This range of outcrossing makes maintenance of pure pigeon pea cultures extremely difficult. In 1976, two experiments were planted at six sites in Kenya to determine both the degree of outcrossing of pigeon pea under Kenyan

conditions and the influence of insect pollinators on the degree of outcrossing. Stem color was used as the genetic marker. At one site, the experimental plot was planted near a 30-beehive apiary to expose it to a very high insect-pollinator population. Insect-pollinator activity was determined at all sites by counting the number of pollinator visits per unit area. The results of outcrossing are shown in Table 2.

Table 2: Estimates of the degree of outcrossing of pigeon pea at six sites in Kenya

Site	Mean degree of outcrossing %
Katumani	35.44
Kibos	25.20
Kampi ya Mawe	41.96
Mtwapa	43.94
Kabete: Low pollinator population	46.66
" " "	94.50

As Table 2 shows, there is a very wide range of outcrossing in pigeon pea in Kenya. Under high insect-pollinator population, the observed outcrossing of 94.50% means that this crop should be regarded as open-pollinated. This observation has far-reaching consequences on breeding methods which should be adapted in the improvement of this crop. The degree of outcrossing was directly influenced by the number and activity of insect pollinators at each site ($r = 0.994$; $p = 0.001$).

Williams (1977) has reported a list of insect genera and species and their foraging activities on pigeon pea in Hyderabad, India. In a similar survey in Kenya, seven genera and 24 species of insect-pollinators of pigeon pea were observed. In this study, the most important pigeon pea pollinators were 10 *Chalicodoma*, 5 *Megachile*, 5 *Xylocopa* species and *Apis mellifica* race *adansoni* Ltr.

3. Population improvement approach

Since outcrossing in pigeon pea is quite high in Kenya, the population-improvement approach was adopted, rather than the traditional pure-line one. Two selection methods were used, namely Stratified Mass Selection (SMS) (Gardner, 1961) and Modified Simple Recurrent Selection (MSRS). Four

improved populations of SMS and 2 of MSRS were tested in replicated yield trials in 3 locations in Kenya in 1977. Selection pressure used was 10% for SMS and 5% for MSRS with grain yield the criterion. A number of other plant characteristics, especially those likely to influence drought resistance, were measured. Among the parameters measured was the Chlorophyll Stability Index (CSI) (Kilen and Andrew, 1969).

In both SMS and MSRS, no progress was made in grain yield or its components. However, improved populations by both methods had taller plants with more primary branches and slightly more pods per plant. Improved populations also had significantly more leaves and larger leaf area, and more moisture and dry matter per plant. It is interesting to note that the dry matter in the improved populations was not deposited in grains. Progressively improved populations had negative relationships with number of seeds per pod, number of seeds per plant, 100 seed weight and grain yield. However, location mean yields were 849, 1,603 and 1,431 kg/ha for Katumani, Kampi ya Mawe and Thika respectively. Since the populations used mature after 4 months, it is possible to take two similar harvests per year in these bimodal rainfall areas. Yields of early maturing pigeon pea are therefore quite promising in marginal rainfall areas of Kenya.

Characters which are thought to confer drought resistance also showed interesting trends. CSI was reduced by 6.4 and 3.2 by SMS and MSRS respectively. This implies that improved populations may have better drought resistance. Root studies, however, showed increased dry matter accumulation in improved populations, but shallower tap-roots and fewer primary latersals. These observations imply that improved populations have poorer rooting systems and may not have good rooting facilities for drought resistance.

4. Other research work in progress

Progress made on the improvement of local pigeon pea cultivars is much slower since each cropping cycle takes 10 months. Intercropping early-maturing pigeon pea with maize shows yield reductions of up to 75%. Late-maturing local types do better in mixtures with maize.

Population studies show that pigeon pea grain yields do not respond to spacing ranging between 20 cm x 75 cm and 50 cm x 180 cm. Phosphate fertilization has shown erratic results.

MIXED CROPPING

In East Africa, legumes are very rarely grown as monocultures. They are usually intercropped with cereals, cassava and other food and cash crops. In a recent survey by the PPP, 73% of 52 farms surveyed used mixed cropping systems. The systems vary from alternate rows of legumes and maize to alternating maize and legumes within the row, or even maize and legume planted in the same hole. The different programs are trying to find the best mixtures. They are also interested in how weed and insect pests can be controlled in such mixed cropping systems.

OTHERS

The University is interested in other legumes in addition to grain legumes.

Under the *Rhizobium* MIRCEN Project, the black wattle (*Acacia mearnsii*), a tree legume, is being evaluated with the aim of exploiting its potential for nitrogen fixation. The tree grows on a wide range of soils varying from shallow, rocky, poor soils to fertile soils.

In cooperation with the newly formed International Council for Research in Agro-forestry (ICRAF) there is a proposal to evaluate the agro-forestry potential of *Leucaena leucocephala* in food production, conservation and rehabilitation of the marginal rainfall areas of Eastern Africa.

MICROBIOLOGY

The following are strains which have been isolated from legumes. They are now being tested and screened in the microbiology laboratory in the University of Nairobi Soil Science Department using modified Leonard Jar techniques.

Table 3

Legume of origin	Number of strains
Vigna unguiculata (cowpea)	27
Phaseoulus vulgaris (field bean)	100
Pisum sativum (garden pea)	20
Cajanus cajan (pigeon pea)	3
Phaseoulus lunatus (lima bean)	2
Trifolium semipilosum (Kenya white clover)	2
Dolichos lablab (hyacinth bean)	3

Table 3 (continued)

Legume of origin	Number of strains
Acacia mearnsii (black wattle)	6
Vigna mungo (black gram)	1
Vigna aureus (green gram)	2
Glycine max (soybean)	7
Desmodium intortum (silverleaf desmodium)	1
Glycine wightii (perennial soybean)	1
CULTURES FROM OTHER LABORATORIES	
Vigna unguiculata (cowpea)	4
Phaseoulus vulgaris (field bean)	15
Cajanus cajan (pigeon pea)	5
Medicago sativa (lucerne, alfalfa)	7
Glycine max (soybean)	1

Rhizobium cultures were previously stored in YMA slants at 0 - 4°C. Recently we have started storing cultures in YMA slants under liquid paraffin. We hope to achieve longer viability and avoid frequent subculturing which is time consuming and may lead to mutation of rhizobia.

RHIZOBIUM CARRIERS

Local materials are being investigated as carriers for rhizobia inoculants. So far it has been found that filter mud mixed with soil in ratio of 3:1, satisfies the nutritional requirements for *Rhizobium* growth. Molasses is also being tried as a source of carbon.

Following materials are being tested as carriers:

1. Peat
2. Filter mud — By-products of the white sugar
3. Baggase — industry in Western Kenya
4. Sisal dust
5. Coir dust
6. Coffee husk compost
7. Sawdust
8. Charcoal dust
9. Wool ash
10. Ground maize cobs
11. Alfalfa straw

12. Wheat straw
13. Diatomite
14. Forest soil (high in organic matter)
15. Black cotton soil plus light material)

These materials will be tried as pure materials or mixtures.

INOCULANT PRODUCTION

We are, at present, producing inoculant at a small scale using filter mud and black cotton soil in ratio of 3 parts of filter mud to one part of ground black cotton soil. The carrier is sterilized for three alternate days at 121°C (15 lb/sq. inch) for 2 hours. 8 ml of sterile distilled water are added to 150 grams of sterile carrier in a sterile plastic bag, and mixed thoroughly. Then 10 ml of *Rhizobium* culture broth are added, mixed thoroughly, and the content of the plastic bag is incubated at 26-28°C for one week to facilitate multiplication of rhizobia. The population of rhizobia per gram of inoculant is estimated by Pour Plate Technique.

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THE ROLE OF FAO IN THE PROMOTION OF BIOLOGICAL NITROGEN FIXATION

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FAO is currently involved in many agricultural development projects in Asia, Africa, Latin America and the Near East, in which the introduction and adaptation of forage plants and grain legumes are important activities. All provide excellent opportunities for demonstrating the methods of legume inoculation, the testing of strains, and the relationship of inoculation to nitrogen fixation.

The present goal of the FAO program on BNF is to coordinate on-going field projects and current research programs with a view to promoting the efficient and widespread use of nitrogen fixation in current farming practices. Objectives include:

1. Practical demonstrations of the benefits of inoculation of legumes in the field;

2. Improvement of traditional legume crops by the use of selected strains of Rhizobium;

3. Introduction of new legume crops and their specific inoculants in developing countries where the lack of rhizobia in the soil has precluded their cultivation; and

4. Improvement of soil fertility by adopting suitable legume crops and pastures.

These objectives are implemented through the FAO program in the introduction, exploration and collection of forage legumes; through its field projects sponsored by the UNDP, Regular Program Funds; and through a special grant from UNEP. Activities are also facilitated by strengthening those national institutions which deal with legume crops.

A number of national and international institutions are cooperating with the FAO Program on Biological Nitrogen Fixation. These include INTA (Argentina), INRA (France), CSIRO (Australia), University of Queensland (Australia), NifTAL Project (USA), and the MIRCENs in Porto Alegre, Brazil and Nairobi, Kenya, and among the international institutes: CIAT, ICRISAT and IITA.

Progress to June 1979

Missions identifying the constraints to BNF were carried out with a financial contribution from UNEP in the following African countries: Cameroon, Ghana, Ivory Coast, Kenya, Malawi, Nigeria, Rwanda, Senegal, Sudan, Upper Volta and Zaire, and in the Latin American countries of: Argentina, Bolivia, the Dominican Republic, Ecuador, Paraguay and Peru.

Field programs are underway in Argentina and will begin in the second half of 1979 in Peru. In West Africa, field demonstrations in Senegal, Ivory Coast, Upper Volta and Zaire have been initiated in the present growing season (June-October). On both continents grain and forage legume crops are being initiated. Full details of field experiments and their results will be available in November, 1979. All activities are being implemented by qualified Rhizobiologists, acting as consultants.

It is predicted that in the future UNEP will request that FAO identify constraints to the practical applications of BNF in Central America and Asia.

RECENT WORK BY THE JOINT FAO/IAEA DIVISION: THE ^{15}N EXPERIMENT

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INTRODUCTION

On the basis of findings of a previous FAO/IAEA Joint Division coordinated research program entitled "Use of Isotopes in Fertilizer Efficiency Studies in Grain Legumes" (scheduled for publication in 1979), the FAO/IAEA Joint Division is expanding its efforts by coordinating and assisting in research on the application of isotopic tracer techniques to the quantification of biological nitrogen fixation by leguminous plants. The new program will involve approximately twenty agricultural institutes in Member States of the FAO and IAEA with financial support from the Swedish International Development Authority (SIDA).

The main concern of this research is to develop and utilize quantitative measurements of the amount of nitrogen fixed by legumes grown in the field. The use of isotopic nitrogen to quantitatively measure nitrogen fixation under field conditions appears to be the most promising technique. Although it is not practical to label nitrogen in the atmosphere under field conditions and measure $^{15}N_2$ fixation directly, a viable alternative exists in the addition of a labelled nitrogen source to the soil and measuring nitrogen fixation by dilution of the labelled nitrogen taken up by the plant from the soil and labelled source by the unlabelled atmospheric nitrogen that becomes fixed. This requires a non-fixing plant as a control to determine the isotopic composition of the nitrogen taken up from the labelled source and from the soil without dilution by atmospheric nitrogen. The major assumptions are that the sources of nitrogen in the soil are absorbed by the fixing and non-fixing plants in the same ratio, therefore the same isotopic composition, and that fixation by the legume does not alter the chemistry and availability of the soil nitrogen. When the same rate of addition of the labelled nitrogen source is given to both the control and legume, the fraction of nitrogen fixed by the legume (N_f) is determined by the formula:

$$N_f = 1 - \frac{\%\ ^{15}N \text{ atomic excess (of fixing plant)}}{\%\ ^{15}N \text{ atomic excess (of non-fixing plant)}}$$

On the other hand, when the rate of application of

labelled nitrogen source differs between the control and the legume, the "A" value transformation must be used to determine the amount of nitrogen fixed.

OBJECTIVES

The major objective of immediate concern is the improvement of methodology for measuring nitrogen fixation by legumes, using isotopic nitrogen techniques. This will be accomplished by examination of a number of factors, including:

1. Design of experiments to improve precision;

2. Suitability of various non-fixing plants for the determination of the ratio of soil-derived nitrogen to ^{15}N derived from the nitrogen in the added labelled source;

3. Amounts of available nitrogen in the soil that may influence the growth of both the legume and non-fixing plant, and the consequent effect on nitrogen fixation; and

4. Influence of agronomic practices that are important to cooperating members on the precision of nitrogen fixation measurements and the amounts of nitrogen fixed.

Another objective is to measure the amounts of nitrogen fixed by the leguminous plants grown in different ecological situations. The associated errors will be determined.

After the methodology has been successfully established, further objectives will be outlined that will deal primarily with agronomic management practices with the aim of increasing biological nitrogen fixation and crop yields.

REGIONAL CROPS OF INTEREST IN PARTICIPATING COUNTRIES

High yielding locally adapted varieties of nodulating crops will be used in the experiment. Soybean (*Glycine max*) will be utilized in five countries (Argentina, Romania, Senegal, Sri Lanka and USA); cowpea (*Vigna unguiculata*) in Nigeria; broadbean (*Vicia faba*) in three countries (Egypt, Syria, United Kingdom); chickpea (*Cicer arietinum*) in three countries (Bangladesh, India, and Syria); pigeon pea (*Cajanus cajan*) and groundnut (*Arachis hypogaea*) in India; lentil (*Lens esculenta*) in Syria and common bean (*Phaseolus vulgaris*) in Mexico.

Sudan grass will be used as a non-nodulating control crop by all of the participants in the coordinated research program. Another non-nodulating species will be employed as a second control. This second control species should be selected by the program participant on the basis of its physiological similarity to the legume crop of interest. The second non-nodulating species may be selected on the basis of the following similarities to the legume crop:

1. Growth period (it is essential that the control crop has a growth period ideally equal to, but must not be shorter than the legume crop of interest)
2. Root distribution pattern
3. Total nitrogen uptake
4. Climatic adaptation
5. Pattern of nitrogen uptake
6. Plant height

These characteristics may be used as criteria in the selection of a non-nodulating control crop although the selected crop will usually not have all of the characteristics listed.

EXPERIMENTAL TREATMENTS

Common Treatments

1. Non-legume$_1$ at N_1 (Sudan grass* unless otherwise specified)
2. Non-legume$_2$ at N_1 (non-nodulating isoline, wheat, barley, etc.)
3. Legume$_1$ at N_1
4. Non-legume$_1$ and Legume$_1$ at N_1 (alternate rows of each crop)
5. Non-legume$_1$ at N_2 (Sudan grass unless otherwise specified)
6. Non-legume$_1$ at N_2
7. Legume$_1$ at N_2
8. Non-legume$_1$ and Legume$_1$ at N_2 (alternate rows of each crop)
9. Optional treatment
10. Optional treatment
11. Optional treatment
12. Optional treatment

NOTE: i. N_1 = 20 kg N/ha as ammonium sulfate
N_2 = 100 kg N/ha as ammonium sulfate

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* Sudan grass variety should have approximately the same height as the legume plant.

ii. Optional treatments (9-12) should be included if at all possible

iii. Optional treatments (9-12) are any of the following:
   a. additional legume cultivars at N_1
   b. additional legume cultivars at N_2
   c. additional legume species at N_1
   d. additional legume species at N_2
   e. Rhizobium inoculants at N_1
   f. and g. additional non-nodulating test crop; must be grown at both N_1 and N_2

For example, the optimal treatments could be three additional legume cultivars at N_1 and one different source of inoculant. In other words, a participant may choose four treatments from one of the above list or any combination.

DESIGN

Split-plot design with 6 replications in blocks with each block containing two whole plots for nitrogen level, subdivided into sub-plots based on mandatory and optional treatments selected. See sample layout in Figure 1. Treatments 1 and 3 must be located adjacent to each other; Treatments 5 and 7 must also be located adjacent to each other. Follow the randomization pattern for each block which will be included in the Field Record Book furnished by the FAO/IAEA Division. Refer to Figure 1.

PLOT LAYOUT

1. Each ^{15}N-treated plot consists of 6 rows with spacings in nd between rows indicated in Table 2, and the plot size will depend on the row spacing indicated in Table 2. All treatments including optional treatments must have the same row spacing.

2. Plot dimensions are given in Table 3.

3. Figures 2 and 3 indicate areas to receive ^{15}N within each plot and also indicate the ^{15}N harvest area.

4. Figure 4 is an example of a supplemental yield plot layout.* This layout is an example only. Row spacing must be the same as the ^{15}N plots. Plot

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* Nodule observations should not be made on the ^{15}N plots (see Section XIV on nodule observations).

length and the number of rows per plot should be the same as commonly used in experiments in your country. The number of rows per plot need not be six.

Additional treatments for the yield plot may be included which are not in the ^{15}N experiment (a zero, 20, and 100 kg N/ha must be included in the yield plots).

5. Figure 5 illustrates a typical layout of the ^{15}N and yield plots. This layout is an example only, and if a better layout is available, use it. Only the ^{15}N-layout must be followed exactly.

SELECTING AND DESCRIBING THE EXPERIMENTAL SITE

The site selected for this study should be on a soil type representative of the major area of the region on which the crop under test is grown. Care should be exercised in locating the site so as to ensure:

1. Low fertility level of nitrogen; the 0-60 cm of soil should contain less than 70 kg/ha of inorganic nitrogen (see soil sampling section below).

2. A uniform plot area; avoid areas with obvious physical or chemical soil variability. Also, the site should be located so there will be no extraneous influence from trees, shrubs, roads, etc., at the perimeter of the site and so there is ample space for an adequate border of the crop under test to be sown surrounding the plot area. The site MUST NOT be located on old experimental plots where previous differential applications of labelled or unlabelled fertilizers have been made.

3. NO LEGUME CROP should have been grown on the site at least for over the preceding two year period.

4. The site selected should have a minimal amount of organic residues. When an appropriate site has been selected, the records for the site characteristics and history should be completed in the Field Book.

5. The soil profile should be described and classified by standard soil survey methods. A pit for this purpose should be dug in the border area adjacent to the experimental plots. MINIMIZE ALL TRAFFIC ON THE PLOT AREA.

PREPARATION OF EXPERIMENTAL SITE AND SEED INOCULATION

The entire experimental area including border areas, should be uniformly treated in relation to the following:

1. Cultural practices

Ploughing, discing and harrowing should be done according to procedures commonly used in the region before seeding.

Manual weed control should be done both before and after seeding as required--DO NOT USE CHEMICAL HERBICIDES.

Irrigation should be carried out as and when required. Record the actual amount of water used for irrigation, the dates and duration of irrigation, all other cultural practices and any damage to crop by pests and diseases, birds, etc. in the Field Record Book.

2. Fertilizer practices other than Nitrogen

If, in the judgement of the investigator, potassium, phosphorus, magnesium, sulphur, lime or any micronutrients may be limiting for good legume plant growth and production, the nutrient or nutrients should be uniformly broadcast at an appropriate rate over the entire area prior to seeding and worked into the soil up to a depth of 10-15 cm. Micronutrients should be applied only where a known soil deficiency exists. It is recommended that any basic treatment used should not include nitrogen.

The amount and rate and form in which any nutrient is applied, and also dates of application, should be recorded in the Field Record Book.

3. Seed inoculation

The seeds of the nodulating grain legume crop under test should be inoculated with root nodule bacteria which will be sent to the investigator by the Nitragin Co. through Dr. G. E. Ham, USA. The seeds should not be subject to any chemical fungicidal treatments. Instructions for inoculation will be sent by Dr. Ham.

MARKING AND FITTING THE EXPERIMENTAL AREA FOR PLANTING

Before planting and application of the fertilizer treatments, all preliminary cultural operations and basic fertilizer treatments must be completed, the land prepared

for planting and each plot carefully marked with identifying stakes, e.g., painted blue. The sub-plots which are to receive labelled nitrogen should also be measured carefully and marked with identifying stakes, e.g., painted blue. The sub-plots which are to receive labelled nitrogen should also be measured carefully and marked with identifying stakes (see Figures 2 and 3), e.g., red. Planting rows may be measured and staked at the same time.

To facilitate this operation and subsequent operations involving location of ^{15}N-labelled areas, it is suggested that a framework may be constructed with a wire grid system that would delineate the ^{15}N area, the area to be harvested, and the outer unlabelled area. Such a grid system would have to be easily portable so that it could be taken from one plot to the next.

PREPARING PLOTS FOR SEEDING AND ^{15}N TREATMENT

Land Surface Preparation

Seed bed preparation should be appropriate for seeding of legume crop chosen for the experiment.

All plot surfaces should be prepared as if the legume were to be seeded. Plots which will be seeded to non-legume should be handled with minimum modification needed to accommodate the plant to be seeded.

CLIMATOLOGICAL AND OTHER ENVIRONMENTAL RECORDS
(see detailed instructions in Field Record Book)

1. Essential records

   a. Detailed records of rainfall (date, amount, intensity) for the full duration of the experiment.

   b. Where irrigation is used, record dates, duration, and quantity of water and method of irrigation.

   c. Measure soil moisture contents at seeding and maturity and bulk density up to 100 cm.

   d. Daily records of maximum and minimum soil temperatures at seed level for 14 days after seeding and thereafter maximum weekly temperatures.

   e. Soil moisture measurements at the same

positions and frequently as for soil temperature.

2. Desirable records

   a. Level of water table at fortnightly intervals from seeding to harvesting.

   b. Meteorological data for calculating potential evaporation (after Penman), a significant factor affecting crop production:

      i. wind speed - an integrated 24 hours recording

      ii. net radiation - hours of sunshine are sufficient to enable this to be estimated

      iii. air temperature - daily minimum and maximum

      iv. relative humidity readings at 9.00 and 15.00 hours

OBSERVATIONS ON NODULATION AND NODULE ACTIVITY

Observations at three different stages of growth (early vegetative; 21-28 days after germination; early flowering and mid-pod-filling stage) should be made for nodulation studies from the guard rows of the yield plots. At each observation time, a minimum of 6-12 plants for each legume treatment from each replication plot selected at random should be assayed individually for:

1. Nodule activity by using acetylene reduction technique where facilities are available;

2. Nodule number per plant and position in the root system, i.e. primary and secondary root nodules; primary root nodules are those located on the tap root, and secondary root nodules are located on branch roots away from the tap root;

3. Nodule colour when sliced, to calculate the % of the active nodules (active nodules usually look pink or reddish brown in colour, while inactive nodules usually look either white or green);

4. Nodule dry weight per plant; and

5. Extent of insect damage to nodules as a percentage

of total nodules on each plant.

MICROBIOLOGICAL WORK ON NITROGEN FIXATION IN ASIA

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WORK OUTSIDE INDIA

Bangladesh. Virtually no work is presently in progress, but centers where microbiologists are now stationed are the Bangladesh Agricultural Research Institute (BARI) in Dacca, the Institute for Nuclear Agriculture in Mymensingh, and the Bangladesh Agricultural University, Mymensingh. Some research on nitrogen fixation for M.Sc. degrees is also in progress at Dacca University. Inoculants are not produced on a commercial scale. Major grain legumes are Khesari (*Lathyrus sativus*), chickpea (*Cicer arietinum*), lentil (*Lens esculenta*), and black gram (*Vigna mungo*). The total area under pulse production decreased by 16.7% between 1969 and 1975 to 319,000 ha, about 2.5% of the total cropped area, with average yields about 740 kg/ha. There is a limited production of groundnuts, but very few pasture or fodder legumes are grown.

Thailand. Some work on inoculum production, mainly for soybeans, is being undertaken at Kasetsart University, Bangkok. Field responses to inoculation for soybean can be large. At Khon Khaen University, some work on inoculation is in progress; at present the microbiologist is undertaking research at ICRISAT for his Ph.D.

There is virtually no soil microbiology research in Indonesia (apart from inoculation of pasture legume trials) or in Burma or Nepal.

Pakistan. In Pakistan some research is being conducted by Dr. K. A. Malik at the Nuclear Institute for Agriculture and Biology in Faisalabad.

Malaysia. Inoculants are produced at the Rubber Research Institute, where research has mainly been concerned with legume cover crops. But at the Botany Department, University of Kuala Lumpur, and in the Department of Agriculture there has been an interest in other crops. Soybeans apparently respond to inoculation. Soils are often very acidic.

Philippines. Some work is being done at the University of the Philippines at Los Baños, where inoculation trials have been conducted, and inoculants are produced. There has

also been some research on blue-green algal nitrogen fixation.

Middle East. In Iran, there was an active research program improvement on pulse, particularly for chickpea, under the direction of Professor Amir Shahi at the Agricultural University at Karaj near Teheran. There was one soil microbiologist, who, although interested in *Rhizobium* strain isolation and selection, had not conducted any field trials. The potential for soybean (*Glycine max*) and common bean (*Phaseolus vulgaris*) production was under study. They would both require inoculants.

Some work has been conducted in Iraq on isolation of clover and medic rhizobia and the response to inoculation. Two centers were involved, but little has apparently been done in the way of field trials, and little work on grain legumes. The major grain legumes in that area would be chickpea and pigeon pea (*Cajanus cajan*).

Turkey. Three microbiologists are working on grain legumes at the Soil and Fertilizer Research Institute at Ankara. The laboratory facilities are good, and the work of a high standard. Field surveys indicated poor nodulation for most of the major legumes over a significant area. There was a proposal to produce inoculants at the University of Ankhara, where another three scientists are engaged in research on *Rhizobium*. The Department of Soil Microbiology in the Faculty of Agriculture was established 10 years ago and is well equipped and the staff well trained.

Although barrel medic-wheat rotation has been introduced into much of North Africa, there has been no microbiological work done on this system. There is no microbiological research on grain legumes. At ICARDA, Aleppo, Syria, a microbiologist (Dr. Rafiqul Islam) has been working recently on chickpea, lentil, broad bean (*Vicia faba*) and pasture legumes. The distribution of chickpea rhizobia is sporadic in Syrian soils, and responses have been obtained to inoculation. Inoculation of lentil has also influenced nodulation and dry matter production.

In Egypt there is a very large Department of Microbiology at the Ministry of Agriculture, Research Station at Giza. Most of the work is laboratory oriented, but some work by a former NifTAL trainee is being conducted on soybeans, which do not nodulate without inoculation. Obtaining good field nodulation on research stations as well as farmers' fields is a major difficulty. Farmers apply nitrogen fertilizer to soybean and common bean, which also need inoculation. Inoculants are produced in another center, using Nile silt

as a carrier, but they are of very poor quality. The two major universities in Cairo, and Alexandria University give microbiology courses to several thousand students each year. Unfortunately overcrowding and lack of equipment and operating funds restrict research work very severely.

WORK WITHIN INDIA

India is the largest producer of legume crops in Asia, and has one of the largest scientific establishments in the world in terms of manpower, but until recently work in soil microbiology was relatively neglected. There is increasing interest at a national planning level on increasing pulse and legume oilseed production in India.

Most agricultural research work is sponsored by the Indian Council of Scientific Research (ICAR) with headquarters at Delhi. The ICAR has three schemes which sponsor the major work on nitrogen fixation.

The largest body of microbiologists are employed by the All India Coordinated Pulse Improvement Project, directed by Dr. Laxman Singh, Project Director, ICAR Directorate of Pulse Improvement, Kanpur. Some 15 microbiologists are stationed at Agricultural Research Centers (field stations and agricultural universities) throughout the country (see list, p.), and work mainly on coordinated projects agreed on at an annual workshop, covering surveys of nodulation in the field, strain testing, inoculation trials, and screening of germplasm for nodulation characteristics. The project coordinator, Dr. R. B. Rewari is stationed at the Indian Agricultural Research Institute (IARI), New Delhi. The scientists in this scheme would welcome cooperative research with the NifTAL project. Because many of these microbiologists have only been appointed in the last three years, present facilities vary a great deal between centers and this places some limitations on the kinds of research that can be meaningfully conducted. There is an attempt to concentrate work at each center on the two or three crops of major importance in the region where the research center is located. The major crops are chickpea, pigeon pea, green gram, black gram, and cowpea (*Vigna unguiculata*). Some work is also being done on guar (*Cyamopsis tetragonolobus*), moth bean (*Phaseolus acontifolius*), and horsegram (*Dolichos biflorus*), and a small amount on soybean. ICAR has a separate All India Coordinated Research Project on soybean, but with only two microbiologists--Dr. M. V. Shantaram of the University of Agricultural Sciences in Bangalore, and Dr. V. R. Balasundaram of IARI--working under its auspices. One microbiologist at the Central Arid Zone Research Institute

(CAZRI), at Jodhpur, is working on pasture legumes, with another in an ad hoc scheme at the University of Bangalore.

A relatively small ICAR scheme on biological nitrogen fixation was established in 1978 involving some 8 agricultural institutes and universities, sponsoring more basic, laboratory-oriented work on both symbiotic and associative nitrogen fixation, with research programs devised by the centers and approved by an ICAR-appointed committee, which supervises the scheme and controls fund allocation. The grants from this scheme are mainly used to provide support staff and equipment.

Coordinated research on groundnut comes under the All India Coordinated Oilseeds Research Project, with its Directorate (under Dr. Vikram Singh) at Andhra Pradesh Agricultural University, but presently no microbiologists are involved except those from ICRISAT. ICAR also finances a Coordinated Research Program on Algae (with the Project Director Dr. G. S. Venkataraman, Microbiology Division, IARI) which covers nitrogen fixation by blue-green algae in rice paddies, and under the All India Coordinated Rice Improvement Project, work on nitrogen fixation associated with rice is carried out at the Central Rice Research Institute at Cuttack, at Tamil Nadu Agricultural University, Coimbatore and at IARI, New Delhi. Some work on Azotobacter is carried out with varying degrees of sophistication at several other research centers.

Several agricultural universities have microbiology departments with staff working on nitrogen fixation in addition to the above schemes, notably Haryana Agricultural University at Hissar; IARI at New Delhi; the University of Agricultural Sciences at Bangalore; and Tamil Nadu Agricultural University at Coimbatore. Some related research is also conducted at the Agricultural College at Madurai; JNKVV University at Jabalpur; Punjab Agricultural University at Ludhiana; Institute of Advanced Studies, Madras Botany Department; Bose Institute, Calcutta, Microbiology Department; Kalyani University; Annamallai University; and the University of Agricultural Sciences, Dharwar campus. Biochemical work is being conducted at the Indian Institute of Sciences, Bangalore, and at Boroda University. Work on plantation crops and associated legume cover crop is in progress at the ICAR Central Plantation Crops Research Institute at Kayamkulam, Kerala.

For newly introduced crops such as soybean, responses to inoculation are invariably obtained in the first season, as R. japonicum are usually absent from soils in India. A few nodules can be formed by "cowpea" group rhizobia, and

these have provided superior inoculum strains in some locations. Little information is available on subsequent survival of the inoculum in farmers' fields, but on research stations indigenous soil populations of R. japonicum have been established. The area under soybean cultivation at c 60,000 ha is approaching the "take-off point" in terms of economy of handling the harvested beans and oil extraction, and associated increased returns to the producer, and increases in the area under cultivation are predicted.

Chickpea is the major pulse crop in India (c 7.3 million ha), but mean yields are low (c 580 kg/ha) although yields of 4-5,000 kg/ha have been obtained in experiments. The area sown to chickpea has declined in the last fifteen years, and production has moved from the northern states into north central and central states as wheat and rice production has increased in the northern states. This suggests that new areas are being used for chickpea production, and responses to inoculation can be expected. Field surveys show poor or no nodulation in some areas. Responses to inoculation have been obtained in land traditionally used for chickpea cultivation and an example is shown in Table 1.

Table 1*: Gram field experiment--Delhi, Rabi 1967-68

Treatment	Gram yield, kg ha^{-1}	N uptake kg ha^{-1}
Uninoculated	1033	34.5
Rhizobium	1323	45.0
C.D. at 5%	156	3.4

On at least 2 million ha annually, pulses (mainly chickpea, green gram and black gram) follow paddy rice. Where the pulse has been absent for some time, substantial responses to inoculation (up to 150% for chickpea) have been obtained, but little is known of responses where the rotation is more nearly "paddy-pulse-paddy-pulse," or how the inoculum survives under a subsequent rice paddy.

In terms of area under production, groundnut (Arachis hypogaea) is the next most important legume, with the area fluctuating considerably but around 7 million ha annually with yields of about 700 kg/ha. Where groundnut production

* From W. V. B. Sundara Rao, Plant & Soil Special Vol. 1971, 287-291.

is starting in large, new, irrigation schemes, nodulation is often very poor, as can also be the case in rainfed crops, suggesting that scope exists for inoculation. Farmers often use urea fertilizer, which suggests that the symbiotic nitrogen fixing system is defective. Responses to inoculation have been obtained on research stations.

Pigeon pea is the second most important pulse crop with about 2.5 million ha sown annually with average yields of about 680 kg/ha. Response in terms of grain yield to inoculation is rare, perhaps because of the low harvest index, but also because of the pattern of nodulation of the crop, with nodules senescing from 30 days after germination and new nodules forming on new roots deeper in the soil. Nodules form at soil depths greater than 1 meter. Surveys of farmers' fields often report very poor nodulation, but this may be because of the difficulty in recovering the nodules from soil as their attachment to the root is very fragile. Early nodulation can be influenced by inoculation and a response in grain yield has been obtained at ICRISAT in a Vestisol, with yields of 1700 kg/ha, increased 25% by inoculation.

In an Alfisol, yields were increased by as much as 30% to 1000 kg/ha by addition of nitrogen fertilizer at the rate of 20 and 200 kg N/ha, suggesting that the nitrogen supply from the symbiotic system was limiting yields.

Increases in grain yield of field crops of other pulses have also sometimes been obtained at various centers in the coordinated trials.

In India, the quality of inoculants produced severely limits the potential for increasing yields through inoculation. The Indian Standards Institute has set minimum standards for Rhizobium inoculants, but it is not mandatory for manufacturers to conform to these. Inoculants presently produced are not sterile apart from Rhizobium (the optimum condition), and the numbers of contaminants often exceed the numbers of rhizobia, making them virtually worthless for use by farmers. Lack of an infrastructure for distribution and storage of inoculants prior to use also restricts the potential use. If responses to inoculation can be reliably obtained, the extension agencies would readily include inoculation in the package of practices for grain legume production, but in the present circumstances are understandably reluctant to do so. If inoculation is recommended, the potential market for inoculants is enormous.

WORK OUTSIDE INDIA

The Pulse and Groundnut Microbiology Program at ICRISAT

Research is focused on improving nitrogen fixation by pigeon pea, chickpea and groundnut by manipulating both the Rhizobium and the host plant symbionts. We have developed dilution-plant infection techniques for counting the specific Rhizobium populations nodulating these legumes from mixed microbial populations such as soil and non-sterile inoculants. Cowpea type Rhizobium numbers are generally high in the surface 30 cm of Alfisols on ICRISAT farm, but seem sparse beyond 1.1 m depth. Vertisols generally contain fewer of these rhizobia, and some fields contain virtually none (less than 100/g soil). The paddy soils at ICRISAT contain few rhizobia.

We have collected from many countries, isolated, and purified over 900 strains nodulating our legumes, and made a preliminary assessment of their nitrogen fixing ability. Strains from this collection are available to anyone. We have obtained field responses in some experiments to inoculation, noticeably for chickpea after paddy and in a saline soil. We will concentrate future efforts on understanding the competition between inoculum strain(s) and the indigenous soil population of rhizobia using genetically marked and serologically identifiable strains. A collaborative project with the John Innes Institute is concerned with this endeavor.

Work on methods of production and application of inoculants has started. We are also devising methods for monitoring inoculant quality that will be of use to concerned governments.

The pattern of nodulation and nitrogen fixation throughout the growth cycle has been studied. Acetylene reduction assays of nitrogenase activity and plant nitrogen-uptake measurements are being used to follow nitrogen fixation. There are great effects of season, location, soil type and fertility status. For example, at Hyderabad in Central India, rain-fed chickpea nodules cease nitrogen fixation early in pod fill stage, quite contrary to their continued activity at Hissar in North India. Insect predation of nodules is common in some locations. In surveys of farmers' fields, nodulation ranged from poor, or absent, to excellent. Pigeon pea yields responded to a large addition of nitrogen fertilizer in one experiment, suggesting that nodules were not able to supply enough nitrogen for maximum yields. There is a large diurnal periodicity in nitrogenase activity and this, coupled with the effect of clouds and shading,

indicates a close link between rates of photosynthesis and nitrogen fixation. Water stress without obvious wilting markedly affected groundnut nitrogen fixation and yield, and there were indications of differences between cultivars in this response.

The residual effects of our legumes on the nitrogen nutrition of subsequent crops are under examination. For example when compared with maize, a previous groundnut crop enhanced yields of millet by 655 kg/ha or 49%.

Screening of several hundred field-grown germplasm lines for each crop has shown very large variability for symbiotic characteristics. For example in the 110 pigeon pea crossing block entries, nodule number per plant varied 6 fold between lines. We are at the stage of choosing parents for a crossing program to follow the heritability of these traits with the aim of increasing nitrogen fixation by breeding. We have a collaborative project with North Carolina State University for groundnut work.

Future projects will:

Survey the distribution of mycorrhizal fungi in soils of the semi-arid tropics, and select fungal strains capable of stimulating growth and nutrient uptake in the presence of indigenous mycorrhizal populations in soil;

Examine the role of plant genotype in the mycorrhizal response;

Examine the response of ICRISAT crops to inoculation within the field--particularly under low fertility conditions;

Examine the response of field-grown chickpea, pigeon pea, groundnut, millet and sorghum to inoculation with mycorrhizal fungi, particularly under low fertility conditions.

Staff includes:

Peter Dart	...	Program Leader-Microbiology
J. V. D. K. Kumar Rao	...	Microbiologist (pigeon pea)
O. P. Rupela	...	Microbiologist (chickpea)
P. T. C. Nambiar	...	Microbiologist (groundnut)

The Cereal Microbiology Program at ICRISAT

Research is focused on nitrogen fixation associated with pearl millet, sorghum, minor millets and some tropical grasses. Several hundred lines of worldwide origin have been tested under field conditions with about 10% having high nitrogenase activity. There is a large variability between plants, fields and seasons in activity, which is correlated with soil moisture. Pot experiments and nitrogen balance experiments with hybrids of napier grass x pearl millet (*Pennisetum purpureum* and *P. americanum*) indicate that significant amounts of nitrogen can be fixed by root-associated bacteria. At least 6 types of organisms seem involved in the activity and can be isolated from surface-sterilized roots. Future work will be concentrated on nitrogen balances for millet and sorghum production in the field and in lysimeters, to estimate nitrogen fixation.

The possibility of using ^{15}N to label soil organic matter and measure nitrogen fixation is also being explored. Crosses have been made between millet lines with high nitrogenous activity and high nitrogen uptake.

List of Some Microbiologists Working on Nitrogen Fixation in Asia

	Name and Position	Institution
1.	Dr. A. Balasubramanium Microbiologist (Pulses)	Agriculture College and Research Institute Tamil Nadu Agricultural University Coimbatore INDIA
2.	Dr. V. R. Balasundaram All India Coordinated Pulse Improvement Project	Indian Agricultural Research Institute (IARI) New Delhi 12 INDIA
3.	Dr. G. R. Gajendra Gadkar Microbiologist	J.N.K.K.V. University Jabalpur INDIA
4.	Dr. T. K. S. Gowda Microbiologist	Agricultural Research Station Gulbaraga 585102, (Karanataka) INDIA

	Name and Position	Institution
5.	Dr. B. R. Gupta Microbiologist (Pulses)	Dept. of Soil Science & Agricultural Chemistry C.S. Azad University of Agriculture and Technology Kanpur INDIA
6.	Dr. S. V. Hedge Scientist (Microbiology)	Univ. of Agricultural Sciences G.K.V.K., Bangalore-560065 INDIA
7.	Dr. A. L. Khurana Microbiologist	Dept. of Microbiology Haryana Agricultural University Hissar-125004 INDIA
8.	Dr. A. S. Khurana Microbiologist	Department of Plant Breeding P.A.U., Ludhiana INDIA
9.	Dr. N. B. Pawar Microbiologist	Agricultural Research Station, Badnapur Dist. Aurangabad (M.S.) INDIA
10.	Dr. Raman Rai	Rajendra Agricultural University T.C.A., Dholi (Muzaffar) Bihar INDIA
11.	Dr. M. Rangarajan Microbiologist (Pulses)	Agriculture College and Research Institute Madurai INDIA
12.	Dr. M. Rangaranjan Microbiologist	Agricultural College and Research Institute T.N.A.U., Madurai INDIA
13.	Dr. H. S. Nagaraj Rao Microbiologist (Pulses)	Agricultural Research Institute A.P.A.U., Rajendranagar Hyderabad-500030 INDIA

	Name and Position	Institution
14.	Dr. R. B. Rewari Project Coordinator All India Coordinated Pulse Improvement Project	Indian Agricultural Research Institute (IARI) New Delhi 12 INDIA
15.	Dr. M. V. Shantaram	All India Coordinated Research Project on Soybean University of Agricultural Sciences Hebbal, Bangalore 560065 INDIA
16.	Dr. L. C. Sharma Microbiologist	Agricultural Research Station, Durgapura Jaipur, Rajasthan INDIA
17.	Dr. Laxman Singh Project Director	Indian Council of Scientific Research (ICAR) Directorate of Pulse Improvement Kanpur INDIA
18.	Dr. Vikram Singh Director	All India Coordinated Oilseeds Research Project Andhra Pradesh Agricultural University Rajendranagar, Hyderabad INDIA
19.	Dr. J. S. Srivastava Microbiology (S.R.A.)	Dept. of Genetics and Plant Breeding Faculty of Agriculture B.H.U., Varansi INDIA
20.	Dr. G. S. Venkataraman Project Director Microbiology Division	Coordinated Research Program on Algae Indian Agricultural Research Institute (IARI) New Delhi INDIA

	Name and Position	Institution
21.	Dr. K. A. Malik	Nuclear Institute for Agriculture and Biology J Hang Road P.O. Box 128 Faisalabad PAKISTAN
22.		Institute for Nuclear Agriculture P.O. Box 4 Mymensingh BANGLADESH
23.		Soil and Fertilizer Research Institute P.K. 54 Yenimakalle Ankhara TURKEY

INTERNATIONAL SOYBEAN PROGRAM (INTSOY)

R. Stewart Smith
Soil Microbiologist/INTSOY
Dept. of Agronomy
University of Illinois at Urbana-Champaign

The objective of the International Soybean Program (INTSOY) is to assist in the development and exploitation of the inherent potential of the soybean as an efficient source of high-quality protein and high-quality edible oil for diets of both the rural and urban poor. The US Agency for International Development provides support to the University of Illinois at Urbana-Champaign and the University of Puerto Rico, Mayaguez Campus, to assist in developing INTSOY as an international soybean resource base. INTSOY provides technical assistance to AID and cooperating countries, agencies, and institutions on the production, plant protection, marketing, and use of soybeans. Soybeans offer a greater potential for lessening developing country protein and calorie shortages than any other grain legume. The ability of the soybean in association with Rhizobium japonicum, to fix atmospheric nitrogen thereby eliminating the need for costly petro-chemical fertilizer, makes it an attractive crop to the small farmer with low cash reserves for the purchase of production inputs.

INTSOY research activities have been interdisciplinary, with scientists from both universities in the areas of plant breeding, agronomy, soil microbiology, pathology, entomology, nematology, weed science and food science contributing to research programs on soybean production and use in the tropics and subtropics. An array of trials has been developed to identify, evaluate, and hasten the process of adoption of improved soybean varieties. It is now known that soybean can be developed as a high-yielding crop at tropical latitudes. Substantial attention has been given to cultivars which exhibit resistance to diseases. Pathogens that affect seed quality and germination have been intensively studied through cooperative efforts of the Universities of Illinois and Puerto Rico.

Two components of the INTSOY program relate directly to the International Network of Legume Inoculation Trials being promoted through NifTAL.

The first is the International Soybean Variety Experiment (ISVEX) supervised by Dr. William H. Judy, INTSOY Agronomist. ISVEX was organized in 1973 and is conducted annually in 80-90 countries at 200-300 sites. The ISVEX

trial is designed to:

1. Evaluate the adaptation and response of soybean cultivars under a wide range of environmental conditions;

2. Provide research workers an opportunity to compare local and introduced varieties;

3. Provide a source of new germplasm which the Cooperator may use directly or incorporate into his breeding program; and

4. Identify areas of the world which have a potential for soybean production.

Each Cooperator is given a complete ISVEX instruction booklet with recommended management practices and requested observations, soybean seed as required and sufficient inoculant. Each Cooperator returns data on: days to flower, days to maturity, nodule rating, plant height at maturity, lodging score, shattering score, number of plants harvested, yield of dry soybeans, pods per plant, 100 seed weight, seed quality rating, and percent germination. After receiving data from the Cooperators, INTSOY analyzes all data and publishes a detailed report including the data from each cooperating site for the annual ISVEX report.

The second INTSOY component relating to the Rhizobium Experimentation Network is the work I am doing with Rhizobium japonicum and the inoculation of soybeans in the tropics and subtropics. Two international projects have been initiated: The International Soybean Rhizobium Inoculant Experiment (ISRIE) and the International Inoculant Shipping Evaluation (IISE).

The International Soybean Rhizobium Inoculant Experiment (ISRIE) is a soybean inoculant response trial which is being done by over 100 Cooperators in the tropics and subtropics. The objective is to determine soybean yield response to inoculation with Rhizobium japonicum in tropical areas. ISRIE has four treatments: (a) non-inoculated control, (b) rhizobia inoculated, (c) rhizobia inoculated plus nitrogen fertilized, and (d) nitrogen fertilized. Davis variety seed, granular inoculant and instruction booklets are being sent from the University of Illinois to all Cooperators.

We have agreed at this Network Planning Workshop that NifTAL will check with INTSOY and not ask a Cooperator contacted by both organizations to duplicate the soybean

inoculant response component in the Network experiment.

The International Inoculant Shipping Evaluation (IISE) is an inoculant trial evaluating the quality of granular soybean inoculant after exposure to international shipping and storage conditions. High temperature, loss of moisture and time elapsed use stresses which affect the quality of inoculants. Inoculants shipped to the tropics for research or commercial use may have encountered these kinds of stress.

Samples of commercial granular soybean inoculant (50 g.) are being sent to more than 100 Cooperators in the tropics and subtropics. Attached to the sample is a temperature indicating label which irreversibly changes color as each of the following temperatures are reached: 38°, 43°, 49°and 54°C. Instructions accompany the sample directing the Cooperator to complete a data sheet indicating which temperature has changed color, and to return the sample to the INTSOY microbiology lab at the University of Puerto Rico. The maximum temperature to which the inoculant was exposed will be recorded and R. japonicum numbers and percent moisture determined.

Both inoculant trials are being sent from INTSOY, University of Illinois, in cooperation with the International Soybean Variety Experiment (ISVEX).

Both international inoculant trials are similar to proposed Network Trials in several ways. Coordination and cooperation between the two organizations can assist each project in meeting its goals. Copies of the instruction booklets for both ISRIE and IISE have been sent to NifTAL. In addition, two cooperative projects between INTSOY and NifTAL are being formulated.

The objective of the first experiment is to determine the establishment and persistence of four strains of R. japonicum from a commercial inoculant at various pH values in Puerto Rico soil which is acid and high in available aluminum. One aspect of this trial will include nodule sampling. The nodules will be sent to NifTAL for serological typing. This will provide an opportunity to test the proposal that NifTAL offers a nodule typing service to overseas participants in the International Network of Legume Inoculation Trials.

A second cooperative project will be planted in Puerto Rico to field test strains of R. japonicum which have been determined to be acid tolerant under laboratory evaluations conducted by Dr. Don Munns (University of California at Davis). Those R. japonicum strains which have been

determined acid-tolerant will be used in an experiment to be planted on an acid soil with high aluminum saturation.

CURRENT WORK ON NITROGEN FIXATION BY TROPICAL LEGUMES IN LATIN AMERICA

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Centro Internacional de Agricultura Tropical (CIAT)

PREFACE

This is not a scientific paper. It is a guide to who's who and what they are doing with respect to nitrogen fixation research with tropical legumes in Latin America. It is orientated specifically to the NifTAL planning workshop for a network of *Rhizobium* testing that might involve sites in Latin America. The information presented may in a few cases be incomplete or even out of date; therefore comments and recommendations in this respect are welcomed. An appraisal is made of each research group with respect to their capacity to participate effectively in a program of *Rhizobium* testing at the field level. Readers are referred particularly to the first three items in the section headed "DOCUMENTATION."

The views expressed in this article are entirely those of the author and should not be construed to represent those of the management or Board of CIAT nor its donor agencies.

INTRODUCTION

Although a large number of researchers in tropical Latin America are working in biological nitrogen fixation, very few are involved in comprehensive programs that embrace not only collection and isolation of strains of *Rhizobium* but also evaluation of their effectiveness at both the glass-house and field level. This last aspect is particularly neglected and only four groups are known to be actively involved in field evaluation of strains of *Rhizobium*, (CIAT Beef Program; CIAT Bean Program; EPAMIG and UFRGS/IPAGRO).

There are many individuals, mainly in the universities, conducting strain selection programs which are executed enthusiastically but with relatively little direction. On the other hand there are many agricultural institutes with legume programs conducted at an agronomic level without rhizobiological back-stopping. The isolation in which these groups work with respect to each other despite their common goals is unfortunate and is attributable to the lack of effective communications media such as journals, the infrequency of conferences and workshop, the economic and logistic difficulties in attendance at international scientific meetings, and inter-person and inter-institution jealousies. Relatively little can be done about the last

circumstance, but one can expect an improvement in the others with time.

Against this background there is an opportunity for agencies such as NifTAL to make a major impact, first through encouraging and supporting collaboration between groups within countries; second by promoting a field orientation in groups presently engaged in strain selection; and third by making strains available as inoculants for use by legume agronomists.

INTERNATIONAL PROGRAMS

CIAT, Cali, Colombia

CIAT, one of ten international centers administered by the CGIAR, has as its objective "to generate and deliver, in collaboration with national institutions, improved technology which will contribute to increased production, productivity and quality of specific basic food commodities in the tropics--principally in Latin America and Caribbean countries--thereby enabling producers and consumers, especially those with limited resources, to increase their purchasing power and improve their nutrition." Consistent with CIAT's declared low input strategy, biological nitrogen fixation research features prominantly in two commodity programs.

Bean Program. The bean program works to improve *Phaseolus* bean crops. Beans are an important protein source for rural and low-income families throughout Latin America. Consumer prices for this grain legume are high, largely because of low crop yields caused by diseases and insects. Scientists are striving to alleviate bean production problems through research and training in all phases of *Phaseolus* crop improvement, especially by development of pest resistant germplasm.

The objective of the soil microbiology section of the Bean Program is to ensure that the benefits from biological nitrogen fixation in this crop are maximized. The strategy employed involves not only the classical strain selection approach but also novel and exciting work which exploits varietal differences in nitrogen fixation by *Phaseolus vulgaris* to breed specifically for enhanced symbiotic performance.

Dr. Peter Graham is head of the section. Silvio Vitery and Luz Dary Ruiz are his research assistants. Gloria Isabel Ocampo is the bacteriologist. The activities of the section have been reported. Participation rating: 5.

The objective of the Soil Microbiology Section of CIAT's Beef Program is to maximize the benefits of biological nitrogen fixation to adapted forages in the acid, infertile soils of tropical Latin America. Priority has been given to the legume/*Rhizobium* symbiosis. The research strategy is (1) to maintain and augment the CIAT *Rhizobium* germplasm resource; (2) to evaluate the symbiotic nitrogen fixation potential of *Rhizobium* strains with adapted legumes; and (3) to test expression of symbiotic potential of selected strains in field situations, initially at Quilichao, Carimagua and Brasilia and then in regional trials throughout the Beef Program's target areas.

Rhizobium Collection

The number of strains in the CIAT *Rhizobium* collection for tropical forages doubled during 1978 to 2043 through donation by collaborators (principally R. A. Date of CSIRO, Brisbane) and collection expeditions to eastern Venezuela (CSIRO/CIAT), Ecuador (CSIRO/CIAT), and northeastern Brazil (EMBRAPA/CSIRO/CIAT). The second edition of the catalogue of strains of *Rhizobium* for forage legumes is available on request.

Research on collection methodology has revealed that although silica gel and calcium chloride do not differ significantly in the rate at which they dessicate nodules in storage vessels the viability of rhizobia in stored nodules is greater and the level of contaminating organisms on primary isolation plates is reduced when calcium chloride is used. It is now known that a key factor in past failures with isolation of *Rhizobium* from nodules of plants (especially *Stylosanthes* spp.) growing in acid soils is that many such strains have an acid requirement for growth and cannot grow on the standard medium (pH 7) used for isolation. This implies that the search for acid-adapted *Rhizobium* in existing collections of strains which were orginally isolated onto routine non-acid media may not be the most valid nor fruitful approach. Collecting activities have been stepped up using acid media to isolate and maintain cultures.

A practical manual for the collection, isolation, characterization and preservation of strains of *Rhizobium* was prepared in conjunction with R. A. Date and is available from CIAT on request.

Strain Selection

Strains of *Rhizobium* for forage legumes which are nominated as promising by the Beef Program's germplasm

committee continue to be selected by a five stage program.

Stage I (aseptic tube culture)

Forty-three strains of Rhizobium isolated from root nodules of Stylosanthes species from various soil types were tested with two S. capitata genotypes (CIAT 1019 and CIAT 1078). Nodulation did not occur in any host genotype by strain combination. When the standard agar rooting medium was acidified to pH 4.9 however, nodulation was observed with 15 strains tested with S. capitata (CIAT 1019). It is concluded that S. capitata has an acid requirement for nodulation. S. capitata exhibited greater specificity in in its strain requirement than S. guianensis (CIAT 136), S. hamata (PI 40264A) and S. hamata (PI 38842) each of which nodulated with all 43 strains.

Eight out of 15 strains of Rhizobium tested with Zomia sp. (CIAT 728) formed nodules under the conditions of the test.

Only half of the strains of Rhizobium tested with Macroptilium sp. (CIAT 535) formed nodules, indicating a much higher degree of specificity of strain requirement than is the case with the very promiscuous Macroptilium atropurpureum cv. Siratro.

Stage II (sand culture with pH 7 nutrient solution)

Thirty-nine strains of Rhizobium were ranked in order of their nitrogen fixation potential with Desmodium ovalifolium (CIAT 350). The best non-CIAT isolate was 26th in the effectiveness ranking. Variation in strain effectiveness can be attributed mainly to differences in the mass of nodules formed (see Figure 1) rather than the rate at which the nodules function (specific nodule activity).

The results of experimentation with Stylosanthes capitata (CIAT 1019) indicated that growth requirements of the plant have not been met satisfactorily by the medium used routinely in this stage. CIAT 71, a strain of known effectiveness with S. capitata, was ineffective in the test. Work continues to develop a nutrient solution suitable for sand culture of S. capitata.

The wide spectrum strain CB 756 was moderately effective with Macroptilium sp. (CIAT 535). Three strains (CIAT 320, 420 and 318) were more effective.

Stage III (pot culture in unsterilized site soil)

Plants inoculated with the best strain in a trial with Stylosanthes capitata yielded double the dry matter of uninoculated control plants. The strain CIAT 71 which has to date been recommended for S. capitata only on the basis of high effectivity with S. guianensis and genetic compatibility with S. capitata was confirmed as a highly effective nitrogen fixing symbiont for this host and has increased attractiveness as a wide spectrum inoculant strain for acid soils. CB 756, a strain often used to inoculate Stylosanthes, was confimed to be ineffective with this S. capitata accession.

The Rhizobium strain CIAT 71 originally isolated from Stylosanthes nodules proved to be one of the most effective strains on Zornia sp. (CIAT 728), a taxonomically closely related genus. The strain CIAT 103, which had been recommended previously for Zornia on the basis that it was a Zornia isolate, is only moderately effective with this accession.

Only three out of twelve strains of Rhizobium that were highly effective in nitrogen fixation with Desmodium distortum grown in sand jars were capable of nodulating and fixing nitrogen under acid soil stress.

In trials with Centrosema hybrid brasilianum x virginanum (CIAT 438), ranking of effectiveness in nitrogen fixation in acid soil in the presence of competing native strains of Rhizobium differs from the order of merit under optimal plant growth conditions (Fig. 10.5a). The best strain under stress in site soil was eighth in effectiveness order in sand jars. Also, several strains that were fully effective in sand jars fixed no nitrogen in acid soil. It was particularly alarming that strain CIAT 327 which was 49th out of 50 strains in sand jars gave the second highest yield in the Stage III trial.

In trials with Desmodium heterophyllum (CIAT 349), only one out of ten strains of Rhizobium that were fully effective in nitrogen fixation at Stage II was fully effective in nitrogen fixation under stress in acid soil.

Stage III results emphasize the important modifying role which the soil can play on the legume/Rhizobium symbiosis and demonstrate the need for caution in over-dependence on the standard sand jar test to select strains of Rhizobium for stress conditions.

Stage IV (field trial of selected strains and inoculation technologies

Quilichao. Data from the field trials with Desmodium, Stylosanthes, Centrosema, Galactia, Macroptilium, and Pueraria phaseoloides (CIAT 9900) are summarized in Table 1.

Carimagua. Results of the field trials with Desmodium ovalifolium (CIAT 350), S. capitata (CIAT 1019), S. capitata (CIAT 1078) and Macroptilium sp. (CIAT 535) are summarized in Table 2. The experiment with Macroptilium has been terminated due to lack of host plant adaptation to the soil, climatic, insect and disease stresses of the region. With S. capitata accessions neither 1019 nor 1078 survived into the second year under small plot, pure sward conditions. Adult plants of 1019 were virtually eliminated by spider mites and in 1078 stemborer reduced the population of mature plants to near zero. These results are inconsistent with the observed behavior of these accessions in mixed pasture with grasses. Some useful data may be obtained on the persistence of introduced strains in soil and their ability to nodulate new seedlings, but it is not possible to study the inoculation response for more than one growing season with this experimental design. Future experiments with these accessions will be performed in larger plots with mixed swards.

Acid Tolerance by Rhizobium

Results from field and pot trials show that a response to inoculation with selected strains of Rhizobium is the rule rather than the exception. There tends to be a reduction in the response over time however. It is likely that protection of the inoculant strain with pelleting at the time of sowing permits an early and high percentage infection by the effective introduced strain thus giving a marked initial response. A critical point is reached when the primary nodule population decomposes (after 2-3 months) and the rhizobia must survive in the acid soil as free-living soil saprophytes. Multiplication at low pH is of paramount importance for reinfection of the legume root, competition with native strains of Rhizobium for nodule sites and persistence in the soil microflora. Research was therefore directed at development of a medium to test for this character. Alkali production by tropical rhizobia has been an obstacle to the development of such a test causing the pH to rise from its initial value of around pH 4 to above pH 8 and thereby confusing interpretation of the result. A stable acid medium in which the ability of Rhizobium to produce alkali has been eliminated was developed. The medium permits selection of strains genuinely

capable of multiplication at low pH (Fig. 10.6) and will enable the effect of aluminum and other acidity stresses on Rhizobium to be determined.

Demonstration that alkali production by the tropical rhizobia is dependent on the culture medium reopens the debate over whether these microorganisms actually produce alkali in the rhizosphere of their host and whether it was correct to attribute an evolutionary and ecological role to the process. It has been considered that lack of alkali production by the non-typical Rhizobium for Leucaena leucocephala is the prime reason for the lack of adaptation to acid soils in this species. Parallel experiments at Quilichao and Carimagua employing identical treatments and a recently assembled collection of strains of Rhizobium isolated from Leucaena has revealed that there is not, as was thought, a block to nodulation of Leucaena below pH 5.0. A wide array of strains from differing soil types were capable of forming effective symbioses in acid conditions. A few strains were exceptionally effective and are being investigated further.

The section is headed by Dr. Jake Halliday. Fabio Gutierrez is the principal research assistant, Gladys Sanchez and Lucia Mejia de Mayor the bacteriologists, Ramon Gualdron the research assistant in the Carimagua station, and Karen Spedel the research associate at Brasilia.

The activities of the section have been reported[9-17]. Principal legumes of interest are Stylosanthes spp., Zornia spp., Desmodium and Leucaena leucocephala.

The section offers training to individuals holding positions in organizations actively engaged in pasture research in the Beef Program's target area.

Strains of Rhizobium from the collection of over 2,000 isolates from tropical forage legumes are available either in the form of pure cultures or as peat-based inoculum, of which 100 kg was produced in 1978. Participation rating: 5.

Drs. Graham and Halliday handle production of what have become referred to as the "Noticias"[18], a quarterly bulletin of general information with a detailed bibliography of articles on Rhizobium in the CIAT library.

MIRCEN, Porto Alegre, Brazil

'MIRCEN' stands for Microbial Resources Center, and IPAGRO/UFRGS is one of a number of such entities worldwide

in receipt of funding from UNEP/UNESCO/ICRO. Although the concept of these centers originated at an UNEP meeting in Nairobi in 1974, 1978 was the first operational year of the MIRCEN at Porto Alegre.

The objectives have been defined as:

1. Promotion of increased awareness of the potential of biological nitrogen fixation through newsletters, field demonstrations, conferences and direct contact with researchers and extensionists.

2. Maintenance of a Rhizobium culture collection and distribution and interchange of strains with other research centers throughout the world.

3. Applied research on topics of importance to regions where inoculation with Rhizobium is required, i.e. strain selection, inoculant production, and other factors limiting to nitrogen fixation.

4. Practical training for laboratory personnel, researchers, extensionists, and technicians from commercial inoculant producers.

Dr. J. R. Jardim Freire heads the group and details of staffing can be found in the section on UFRGS/IPAGRO. One training course has already been staged (July 1978) and two publications disseminated, issue number one of the MIRCEN Rhizobium Newsletter[3] and a "Special Edition" of the Newsletter[19] admirable for the practical orientation of its content.

MIRCEN, unlike the two programs in CIAT, is not commodity restricted, and can therefore be considered as the most important center for Rhizobium research in Latin America.

FAO/UNEP

As part of a global program promoted by Dr. Fernando Riveros consultancy reports on various Latin American countries[4] were compiled in 1976/1977. Projects are in progress in N. E. Argentina (tropical forages) and will soon be initiated in Peru (tropical forages, Pucallpa; temperate forages, Ayacucho; soybean, Tarapoto). Participation rating: 5.

BOLIVIA

Centro de Investigacion Agricola Tropical, Sta Cruz

Dr. Rob T. Patterson of the British Mission has experience in inoculation trials with tropical forages, namely *Glycine wightii*, *Desmodium intortum*, *Stylosanthes guianensis*, and *Macroptiloma axillare*.

Universidad Boliviana "Gabriel Rene Moreno," Sta Cruz

The Faculty of Agriculture has a project on tropical forage legumes. Miguel Cortez has been evaluating the need for inoculation throughout the tropical regions of Bolivia.

BRAZIL

CENA, Piracicaba

This center for nuclear research has an active nitrogen fixation group in the persons of Dr. Alaides Ruschel and Siu Mui Tsai Saito. Although a lot of attention is given to non-*Rhizobium* research (nitrogen fixation in sugar cane) sound work has been accomplished on rhizobiology, principally with *Phaseolus vulgaris*. A developing interest in legume-based pastures within the beef production program at the center makes it likely that *Rhizobium* studies with tropical forage legumes will be initiated. Facilities at the Center, especially for sophisticated research with isotopic nitrogen, are exceptional[20,21,22].

CNPq/EMBRAPA/UFRRJ (km 47)

Although the research program directed by Dr. Johanna Dobereiner has a strong and understandable bias towards nitrogen fixation by *Azospirillum* spp. in association with grasses, it does also have a responsibility for the legume/*Rhizobium* symbiosis. Until recently Avilo Franco directed a program of research on legumes (principally *Stylosanthes* spp., *Phaseolus vulgaris* and *Glycine max*) with emphasis on minor element requirements. He is currently undertaking his Ph.D. in the US with Dr. Don Munns and there are no plans to replace him during his absence. Helvecio de-Polli, who was also involved in legume work (pelleting with minor elements) is also leaving to study for a higher degree. The Annual Report (for 1977) of the group is available[23].

EMBRAPA: CPAC, Brasilia

The federal agricultural research organization EMBRAPA has a center with responsibility for investigations relating to agricultural exploitation of the "Cerrados" (acid, infertile soil savannahs)[24]. The soil microbiology group is comprised of Allert Rosa Suhet and Milton Vargas. Research interests are in nitrogen fixation by soybean and strain selection for forages adapted to acid, infertile soils. A research associate from the soil microbiology section of CIAT's beef program will be stationed there from June 1979 to augment the work on forage legumes. Dr. Derrick Thomas is a legume agronomist at the station with previous experience, and intense interest, in inoculation experiments with forage legumes. He has inoculation experiments in progress with *Leucaena leucocephala*.

EPAMIG, Sete Lagoas

At the beef production program of the agricultural research department of the state of Minas Gerais, legume-based pastures are being developed of infertile, acid soils. Nuno Maria de Sousa Costa is the agronomist in charge of what is an extremely impressive and go-ahead legume introduction and evaluation program. A trained microbiologist is on staff at Sete Lagoas (Ana Maria Quadrelli de Escuder) but the rhizobiology aspect of the work is hampered at present by lack of finance and facilities. Despite this, experiments have recently been initiated on the response of tropical forage legumes to inoculation with *Rhizobium*. Species of interest are obviously the tropical forage legumes and some emphasis is being given to *Leucaena leucocephala*.

INPA, Manaus

Dr. Rosemary Bradley is the soil microbiologist with INPA (National Institute for Amazonia Research). Her training and talents are currently under-utilized due to lack of definition of, and application to, specific objectives by INPA with respect to legume research. At the suggestion of CIAT she is becoming involved in rhizobiological back-stopping of organizations such as PROPASTO and CIAT who aspire to introduce legume-based pastures in areas where the jungle is being cleared. She should be considered a key person also with respect to a NifTAL Network because of her strategic location. Dr. Bradley may receive travel funds to service *Rhizobium* inoculation experiments throughout northern Brazil through an informal agreement with CIAT's soil microbiologist. Unfortunately she will be away

from post on extended leave for part of 1979 but has two assistants capable of running things in her absence.

INSTITUTO AGRONOMICO, Campinas

This Sao Paulo state research organization has a soil microbiology section headed by Eli Sidney Lopez. Although there is an increasing interest in VA mycorrhizas, rhizobiology is still the principal activity in the group. An excellent and varied collection of strains of *Rhizobium* is maintained, and documented, at a high standard. Eli Lopes has invested a great deal of effort in acquiring facilities for research which must now be rated among the best in Latin America. The group has quite broad objectives in improving nitrogen fixation in crops of importance to the state of Sao Paulo. The main species of interest are *Phaseolus vulgaris* (temperature tolerance), soybean and tropical forage legumes for acid soil conditions. Peanuts have been receiving enthusiastic attention from Roberto Giardini. A field aspect has been lacking from the program so far but is planned for the near future. Work on forage legumes will be with the pasture program in the neighboring Instituto de Zootecnia (Animal Husbandry Institute) at Nova Odessa where Jose Eduardo de Almeida is keen to initiate work.

UFRGS/IPAGRO, Porto Alegre

The Faculty of Agronomy of the UFRGS (Federal University of Rio Grande do Sul) and the soil microbiology section in IPAGRO (state institute for agronomic research) can be considered as a single unit for all practical purposes since many projects are executed jointly and some staff are common to both entities.

Dr. J. R. Jardim Freire heads the group. He is currently Director of the Faculty of Agronomy but despite a heavy administrative burden maintains a strong involvement in the soil microbiology groups of UFRGS and IPAGRO. Dr. Caio Vidor is executive director of UFRGS/IPAGRO with responsibility for *Rhizobium* ecology. Dr. Joao Kolling is full time with IPAGRO and handles field selection of *Rhizobium* strains, soil fertility and limiting factors. Maria Helena Pedroso is in charge of inoculant production and the supply of inoculant strains to commercial producers. Jessi Soares Pereira looks after serology. I. G. Kolling runs gas chromatography and Dercio Scholles has responsibility for tropical forages. P. Selbach works on soil limiting factors. Two MIRCEN funded positions are vacant for a microbiologist and an extensionist.

Main crops of interest are soybean, common bean (Phaseolus vulgaris) and alfalfa. Research at present tends to be site specific in that it relates to the somewhat unique subtropical climate of Rio Grande do Sul. For example tropical forages such as green leaf desmodium, perennial soybean and siratro are being evaluated for use as summer legumes in pastures. Selection of strains of Rhizobium and plant lines for high temperature tolerance plays an important role. Although soils of the region are very acid, liming to pH 5.5 is economic and thus selection of acid tolerant rhizobia has not been pursued. The group recognizes the need to broaden their research interest as part of their international responsibilities in the role of MIRCEN (see earlier section).

COLOMBIA

ICA/CIAT, Carimagua

Projects executed by the soil microbiology section of CIAT's Beef Program in the Llanos Orientales of Colombia as part of the stage IV of the strain selection program[7] are executed jointly with ICA, the national agricultural research organization. No personnel from ICA collaborate in the projects at present because Fernando Munevar is away from post studying with Art Wollum for his Ph.D. This section is included to emphasize that any proposed experiment for the Carimagua station, which could be considered of strategic value to the NifTAL Network, should be submitted to the joint ICA/CIAT "consejo." Although forage legumes receive the lime light at this station a proposed Rhizobium strain trail with peanuts might be favorably received due to interest in use of this cash crop prior to sowing improved pastures.

ICA, Palmira

Raul Varela conducts research on soybean rhizobia, most recently on tolerance to compounds used as seed treatments.

CUBA

ICA, La Habana

Mirtha Lopez and Eduardo Sistachs work on the rhizobiology of tropical forages in the Instituto de Ciencia Animal.

DOMINICAN REPUBLIC

UASD, Sto. Domingo

Rafael Martinez is a phytopathologist at the Universidad Autonoma de Santo Domingo. Although he expressed interest in initiating rhizobiology work in response to proposals made by FAO consultants he has not taken up an invitation to CIAT for training.

CNIECA, San Cristobal

The Centro Nacional de Investigaciones, Extension y Capacitacion Agropecuaria conducts research with soybean, common bean and tropical forage legumes. However, mainly for lack of rhizobiological back-stopping, legumes are sown uninoculated.

CEAGANA, Sto. Domingo

Alfrida Pimental is conducting *Rhizobium* strain selection and evaluation for *Leucaena leucocephala*.

ECUADOR

INIAP, Pichilingue

Although an inoculation trial (in pots) was performed with *Centrosema pubescens* by Carlos Palacios in 1974 there are at present no projects in Ecuador involving *Rhizobium* nor are there trained rhizobiologists in that country.

HONDURAS

United Fruit Company, La Lima

D. C. Sharma of the Division of Tropical Research has interest and experience in the inoculation of tropical forage legumes used as cover crops in banana plantations. The species used were *Centrosema pubescens* and *Desmodium intortum*.

MEXICO

Centro de Rhizobium de BANXICO, Tezoyuca Mor

Antonio Moreno and Josefina de Trujillo are fortunate in having excellent facilities for *Rhizobium* evaluation at laboratory, glasshouse and field level. Principal plants

of interest are tropical forage legumes.

Colegio Superior de Agricultura Tropical, Cardenas Tabasco

Maria Eugenia Velasco has been selecting strains and testing for inoculation responses on perennial soybean, *Centrosema* and *Stylosanthes*.

INIP, Palo Alto

Gaspar de los Reyes Gonzales is the rhizobiologist in the forages program of the Instituto Nacional de Investigaciones Pecuarias.

Instituto Politecnico Nacional, ENCB, Mexico

Dr. Maria Valdes is head of the Soil Microbiology Laboratory. Despite an increasing interest in VA mycorrhizas, rhizobiology is still the main research and teaching subject. There is no direct involvement in field research but it should be borne in mind that almost without exception the soil microbiologists presently engaged in agricultural research in Mexico were trained at ENCB and that Dr. Valdes maintains close contact with former students to an extent that it could be said that she performs informally a coordinating role.

PANAMA

University of Panama

Blanca de Hernandez is associate professor of microbiology in the School of Biology. Samuel Hammond, a member of her staff, recently received training at CIAT. The university itself has very little opportunity for field research but Hammond will be teaming up with the forage agronomists of IDIAP (Instituto de Investigaciones Agropecuarias) to perform field evaluation of *Rhizobium* strains for tropical forages.

PERU

IVITA, Pucallpa

The institute for veterinary research is conducting experiments on the use of legume-based tropical pastures to prevent the running down of soil fertility in jungle clearance zones. Dr. Jose Toledo, the director of the institute, recognizes the importance of a direct rhizobiological input in the program but plans to have one of his

technicians trained for this at CIAT have not come to fruition.

Universidad Nacional Mayor de San Marcos, Lima

Jose Gomez Carrion has conducted strain collection and evaluation for both tropical and temperate legumes. So far a field aspect has been lacking from the evaluation procedure. Theoretically the research performed at Lima is implemented at IVITA, Pucallpa, but it has not been a satisfactory arrangement from IVITA's point of view.

SURINAM

Centre for Agricultural Research, Leysweg

Dr. J. F. Wienk is in charge of collaborative projects between the University of Surinam and the Agricultural University, Wageningen, the Netherlands. Although the project is in its infancy, there is an interest in *Rhizobium* inoculation in cowpea, peanut, soybean, mungbean, leucaena, centrosema and kudzu.

VENEZUELA

CENIAP, Maracay

Dr. Luis Ayala and Thisbe Diamante de Fernandez are the rhizobiologists with this regional center of the Fondo Nacional de Investigaciones Agropecuarias (FONAIAP). Main legumes of interest are soybean, common bean, cowpeas and peanuts.

FUSAGRI, Maracaibo

The FUSAGRI group work in close collaboration with the University of the State of Zulia. Dr. Ivan Casas is the microbiologist in the Agricultural Research Institute. Facilities and potential for execution of field work are excellent but no recent information on projects in progress is available.

IVIC, Caracas

Dr. Paul M. Williams has recently initiated a research program on rhizobiology of soybean, common bean and cowpea.

Universidad de los Andes, Merida

Silvino Reyes and Roberto Skwierinski are interested in the evaluation of inoculation with *Rhizobium* to improve nitrogen fixation of both grain and forage legumes in the acid, infertile soils of the western plains of Venezuela.

Universidad del Oriente, Nucleo Monagas, Jusepin

Rafaela de Monasterios is the soil microbiologist in a group that works primarily with peanut and the tropical forage legumes. Cesar Alcala has conducted several pot trials on the interaction between *Rhizobium* inoculation and fertility level in forage legumes.

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THE INPUTS (INCREASING PRODUCTIVITY UNDER TIGHT SUPPLIES) PROJECT NETWORK

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INTRODUCTION

Because resources used for agricultural production at the present technological levels are becoming scarce, research strategies aimed at identifying and increasing the use of alternative, more plentiful resources are vital. Emphasis is presently placed on increased research efforts in intercropping, nitrogen farming, and recycling of organic residues. At the same time, research efforts are being planned to develop increased understanding of farmer decision-making processes. The INPUTS project serves as a vehicle for collaborative and cooperative research effort for some of these studies.

The INPUTS (Increasing Productivity Under Tight Supplies) project was conceived in mid-1974 at a time when the vulnerability of agriculture to the diminishing availability of fossil energy was manifested through widespread fertilizer shortages. The overall project objective is to seek technological and economically viable alternatives to the high input/high energy requirements of modern agriculture. Its strategies--indeed its pillars--are collective planning, cooperative implementation, and collective evaluation.

Phase One

At the initial project planning meeting held in October 1974, and attended by 41 scientists from 14 countries and 4 international organizations, the participants, on the basis of current research findings and availability of resources, designed specific plans to undertake field research in specific areas aimed at increasing the efficiency of fertilizer use. These were:

1. Evaluating the efficiency of slow-release fertilizers such as sulfur-coated urea (SCU) and isobutylidene diurea (IBDU);

2. Evaluating the efficiency of placement methods such as mudball technique and banding, for flooded paddy and upland, irrigated conditions;

3. Evaluating the efficiency of intercropping systems consisting of cereal crops grown in combination with legumes; and

4. Evaluating the efficiency of locally available organic materials in crop production.

To provide for timely project implementation, institutional support was provided by the International Fertilizer Devclopment Center, USA, (supply of SCU); Mitsubishi Chemical Industries, Japan, (supply of IBDU); Kyushu University, Japan, (soil chemical analysis); Virginia Polytechnic Institute and State University, USA, (statistical analysis); and all participating institutions in various countries (research implementation using own resources).

During the next 18 months, 43 field studies were completed by 23 organizations in 13 countries. Results of these were presented at the First Review Meeting held in June 1976 and attended by 53 scientists from 17 countries and four international organizations. The following were the highlights of the findings of the first year's efforts:

1. Intercropping cereals with legumes, versus growing them alone, generally increased the yield of the total system, provided better returns to the farmer, and also provide components for a more balanced diet.

2. Under certain agroclimatic conditions for paddy, SCU and IBDU were found to be agronomically superior to regular urea, although economic feasibility remains in question.

3. Mudball technique of fertilizer application, although agronomically sound, entailed high labor costs, thus making its use uneconomic.

4. Under most upland, irrigated conditions, regular urea was found to be superior to SCU.

5. Use of poultry dung, cow dung and other locally available organic materials were found to be satisfactory alternatives to fertilizer use, where available.

Phase Two

Based on the findings presented at the First Review Meeting, some studies were strengthened for continued research during the second phase, and others were modified.

Since the mudball technique was found economically inefficient, it was replaced by the use of urea briquette in the experiment. The intercropping study was further strengthened and treatments for evaluating organic materials were also included within its design.

To provide for speedy implementation of the recommended research, institutional support was again indicated, this time by International Fertilizer Development Center, USA, (supply of SCU); Mitsubishi Chemical Industries, Japan, (supply of IBDU); Joint FAO/IAEA Division, Austria, (supply of labelled N); Benchmark Soils Project, University of Hawaii, (soil chemical analysis and classification); NifTAL Project, University of Hawaii, (supply of Rhizobium inoculants); and University of Hawaii, Department of Horticulture, (supply of Leucaena seed).

Since the success of any agronomic innovation can only be measured by farmer acceptance and adoption, and since international understanding of farmer decision-making process is inadequate, a significant evolution took place at the First Review Meeting. Socio-economic studies were included in the INPUTS project. A specific study on farmer decision-making in technology adoption was identified and its methodology subsequently developed.

Agronomic and socio-economic studies have now been conducted in various countries, and results of 48 such agronomic and seven socio-economic studies conducted by 24 organizations in 13 countries and territories have been reviewed.

International Participation

Perhaps the greatest strength of the INPUTS project has been its international character. During the past three years, participants from 40 organizations located in 21 countries have attended meetings.

Other INPUTS Project Meetings

In order to improve the efficiency of the various field studies being implemented under the project, a Research Methods and Program Management Workshop was held in Honolulu during March-April 1977. It was attended by junior colleagues of the participating scientists. The objectives of the workshop were to make participants aware of the detailed aspects of conducting field agronomic and socio-economic research, and to expose them to fundamentals of human resource management. It was attended by 20 junior and middle level scientists from 12 countries. In May 1977, a Research

Methodology Assessment Meeting was held in Chiang Mai, Thailand to enable participating scientists to observe INPUTS studies in the field and to discuss and refine the methodologies being used for various studies. This meeting was attended by 24 participating scientists from 14 countries. Altogether, over 180 participants have attended the 5 meetings.

MAJOR ACCOMPLISHMENTS OF THE INPUTS PROJECT

Perhaps the three most important milestones of the INPUTS project over the past 3½ years have been:

1. Conceptualization of methodologies for conducting field agronomic and socio-economic research on an international cross-cultural basis with standardized formats. In the agronomic trials, treatment rates were developed as percentages of the locally recommended rate rather than as quantities used uniformly everywhere. In the socio-economic study, a standardized, workable methodology was evolved and used in all six countries where the study was conducted during the past year.

   In both kinds of studies some inherent drawbacks exist. In the agronomic studies, the accuracy of what constitutes the recommended rate of application is of paramount importance; in the socio-economic area, some efficiency of the study could be lost in the effort to standardize it. In both cases, however, since these concepts enable uniform statistical analysis, the advantages significantly outweigh the disadvantages.

2. Establishment of effective communication channels between scientists in various countries. In spite of the so-called "communication explosion," the inadequacy of effective two-way communication among people in different countries working on the same problem remains a serious constraint to accelerated agricultural development. Perhaps the INPUTS project has contributed to the removal of some of the barriers in the path of this two-way communication.

3. Development, through informal and indirect exposure, of cross-cultural awareness and understanding. These are abstract, non-quantifiable and non-definable personal experiences. To the extent that the project has raised the "human being" within each participant above the "scientist" in him, it has led to the cultural enrichment of all of us.

CURRENT RESEARCH ON BIOLOGICAL NITROGEN FIXATION IN THE USA

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Research and development of biological nitrogen fixation (BNF) technology in the USA is supported financially by several organizations: federal agencies, state agencies, research foundations and private industry. The funding by federal agencies for fiscal year 1977 is listed in Table 1. In Table 2, an estimate of the amount of support for basic and applied research is given for fiscal year 1977.

In the USA and Puerto Rico, more than half the state research institutions have a significant effort in BNF research. The amount of financial support from states, foundations and private industry is not known, but the total is not likely to exceed 50% of the total federal support.

Farmers in developing countries are presently investing about 5 billion dollars each year to buy commercial nitrogen fertilizer. By 1985, at least 7 billion dollars will be invested if present trends continue. To supply adequate food for the people of the world, estimates by UNIDO are that the use of commercial nitrogen fertilizer will increase from the current 50 million metric tons (MT) annually, to about 135 million MT by the year 2000. The developing countries will need about 50 million MT by the year 2000 at an estimated cost of 25 billion dollars per year. Consider the nitrogen needed to increase quantity and quality of food produced in farming systems in developing countries. Include the large financial and energy investments being made in commercial nitrogen fertilizer.

A reasonable conclusion is that an increased investment in research for the development and utilization of BNF technology to supply some of the nitrogen is needed.

Perhaps 80 to 90% of all BNF research activities relate to the legume-*Rhizobium* system. The root-nodulating woody species/*Frankia* system, the *Azolla* system, the associative bacteria/grass system, blue-green algae and the free-living bacteria are all being studied, but usually at only a few research institutions. At this time, only the legume-*Rhizobium* and the *Azolla* systems are used by farmers in several countries to increase agricultural production and income. Blue-green algae are used with rice to a limited

extent. The nodulated non-legume woody species have rarely been used in management for crop or forest production.

In the USA, probably 70 to 80% of all studies on legume-*Rhizobium* relationships are on soybeans (*Glycine max*). Other crops have received some attention, notably the clovers and alfalfa. Only very recently have other grain legumes and forages, especially tropical species, been studied. We owe a debt to those intrepid pioneers who have studied the less-known legumes.

The selection of useful rhizobial strains is being done mainly by commercial inoculant producers in the USA. Isolates by scientists in USDA and state experimental stations have contributed much to the germplasm pool. Only recently have microbial geneticists turned their attention to the rhizobia. At present, no superior strain useful in agriculture has been produced by genetic manipulation; it is hoped that a useful strain will result from one of the few well-funded projects in microbial genetics.

Selective breeding of legume host genotypes with increased ability to nodulate effectively is a relatively recent development. More than a half-century ago, some legume plants were noted that resisted nodule formation and did not fix nitrogen (for example, redbud (*Cercis canadensis*). In the early 1940's, non-nodulating lines of soybeans and clover were identified. As scientists have recently tested various cultivars of legumes, they found significant variation in their capacity to fix nitrogen even when the best available rhizobia were present. Especially significant to the farmer is the finding that some commonly used legume cultivars are very low in BNF potential. A recent example is given by Zary, et al. (1978).

Studies on the infection process have supported the lectin theory of recognition, but the exact mechanism of infection, nodule initiation and formation is still to be elucidated.

Studies on nutrition and physiology of the rhizobia have been made, but further studies should clarify how these characteristics of strains relate to problems concerning growth and survival in soils, in the nodules, and in commercial inoculant preparations.

The role of combined nitrogen in BNF is still controversial. Although combined nitrogen inhibits the enzyme nitrogenase, its role in the nodulated legume is more complex. How much nitrogen is needed to get the legume plant developing rapidly with a good root system and

vigorous nodules? Well-nodulated soybeans in the midwestern US have rarely given economic yield increases with added combined nitrogen, while common beans are often fertilized heavily with nitrogen to product economic yields. Thirty to fifty pounds of fertilizer nitrogen is often recommended for soybeans in tropical areas. What is the best economic relationship? What can be done for the small-holder farmer who may not be able to purchase fertilizer nitrogen?

Most of the research activities in BNF in the USA are oriented toward basic research, even though some may be "mission-oriented." Basic research is absolutely necessary to provide a foundation of knowledge and may provide some future "breakthroughs." Research applied to current field problems is essential if BNF technology is to be utilized properly. Most of us would consider most of the NSF-funded research under ASRA (formerly RANN) as basic, and the projects under USDA-SEA Competitive Grants are often basic. Titles don't reveal much, but "The Proton-motive Force in Nitrogen Fixing Bacteria" and "Structure and Mechanism of Nitrogenase" are examples that represent the trend. Probably $5 is spent on basic research for every $1 spent on research directly applicable to field problems. The studies done under the S-112 regional project are excellent examples of the latter type of research and have illustrated that commercially produced inoculants available in the US have varied from high quality to extremely low quality. Inoculant technology is a neglected field of research except by some commercial producers. More studies are needed to determine the conditions and the crops where it is economical to inoculate. Can we find plants and rhizobia that optimize BNF? A further challenge is to incorporate BNF technology into economic farming systems.

Table 1: Amount of Federal Funding for Research on Biological Nitrogen Fixation, FY 1977*

AGENCY			FUNDING FOR BNF RESEARCH
Environmental Protection Agency ..... Office of Research & Development			$ 28,000
National Aeronatics & Space Administration ..... Space Biology Program			None
National Science Foundation			2,867,200
Directorate for Applied Science & Research Applications		$ 1,420,000	
Directorate for Biological, Behavioral, & Social Sciences		1,427,800	
Biochemistry & Biophysics Programs	$ 207,000		
Developmental Biology Program	142,300		
Metabolic Biology Program .	237,500		
Genetic Biology Program ...	80,000		
Cell Biology Program	None		
Ecology Program	181,000		
Ecosystem Studies Program .	500,000		
Systematic Biology Program	80,000		
Population Biology & Physiological Ecology Program	None		
Directorate for Scientific, Technological, & International Affiars		19,400	
Division of International Programs	19,400		
Division of Policy Research & Analysis	None		
US Department of Agriculture			3,920,000
Agricultural Research Service		450,000	
Cooperative State Research Service ...		3,270,000 [1]	
Forest Service		200,000	
US Department of Energy			517,000
Division of Biomedical & Environmental Research		517,000	
Fuels from Biomass Systems Branch		None	

Table 1 (continued)

AGENCY	FUNDING FOR BNF RESEARCH	
US Department of Health, Education & Welfare		$ 100,000
FDA Bureau of Foods	None	
NIGMS Cellular and Molecular Basis of Disease Program	$ 100,000[2]	
US Department of State		263,000
AID Development Support Burea	263,000[3]	
TOTAL FEDERAL SUPPORT		$ 7,695,000

[1] Data are only for federal support of CSRS federal-state research system, and do not include funds from state and other non-federal sources.

[2] These funds are for two grants for research on enzymes and were only peripherally involved with the study of nitrogen fixing bacteria.

[3] These data, which are included in the total for federal support of research in the area of biological nitrogen fixation, are for the Development Support Bureau and do not include any research funded in other AID programs. Although support is approximately $1,300,000.

* From National Science Foundation, Interagency Committee on Plant Sciences, 1979. Federal support for research in the plant sciences. Washington, D.C. 90 p.

Table 2: Amount of Federal Funding for Research on Biological Nitrogen Fixation, FY 1977, by Type of Research[1]*

Agency	Cost of Basic Research	Cost of Problem-Oriented or Applied Research
Environmental Protection Agency		
Office of Research & Development	None	$ 28,000
National Aeronautics & Space Administration		
Space Biology Program	None	None
National Science Foundation		
Directorate for Applied Science & Research Applications (formerly RANN)	None	1,420,000[2]
Directorate for Biological, Behavioral, & Social Sciences	$1,427,800	None
Directorate for Scientific Technological & International Affairs	9,700[3]	9,700[3]

* From National Science Foundation, Interagency Committee on Plant Sciences, 1979. Federal support for research in the plant sciences. Washington, D.C. 90 p.

[1] Agency program officers identified the type of BNF research that was funded. It should be kept in mind that basic research in a mission agency usually is closely related to specific needs in the agency's areas of responsibility and might not be considered as basic research in a traditional scientific sense.

[2] Funding was for multidisciplinary projects, and only a portion of the funds was for plant science research. See text on program.

[3] Estimate. Breakdown not available by type of research, but about half of all plant studies funded by the Division of International Programs, which supported all of the BNF work in this directorate, was basic research; the rest was problem-oriented. Total support for BNF research was $19,400 in FY 1977.

Table 2 (continued)

Agency	Cost of Basic Research	Cost of Problem-Oriented or Applied Research
US Department of Agriculture		
Agricultural Research Service	$ 180,000[4]	$ 270,000[4]
Cooperative State Research Service	Little or none	3,270,000[5]
Forest Service	None	200,000
US Department of Energy		
Division of Biomedical & Environmental Research	517,000	None
Fuels from Biomass Systems Branch	None	None
US Department of Health, Education, & Welfare		
FDA Bureau of Foods	None	None
NIGMS Cellular & Molecular Basis of Disease Program	100,000[6]	None
US Department of State		
AID Development Support Bureau	None	263,000[7]
	$2,234,500	$5,460,700

[4] Estimate. Breakdown not available by type of research. However, in overall ARS research program in plant sciences, about 60 percent of FY 1977 expenditures was for problem-oriented and applied studies, and 40 percent was for supported basic research. Total support for BNF research in FY 1977 was $450,000.

[5] Estimate. Breakdown not available by type of research, but CSRS research is largely problem-oriented and applied.

[6] Funds were for two grants for research on enzymes; studies were only peripherally concerned with the bacteria in biological nitrogen fixation.

[7] These data are only for funding by the AID Development Support Bureau and do not include any research funded in other AID programs.

PROGRAM IN BIOLOGICAL NITROGEN FIXATION SUPPORTED BY THE BUREAU FOR DEVELOPMENT SUPPORT AGENCY FOR INTERNATIONAL DEVELOPMENT

The Agency for International Development (AID) is an action-oriented US Agency dedicated to helping to alleviate food and agricultural problems, particularly in developing countries, using US technology where appropriate. There is an urgent need to make systems available that provide nitrogen for crop production without using scarce and costly fertilizer nitrogen.

The program in biological nitrogen fixation (BNF) is based on the premise that AID funds should be used to develop knowledge and technology of immediate help to the small family farmer. AID (DS/AGR) initiated a program in 1975 to develop and adapt BNF technology to tropical farming systems, to test this technology in the developing countries and to assist these countries to exploit BNF in their farming systems. Assistance involves supplying nodule bacteria and legumes of high quality, finding solutions to limiting factors, helping to train personnel, conducting cooperative research on BNF with scientists in developing countries, providing technical assistance in developing indigenous production of legume inoculants of high quality, and developing appropriate cropping systems using BNF.

Approximately 80 percent of the overall effort is aimed at developing the legume-rhizobia system and utilizing the technology related to nitrogen fixation by legumes or other root nodulated plants. About 20 percent of the overall effort is directed to evaluation and domestication of other systems.

The current program has projects to develop BNF technology with 20 US institutions and cooperative studies between US institutions and 9 developing countries (Morocco, Senegal, El Salvador, Guyana, Egypt, Chile, Thailand, Nigeria and Brazil), also linkages with 4 IARCs, and has provided technical assistance on production plants in Thailand, Guyana, Sri Lanka and Spain. To meet the urgent need to exploit BNF technology as widely as possible, the requirements for projects are expected to increase.

Projects have been developed as indicated below. Further information can be obtained from project leaders or the author.

1. NifTAL (Nitrogen Fixation in Tropical Agricultural Legumes) with the University of Hawaii: To work on developing effective strains of rhizobia, more adequate inoculation methods and more effective nitrogen fixation in the

useful tropical legumes. Training course on Rhizobium technology scheduled for six-week periods about once each year. NifTAL, P.O. Box "O", Paia, Hawaii, 96779, USA. Leaders: Drs. Jake Halliday*, A. S. Whitney, and B. Bohlool.

2. World Rhizobium Study and Collection Center at USDA, Beltsville Agricultural Research Center: To provide a comprehensive germplasm bank for rhizobia for all legumes--tropical and temperate--and other nitrogen fixing microorganisms of agricultural significance. Leaders: Drs. Deane F. Weber and Harold Keyser, BARC/AR/SEA/USDA, Beltsville, Maryland, 20705, USA.

3. International Soybean Program (INTSOY) of University of Illinois and University of Puerto Rico: To study inoculant delivery problems as well as genetic interactions with tropically adapted soybeans. Leaders: Drs. Stewart Smith and W. Thompson, INTSOY, University of Illinois, Urbana, Illinois, 61801, USA.

4. Biological Nitrogen Fixation--Consortium for Soils of the Tropics (CST) will use their State-of-the-Art (SOTA) studies to improve institutional capability to conduct research related to biological nitrogen fixation (BNF) in the tropics, to train scientists in BNF technology, and to advise developing country administrators/scientists regarding BNF utilization. Studies indicated below are being conducted cooperatively under the leadership of the institution indicated.

   a. CORNELL UNIVERSITY, Dr. M. Alexander, Dept. of Agronomy, Ithaca, N.Y., 14853, USA. Also, Drs. S. Mughogho, H. Lowendorf, T. Scott, D. Bouldin.

      1) Survival and Persistence of Rhizobium in Soils.

      2) Field Management and Exploitation of BNF.

   b. UNIVERSITY OF HAWAII, Dr. B. Bohlool, Dept. of Microbiology, Honolulu, HI, 96822, USA. Also, Dr. J. Walker, T. Lumpkin, and R. Yost.

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* Dr. Jake Halliday joined the NifTAL staff as Project Director in March, 1979, during production of this Proceedings.

1) Inoculant Response in Tropical Soils.

2) Agronomic Value of Azolla in Wetland Farming in Tropics.

c. NORTH CAROLINA STATE UNIVERSITY, Dr. H. D. Gross, Dept. of Crop Science, Raleigh, N.C., 27607, USA. Also, Drs. G. Elkan, A. G. Wollum.

1) Field Methodologies for Studying Effects of BNF Under Tropical Conditions.

2) Methodologies for Studying Compatibility of Host Genotype and *Rhizobium* Strain Related to Inoculation of Tropical Legumes.

d. UNIVERSITY OF PUERTO RICO, (to be named), Dept. of Agronomy, Mayaguez, P.R., 00708.

1) Inoculant Production Technology in the Tropics.

2) Inoculant Quality.

5. International Program in Training and Research on Nitrogen Fixation in the Tropics. National Academy of Science with Brazilian National Academy at Rural University and EMBRAPA, Km 47, Campo Grande, Rio de Janeiro. To further studies on biological nitrogen fixation in grasses and legumes. Periodic visits by US scientists to collaborate with Brazilian counterparts in research and training program. Grants to post-doctoral fellows to Brazil for travel and some equipment. US travel and support for Brazilian scientists to work at US institutions. Leader: Dr. M. G. C. Dow, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D.C., 20418, USA.

6. Associative Nitrogen Fixation in Grasses--University of Florida. Studies to find a dependable system and measure agricultural potential of BNF in grasses. Study inoculation and nitrogen contributions. Leaders: Drs. S. West, R. Smith, S. Schank, D. Hubbell and M. Tyler; Depts. of Agronomy, Soil Science and Microbiology, Gainesville, FL, 32611, USA.

7. Sorghum-Millet Collaborative Research Support Program (CRSP)--University of Nebraska. Determine nitrogen fixing potential in wheat varieties.

Leader: Dr. Klucas; Lab. of Agr. Biochemistry. Univ./Nebraska, Lincoln, NB, 68503, USA.

8. Commercial Seed Industry Promotion Project (pending approval). To stimulate and promote the development of private and/or parastatal commercial seed and inoculant industries in target developing countries. Leader: Mr. Walter W. Simms; Industry Council for Development, 821 United Nations Plaza. N.Y., N.Y., 10017, USA.

9. Bean-Cowpea CRSP--In Planning Stage. BNF component to be determined. Leaders: Drs. W. Adams and D. Wallace; Michigan State University.

10. Tropical Soil Management CRSP (in planning stage), BNF component to be determined. Dr. J. Nicolaides, N. Carolina State University.

11. Agro-Forestation Program (in development stage). Inoculation trials with tree legumes. Tree legumes in cropping systems. M. Benge, Program Officer, DS/AGR, AID, Washington, D.C., 20523.

12. Peanut CRSP (in planning stage). BNF component to be determined. Planning entity to be selected.

13. Nitrogen Fixation--Factors Limiting the Legume-Rhizobia Symbiosis. Through USDA/SEA/CR, several small research grants for a three-year study of problems relating to inoculants, inoculation and effectiveness, survival of rhizobia and competition, and host-rhizobia interrelationships. Director: Dr. A. S. Newman, USDA/SEA/CR, Washington, D.C., 20250, USA.

GRANTS AWARDED UNDER THE AID-SEA/CR SYMBIOTIC NITROGEN FIXATION PROGRAM

PROJECT TERM (1976-1979)	LEADERS
Evaluation of Rhizobial Inoculants and Methods of Inoculation to Improve LDC Legume Productivity	David O. Wilson Georgia AES Dept. of Agronomy Experiment, GA 30212
Factors Significant to the Success of *Rhizobium phaseoli* in the Soil and Rhizosphere of *Phaseolus*	E. L. Schmidt G. E. Ham U. of Minnesota Dept. of Soil Science St. Paul, MN 55101
Development of an Improved Type of Legume Inoculant for Use in Developing Countries	Harold L. Peterson Miss. State U. Dept. of Agronomy State College, MS 39762
Compatibility Effects of Strain and Host Genotype on Inoculum Effectiveness in Peanuts	J. C. Wynne G. H. Elkan N. C. State U. Dept. of Crop Sciences Raleigh, N.C. 27607
Factors Limiting Symbiotic Dinitrogen Fixation in *Phaseolus vulgaris*	D. F. Bezdicek D. W. Burke Washington State University Dept. of Agronomy Pullman, WA 99164

PROJECT TERM (1977-1980)	LEADERS
The Effects of Seed Treatment Fungicides on the *Rhizobium*-host Infection Process in LDC Legumes	Paul A. Backman Auburn U. Dept. of Plant Pathology Auburn, AL 36830

Nitrogen-fixation Efficiency of Cowpeas and Mung Beans and Rhizobia spp. in Saline Alkali Soils	V. Marcarian I. L. Pepper U. of Arizona Dept. of Agronomy Tucson, AZ 85721
Symbiotic Nitrogen Fixation in *Phaseolus vulgaris*, *P. mungo* (now *Vigna radiata*), *Vigna unguiculata*, and *Cicer arietinum*	Barbara D. Webster Carl L. Tucker Donald D. Munns U. of California Dept. of Agronomy Davis, CA 95616
Factors Limiting Symbiotic Nitrogen Fixation for Edible Food Legumes in Developing Countries	W. T. Scudder Florida AES Dept. of Horticulture Sanford, FL 32771
Environmental Limitations on the Performance of *Rhizobium* in Tropical Soils	B. Ben Bohlool U. of Hawaii Dept. of Microbiology Honolulu, HI
Factors Limiting the Viability of *Rhizobium phaseoli* in Inoculants	G. E. Ham E. L. Schmidt U. of Minnesota Dept. of Soil Science St. Paul, MN 55101
Alternative Carrier Materials for *Rhizobium phaseoli* Inoculants	D. L. Berryhill North Dakota State U. Dept. of Microbiology Fargo, ND 58102
Biotic and Abiotic Factors Which Influence Saprophytic Competence of Strains of *Rhizobium phaseoli*	Robert H. Miller Ohio State U. Dept. of Agronomy Columbus, OH 43210
Effects of *Rhizobium* Strains and Improved Inoculation Methods on Alfalfa and Lentil Yields in Chile	William Murphy Lynn Barber Central Oregon AES Redmond, OR 97756

Maximizing Symbiotic Nitrogen Fixation Utilizing Cowpea Genotypes and Specific *Rhizobium* Strains	J. C. Miller, Jr. R. W. Weaver Texas A & M Univ. Dept. of Hort. Sci. College Station, TX 77843

PROJECT TERM (1978-1981)	LEADERS
Edaphic Tolerances of Grain Legumes	Donald N. Munns U. of California Dept. of Land Res. Davis, CA 95616
Genetic Enhancement of Symbiotic Nitrogen Fixation in Chickpea Through Breeding of the Host Plant	C. O. Qualset C. L. Tucker D. A. Phillips U. of California Dept. of Agronomy Davis, CA 95616
Field Evaluation of Inoculation Methods to Enhance Nitrogen Fixation by Food Legumes in Nigeria	David O. Wilson Georgia AES Dept. of Agronomy Experiment, GA 30212
Soil Adaptability of Rhizobia for Food Legume Production in West Africa	E. L. Schmidt G. E. Ham J. A. E. Molina U. of Minnesota Dept. of Soil Science St. Paul, MI 55101
Effects of Salinity and Water Stress on Symbiotic Nitrogen Fixation	James R. Sims Ronald H. Lockerman A. S. Abdel-Ghaffar Montana State U. Dept. of Plant and Soil Science Bozeman, MT 59717

Survival of *Rhizobium phaseoli* in Ultisols and Oxisols of Brazil	R. H. Miller Caio Vidor Ohio State U. Dept. of Agronomy Columbus, OH 43210
Transfer Mechanism for Introduction of Improved Nitrogen Fixing Cowpea Genotypes into Developing Nations (Supplement to FY 1977 grant)	J. C. Miller, Jr. R. W. Weaver Texas A & M Univ. Dept. of Hort. Sci. College Station, TX 77843
Genetic Analysis of Host Factors Affecting Nitrogen Fixation in Common Beans	Fredrick A. Bliss U. of Wisconsin Dept. of Horticulture Madison, WI 53706
Establishment of a Bean Inoculation Program Applicable to Small Farms in Developing Countries	David H. Hubbell U. of Florida Dept. of Soil Science Gainesville, FL 32611
Increased Efficiency of Peanut Production through Enhanced Biological Nitrogen Fixation	J. C. Wynne G. H. Elkan N. C. U. Dept. of Crop Sciences Raleigh, NC 27607
Stability of Effectiveness in Cowpea Rhizobia	R. W. Weaver Texas A & M Univ. Dept. of Hort. Sci. College Station, TX 77843

REFERENCES

Wollum, A. G. Annual reports of Regional Project S-112, "Enhancing Biological Dinitrogen Fixation in Soybeans and other Legumes." Dept. of Soil Science, N. Carolina State Univ. Raleigh, N.C.

Zary, K. W., J. C. Miller, Jr., R. W. Weaver and L. W. Barnes. 1978. Intraspecific variability for nitrogen fixation in southernpea (*Vigna unguiculata* (L.) Walp). J. Amer. Soc. Hort. Sci., 108: 806-808.

A SUMMARY OF RECENT RESEARCH AND TRAINING ACTIVITIES AT THE NifTAL PROJECT

A. Sheldon Whitney
Principal Investigator
NifTAL Project

NifTAL is the agronym for a project which is jointly funded by the University of Hawaii and the US Agency for International Development. The acronym stands for Nitrogen Fixation in Tropical Agricultural Legumes. The goal of the NifTAL Project, which was conceived to complement and support legume-oriented programs throughout the tropics, is to promote greater exploitation of the nitrogen fixing potential of tropical legumes, thereby providing a basis for increased protein production with minimal dependence on nitrogen fertilizer. Its objectives are to provide a foundation of tested rhizobial germplasm, improved inoculation methodology, and training for a cadre of technicians who will implement development of the potential of the *Rhizobium*-legume symbiosis.

RESEARCH SUMMARY

Work discussed here has been carried out by many NifTAL researchers. For fuller descriptions and tabular data see the NifTAL *Annual Report*, 1978.

In 1978, nearly 250 strains of *Rhizobium* were added to the NifTAL *Rhizobium* Collection. Most of these were proven strains supplied by laboratories in 9 countries, but others were isolated from nodules collected by NifTAL staff in Hawaii and elsewhere in the tropics. Over 1000 strains and isolates are cataloged in the active and reserved collections at Maui headquarters, and over half of these have been authenticated on at least one host. An abbreviated catalog of strains which performed well at screening trials was published in December, 1977, and is periodically updated. An increasing number of requests for cultures have been generated by this catalog and other NifTAL information dissemination procedures, and cultures of *Rhizobium* strains were supplied to workers in 17 countries during 1978.

Almost 300 strains of rhizobia were screened for effectiveness on target legumes including peanut, pigeon pea, chickpea, soybean, lentil, cowpea, mung bean, *Leucaena*, and nine others. Two broad-spectrum cowpea-type strains (CB 756 and Nitragin 176A22, already in commercial use) perform consistently well in trials involving legumes commonly nodulated by cowpea-type rhizobia. These strains, however, fail in tests on other legumes--a result which verifies the need for legume-specific screening and field testing in addition to growth room and greenhouse testing.

Under a NifTAL subcontract to the University of California at Davis, trials evaluating the tolerance of cowpea-type strains to acid soils were conducted. The tolerance of strains to acidity and/or high soluble Al was evaluated using a liquid medium containing glutamate, mannitol, vitamins, and salts. About one-half of the approximately 60 strains tested could grow at low pH (4.5 to 4.6) or high Al (50 μM) but less than one-third of the strains could grow in the presence of both high Al and low pH.

Comparison of performance in these tests with plant tests indicated that failure to grow in the high Al-low pH medium is a good indicator of failure to establish effective nodulation in soil at pH 4.6. We therefore have the basis for a simple prescreening test. However, some rhizobia that succeed in growing at low pH and high Al nevertheless fail to form nodules (or establish an effective symbiosis) in acid soil (about 1 in 5 strains of those tested on cowpea). This error is to be expected from the known existence of acid-sensitive steps beyond the initial rhizosphere-colonization phase of the symbiosis.

A similar liquid media was used to determine tolerances to low phosphate. Only about 10% of the strains tested were sensitive to low (5 to 10 μM P) phosphate compared to growth at 100 to 1000 μM P.

With mung beans, a small portion of strains that were tolerant on one host variety proved sensitive on another variety, and vice versa. This implies that comparative testing of host tolerances should be done with more than one strain of *Rhizobium* and comparisons of rhizobia should use more than one host variety.

Results from two types of experiments have indicated that there is considerable within-strain variation with respect to acid tolerance. Results of these studies show that most of rhizobial cells are sensitive, while only a small minority (e.g. one cell per hundred or per thousand) are tolerant. This work provides a basis for isolating single tolerant clones from strains of mediocre tolerance. Work is in progress to select and test clones derived from several such strains. If these clones maintain this tolerance to aluminum stress through subsequent generations, this technique will make it possible to select strains for acid soils much more easily than heretofore.

Other soil acidity factors, such as low calcium and high manganese levels, were also evaluated. Tests of about 20 strains indicated that none of the strains were inhibited

by calcium deficiency (50 μM) or manganese toxicity (200 μM). Calcium was shown to have a negligible protective effect against aluminum in an experiment with 3 strains at four levels of each variable.

Tolerance of rhizobial growth to salinity was evaluated by growing rhizobia in liquid medium containing up to 2% NaCl. There were significant differences among strains of cowpea rhizobia, *Cicer* rhizobia, *R. japonicum*, and *R. meliloti*. A preliminary greenhouse trial with *Cicer arietinum* indicated symbiotic sensitivity to salt greater than that of either symbiotic partner when grown separately.

Thirty strains of *Rhizobium leguminosarum* were screened for effectiveness on lentils. Fluorescent antibodies were prepared against five effective strains. The three most effective strains were tested for competitive ability in sterile vermiculite using the fluorescent antibody technique to identify rhizobia in nodule samples. Results of this experiment proved two of the strains to be highly competitive. These two strains, NZP 5400 and Hawaii 5-0 (a strain isolated from Hawaiian soil), were further tested in a field competition experiment (Ustic Humitropept, pH 6.1) and were found to be equally competitive against each other and were able to overwhelm the ineffective indigenous population of lentil rhizobia.

Because *Rhizobium* inoculants in the tropics are frequently exposed to high temperatures during shipping, merchandizing, and/or final use, the tolerance of potential inoculant strains to high temperatures is an important consideration. Ten slow-growing (cowpea-type) strains which had been previously screened for effectiveness were tested in a peat-carrier for 14 weeks at two temperatures: 28°C (moderate tropical ambient) and 37°C (high tropical ambient), At 28°C all the strains maintained relatively high numbers (10^9 to 10^{10}) throughout the 14-week period. At 37°C most strains increased in number (>10^{10}) and then declined slowly to about 10^7 to 10^8. However, three of the 10 strains were very temperature sensitive and declined to nearly zero within 2 to 6 weeks. At least one of these strains (TAL 655) was isolated from a cool, high elevation site in Malaysia.

This experiment has shown the importance of such a temperature screening prior to release of strains intended for use in the tropics.

The hypothesis that re-isolates from nodules after passage through an appropriate host outperform old stock cultures was tested using large Leonard jars in the greenhouse. Passage of *R. japonicum* (soybean rhizobia) through

up to three series of plant nodules gave significant improvement in the performance of strain USDA136b (=TAL 379 and CB1809). There was no benefit for substituting a non-homologous host (cowpea) in this case. There was no benefit for one or two passages of cowpea rhizobia through cowpea, but there was a significant improvement in strains which were subjected to three cowpea passages or through one passage through common bean plus one passage through cowpea. Passage of R. phaseoli was beneficial only when the strain was passed through and re-isolated from both cowpea and bean nodules.

These results generally support the hypothesis. In no case did passage decrease effectiveness. However, some strains responded significantly to plant-nodule passage whereas others did not. It is not known whether the passage merely restores responsive strains to their original effectiveness, or whether it selects the most effective organisms from a variable population and thereby actually improves strain effectiveness over the original isolate. In either case, this technique provides a very useful tool to ensure that the best possible variant of a strain is carried forward, even with non-responsive strains (since effectiveness does not decline).

In strain trials with eleven soybean Rhizobium strains, conducted at the Iole site of the Benchmark Soils Project at Kohala on the island of Hawaii, total yield of plant tops at the early podding stage was used as the measure of strain performance. Two strains significantly exceeded the control: USDA 138 (TAL 377) and USDA 136 = CB1809 (TAL 379), but there were no significant differences between these strains and the others in the group (Table 5). A nitrogen-fertilized treatment (150 kg/ha split-application) was significantly better than the symbiotic treatments, indicating that the symbiotic plants were unable to fix sufficient nitrogen for maximum yield under the cool, damp conditions prevailing during the trial. A Rhizobium strain trial for lentil bacteria was initiated in conjunction with the fourth training course. Seven strains of R. leguminosarum were tested at the Paia site late in the cool season. The plants did not flower at this site and vegetative yield at 15 weeks was therefore used as the measure of strain performance. Three strains were significantly superior at both an early sampling period (4.5 weeks) and at 15 weeks: TAL 640 (UH:I-11), TAL 635 (UH-B88), and TAL 639 (UH:I-7). All of these strains were isolated on Oahu, Hawaii. Although early comparisons were restricted by a moderately high level of nitrogen in the soil at planting time, the plants inoculated with the best strains performed better than both plus- and minus-nitrogen controls at 15 weeks, with an

average weight of 2.25 kg/plant for the top three strains.

A cowpea field experiment was laid out to determine the recovery (in the nodules) of an applied Rhizobium inoculum into a soil containing a high background population of native rhizobia. Numbers of rhizobia in the soil capable of nodulating Macroptilium atropurpureum (siratro) were estimated using the plant infection technique. The native population of Rhizobium was rather high (10^3/g at the surface and 10^5/g below the surface) but this is probably typical of many tropical situations where legumes have been grown for many years.

Three strains of rhizobia were compared at approximately the same level of inoculum coated onto the seed using a standard method. One of the three strains was also applied using different inoculum concentrations (10^3 to 10^9 per seed) and placements (various combinations of seed coating, band placement, and mixing with the soil).

There were no differences in yield (top weight or grain) since the native rhizobia were highly effective. However, there were significant treatment differences with respect to the number of nodules found by the introduced strain. Using the standard seed coating method (10^3 to 10^5 cells/seed) only a few nodules were formed by all except CIAT 239, but none significantly exceeded the control. As the numbers were increased, recovery also increased to a maximum of about 34%. Few nodules were formed by the introduced strains until inoculum levels significantly exceeded the population of native rhizobia below the soil surface. In addition, there was strong evidence that placement of the inoculum near the seed was more beneficial than mixing with the soil.

The contribution of legumes to the nitrogen economy of cropping systems was evaluated in field and greenhouse experiments. Most of the evidence suggested that sequential cropping systems involving grain legumes and grass better exploited the potential of legumes to provide nitrogen to the system than did intercropping systems. Perennial forage-type legumes, however, could be successfully intercropped provided there were no alleleopathic interactions between grass and legume. Leaf materials from a number of different legumes incorporated into the soil on an equal-nitrogen basis were identical in their release of nitrogen to a following grass crop, regardless of nitrogen percentage or degree of mixing with the soil.

The effect of liming was studied in the field, and the effects of fertilization with nitrogen and phosphorus were studied in the greenhouse. The major responses to liming a

Tropohumult were:

1. At pH 5.0 to 5.3, the legumes responded primarily to reduced aluminum in the soil;

2. Above pH 5.3, there was a "starter nitrogen" effect due to lime-induced mineralization of the nitrogen from the soil.

Soybean plants grown in nutrient solution containing various levels of phosphorus and nitrogen responded strongly to phosphorus and (at the highest levels) to nitrogen. The poorer growth of the symbiotic (zero nitrogen) plants was associated with reduced root development which may have serious implications regarding the yield potential of symbiotic plants.

TRAINING PROGRAMS

The Project provided intensive training in *Rhizobium* technology to 13 technologists during 1977-78, 12 of whom were from developing countries. The courses followed the general format developed for NifTAL by J. M. Vincent. The third course was conducted July 11 to August 19, 1977 by the NifTAL staff assisted by consultant R. W. Weaver of Texas A & M University, and the fourth course was conducted February 6 to March 17 by the NifTAL staff. In all the courses, additional resource persons from University of Hawaii faculty and visiting scientists were invited to make presentations and to expand the types of expertise available to trainees.

A total of 25 trainees have now received intensive training in *Rhizobium* technology, and most of these will be in positions to become cooperators in the proposed Network to field test *Rhizobium* strains under different tropical environments. Trainees were from the following countries: Philippines (3), Indonesia, Malaysia, AVRDC (Taiwan), Thailand (2), Bangladesh, India (2), Sr Lanka (2), Turkey, Egypt, Kenya, Tanzania (2), Nigeria (2), Ghana, Trinidad, Panama, and Mexico.

The graduate research assistants supported by NifTAL have been actively engaged in thesis research related to project objectives, while learning new skills and concepts in the process. Research work is being carried or has been completed by the students:

1. Effect of phosphorus nutrition on symbiosis.

2. Ecology of *Rhizobium* associated with *Lens culinaris* and *Cicer arietinum*.

3. *Rhizobium* affinities of tropical peanuts and significance of ineffective nodulation in soybean.

4. Nitrogen fixation in the tuber-forming legumes.

5. The effect of shading on morphology, yield, and nitrogenase activity of grain legumes and tropical forage legumes and grasses.

6. Legume growth and nitrogen fixation as affected by plang competition for light and for soil nitrogen.

BIBLIOGRAPHIC SERVICES

A full-time bibliographer collects, organizes and disseminates information relevant to the work of the project. Computer and manual searches offer coverage of many thousands of scientific publications on a worldwide basis. From an initial data base of 715 computer-generated references, the collection now contains some 2500 cataloged references and approximately 1800 documents, mainly reprints or photocopies of journal articles. The files are growing at the rate of about 30 entries each month. Our interlibrary exchange resources include all the holdings of the University of Hawaii libraries, and for special needs those of the National Agricultural Library in Maryland. When those institutions are unable to fill particular requests, photocopies are ordered from the British Lending Library.

In August, 1978, a selective bibliography with annotations (1181 entries) was published by the NifTAL Project. Supplements to this work will be compiled to keep the listings updated.

The document collection is accessible through a detailed subject index with more than 250 headings, so that relatively refined searches can be performed with ease. Clients may request reference lists pertaining to the legume/*Rhizobium* symbiosis in tropical agriculture by plant host or micro-symbiont species, by geographic and regional reference, and by a long list of influencing factors such as soil conditions, climate, toxic agents, soil antagonists, and nutritional status.

Within the limits of copyright laws, NifTAL can provide photocopies or reprints of available documents to Network participants when such assistance contributes to the

objectives of the collaboration. A note listing citation numbers from the NifTAL lists will suffice as a document request. For unlisted information or subject searches, more details are required.

It is hoped that all relevant publications emmanating from any Network member will be made available to all other members. NifTAL can serve as a clearing house for such distribution. As the Network evolves, policies to best implement the bibliographic functions can be formulated. Simplicity and informality should prevail.

FIRST WORKING SESSION

Strengths and Constraints of Developing Country Research Programs in Symbiotic Nitrogen Fixation

Chairman: Fernando Riveros
Issue Paper: Lloyd R. Frederick
Rapporteur: Victor G. Reyes

STRENGTHS AND CONSTRAINTS OF RESEARCH PROGRAMS IN DEVELOPING COUNTRIES

Lloyd R. Frederick
Senior Soil Microbiology Specialist
Development Support Bureau
U.S. Agency for International Development

I'd like to express my gratitude and pleasure in being able to participate here this week. The fellowship is very congenial, and this workshop certainly provides a fine opportunity to meet with many people who are interested in biological nitrogen fixation (BNF). It is even more important because we share an interest in finding ways to help people in other countries who would like to improve their agriculture.

In a recent review of the AID grants to develop capability to use biological nitrogen fixation in tropical agriculture, the review committee made these comments: "In the judgement of the evaluation panel, the general area of biological nitrogen fixation in the tropics is important enough, and the prospects for progress are important enough, to warrant continued support--perhaps at a rate even higher than at present. If there is one certainty about biological nitrogen fixation in the tropics, it is that the existing stock of knowledge is grossly inadequate. There is need for verification of some of the existing data, better understanding of the basic mechanism of biological nitrogen fixation (including the possibilities of genetic variability of plants and microorganisms) and a lot of detailed work on the environmental parameters which affect fixation." Our strategy at AID has been to move from the institutional base in the US to cooperative research, training, and outreach with scientists in national institutes and agribusinesses in developing countries. And, of course, that's why we're here this week--to determine the most effective way to do this.

When I was given the topic of research program strengths and constraints in other countries, it reminded me of a thistle blooming in a desert--rather thorny and the scene pretty barren. On the other hand, there are some attractive blooms on this plant. How can we talk about the constraints of research programs? There are many constraints, but each situation is unique; so it is difficult to quantify these constraints, or to say anything both meaningful and broadly applicable. But we may well find some attractive rewards in this difficult task of cooperating with other countries while working in an area where we have some definite constraints and also some very

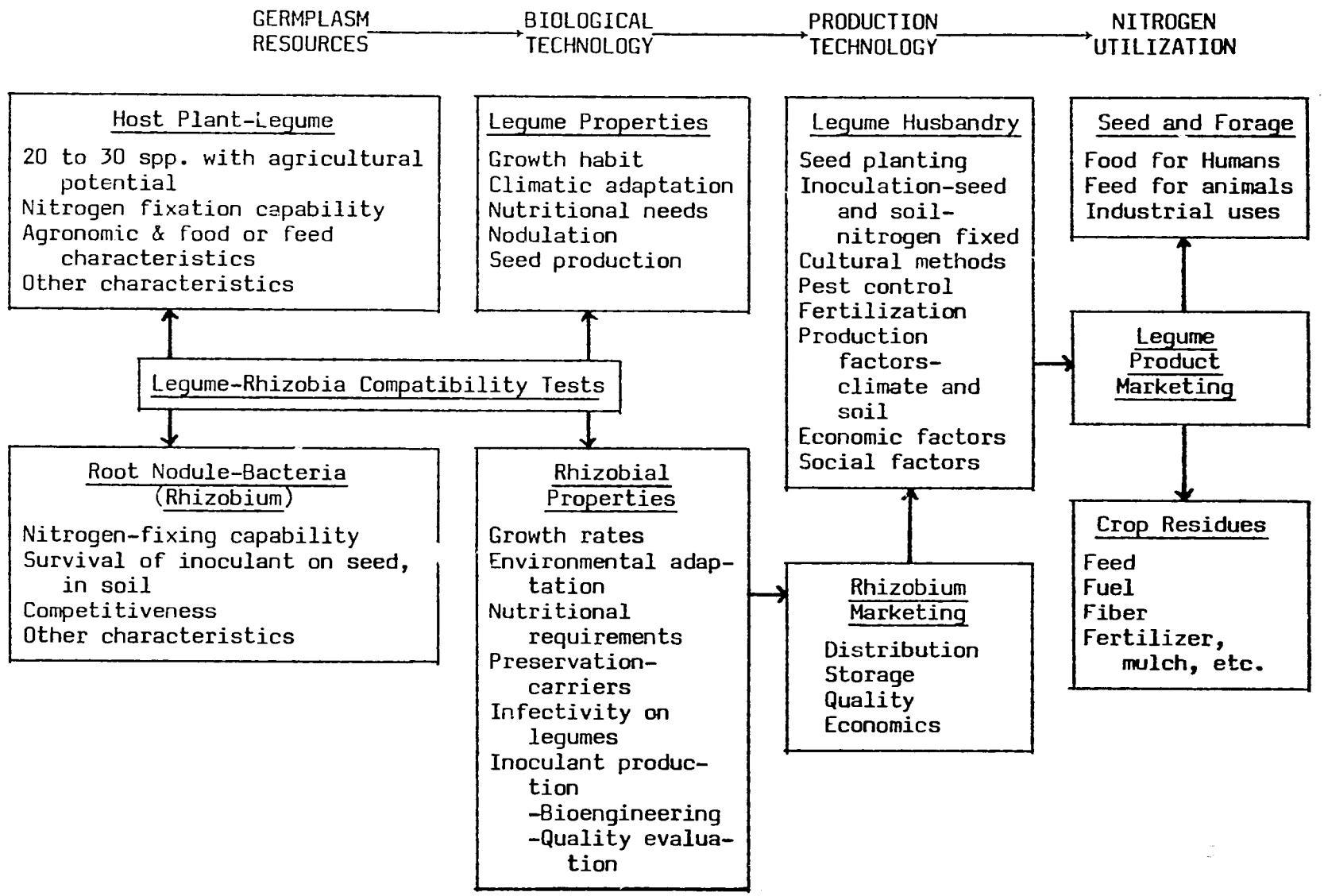
But rarely would the farmer get a good stand of clover in this way. So the farmer pays good money for clover seed to make sure that he has an adequate pasture and forage crop. We suspect that applying Rhizobium inoculant is often necessary in this same way. More studies are needed on Rhizobium populations, but we can't see the rhizobia as we can see the clover plants. We can dig the plants and see the nodules, but that takes more time and effort.

Many plants benefit from nitrogen fixation by soil bacteria, as we all know, but it is rather intriguing that at the present time, of the agricultural crops, only the legumes are known to be able to fix all of their nitrogen from the air (when conditions are favorable) by way of nodules formed by rhizobia. As we also know, some legumes cannot fix all their nitrogen at their present state of development. The degree of interdependence between the crop and the nitrogen-fixing soil bacteria varies. As we heard yesterday, in the legumes the relationship is very intimate. A few ounces of peat, carrying the right strain of Rhizobium and applied to each hectare along with the seed, can replace 200 to 1000 kilograms of nitrogen that otherwise would have to be supplied by commercial fertilizer. Both organisms are simultaneously involved in the process. This is why we call the relationship symbiotic.

I make these very simple and ordinary statements to emphasize the fact that knowing about rhizobia is not enough; we must also know about the plants. And knowing about the plants is not enough; we must also know about the rhizobia. Sometimes we microbiologists have overlooked this, and some plant scientists may have overlooked the bacteria. What I'm pleading for here is cooperation between specialists in all appropriate areas. In the developing countries, where we may not have specialists, but one person wearing all of these "hats," this person will be extremely busy if he tries to do all of these related tasks.

Figure 1 attempts to diagram within one page, the resources needed to develop and adapt biological nitrogen fixation into a useful technology. Unless we understand something about the resources used in a BNF technology, it is very difficult to determine the adequacy of the personnel or the program. In traditional agriculture, the resources and technology and their use may be so common that they are not understood. But if improved agriculture is to be achieved, at least some part of the technology needs to be understood and developed for increased use. An introduced legume may fail if proper rhizobia are not introduced through inoculation.

Figure 1. Some areas to be considered in the development and adaptation of biological nitrogen fixation into a useful technology.



Across the top of Figure 1 in capital letters is the general flow of activities. The first thing needed is germplasm resources--the plants and the bacteria. One reason our BNF programs have not stressed plant resources is that the International Agricultural Research Centers have a mandate to work on certain plant resources, and we didn't want to duplicate their work. The International Agricultural Research Centers also are working on rhizobia, but, as we noted, they are working with very specific crops. A great deal of work needs to be done, and there are many crops to work on.

The germplasm resources are, of course, just the beginning. They are of no use until they are put to work, and I called this area biological technology--the technology of putting the bacteria and the plants to work. But biological technology alone--knowing what is required to grow the plants, and what the rhizobia require--is not enough. It is necessary to develop a production technology with products that are useful and have a market value. Production technology involves the production of good seed, high quality rhizobial inoculant, and also production of crop products that can be eaten, used or sold. In summary, when the combined resources of plant and rhizobia are manipulated by the correct biological and production technologies, the end result is nitrogen utilization.

In the lower portion of Figure 1 there are 10 boxes illustrating some areas to be considered in the flow of technology development for nitrogen utilization. The first are under the general heading of germplas resources. How many species have current agricultural potential, with many others that may have future potential. Among the host plants, one of the things we need to know is the nitrogen fixation capability. A few legumes fix no nitrogen whatsoever. These are not very useful in nitrogen fixation. However, if their product has other value we don't want to dismiss that useful aspect. So, we need to know something of the agronomics and the food, feed, fuel, or fiber characteristics of the legumes, so that we can determine the ways they are useful to us. Other characteristics of the host plant can also affect the selection of germplasm resources.

Simultaneously and parallel to this we have the problems and considerations of the root nodule bacteria. Some people may not like to work with legumes because the system is too complex. When the system has two independent biological systems, the complexities are not doubles; they are at least quadrupled. For the rhizobia, the nitrogen

fixing capability should be quantified. The survival of the inoculant on the seed and in the soil must be ensured. Survival in the soil sometimes is a major limiting factor. Competition is a factor, and even though the proper rhizobia are there, they may not form nodules.

The legume properties--growth habit, climatic adaptation, nutritional needs, nodulation, seed production--fill the next box. One of the real problems that exists in many places is an adequate supply of good seed. We must be aware that each legume is unique. There are many different crops and just because we know all about soybeans, for example, does not mean that we know anything about wingbeans. In fact, the first time I saw a pink wingbean, I thought there was something wrong with it until I found out this is a normal varietal variation. We need to get acquainted with the kinds of variations which are genetic. Then, consider the environmental variations that will influence the amount of nitrogen fixation you can expect. When we go to the field and look at legume plants, someone says, "What is the problem here?" Be very careful. The first thing that most of us need to do is to ask the proper questions. In February, north of the equator, soybeans generally do not show good growth. Why? Perhaps it is photoperiod response to the short days. But some varieties are less sensitive. We must know our plants and our rhizobia well, as we plan to utilize this knowledge in biological nitrogen fixation. There is no substitute for going to the field to determine problems and develop a knowledge of legume characterisitics. Even if you're a Yankee looking at soybeans in Mexico, it's necessary to look in the field to see what is going on.

Next, the properties of the rhizobia are considered. Again, we have to know something about the growth rates. The most effective nitrogen fixing Rhizobium in the world could not be produced commercially if the growth rate were so slow that it became very difficult to make an inoculant out of it. We must be aware of the environmental adaptability, capacity for survival and infectivity of each strain. We must be able to ensure the preservation or survival of rhizobia in the inoculant. As with the seed, we can have highly successful strains in our germplasm banks, but if they can't be produced as a commercial inoculant, then that constraint cancels out the productivity of that strain. The bioengineering involved in inoculant production is important, but most important is the quality evaluation. Most countries, including the USA, do inadequate evaluation of legume inoculants. Australia has maintained the best standards extant.

The next area to consider is legume husbandry. Legume

production technology is an area with which microbiologists are not usually familiar. When microbiologists go out and do field plot experiments for the first time, they often decide "Boy, this is an awful lot of work for nothing," because something happens to their plots and they don't get results. With field trials, a 50 percent mortality of plots is not unusual, even if you're an expert. If you're just beginning, the mortality may be higher than that. If you're a legume breeder, working with standardized trials, and you've done this for years, you may get down to 10 to 20 percent mortality. But in doing actual field trials on farmers' fields (and much of the work should be done on farmers' fields) the mortality rate can be even higher. Nevertheless, it is absolutely necessary to do field trials if we want to produce any valuable information in the area of production technology. If you can't produce a good crop, you're not going to get much nitrogen fixation. Production, of course, is a function of many different things--climate, soil, nutrition, culture methods, pest control, fertilization--the whole business of crop husbandry. We must also consider economic and social factors which contribute to production. For example, one of the motivations for a farmer to produce more than he needs just to survive, is the fact that his neighbor is producing more. So we also need to keep these things in mind as we think about the strengths and constraints of production.

In many places in developing countries agricultural land is located on uneven, rocky land with "slopes" of 15-45°. I mention this because the temptation is to spend all our time on the experiment station and most experiment stations are located in areas that have slopes less than 5 percent, and many, many, many farmers are located on areas where the slopes are greater than 5 percent. In these highly uneven areas, we need some statisticians with some really imaginative approaches. Because the farmers are growing crops here. And these are the places where a BNF system might make a very real impact. In order to combine science with production, some solutions are needed to the problems of designing useful field trials in the terrain where the farms are. Can we be of real help here? Do not wait; put out some very simple trials and develop some possible production improvements that may be useful even if we cannot get adequate statistical design.

Sometimes scientists are surprised and dismayed to find that farmers don't wait for us to get our scientific studies done. In the US, the highest corn yields recorded have been in farmers' fields rather than in experimental plots. Perhaps the farmers put in an ingredient called TLC (Tender Loving Care) that many experimental plots never see. This

ingredient is very important, and it is very disappointing to find experimental plots that show a great lack of TLC. It's difficult to get results that are meaningful when there are about as many weeds as crop plants.

The desired result, of course, is nitrogen (and carbon) utilization--the product (crop) that is produced and marketed, and the management of the waste. Why are some farmers not very excited about biological nitrogen fixation? In some cases, they are not excited because they don't see any dollar signs in the product coming out of it. On the other hand, as Mrs. Yenchai and Mr. Nantakorn told me in Thailand, when they put inoculant on peanuts, and the farmer got twice as many peanuts with the inoculant as he did without, he was very excited, and he wanted to know where he could get more of that "black magic."

When the product (crop) is seed or forage, this can be used to provide human or animal protein and calories. The crop residues can be used for fuel, fiber, feed, or can be incorporated into the soil to provide both nitrogen and other benefits of organic matter to the following crops. Unfortunately, without proper management the nitrogen can be lost from the soil, through leaching, run off or volatilization, and these losses often occur.

There are a lot of pieces to this puzzle, and putting it together requires many people. At least it would be desirable to have many people. But in many of the developing countries, one or two people are trying to bridge this entire technology. And we must also be aware, as we try to work in these systems and assist these people, that the facilities are often very meager by the standards of technologically developed societies. Equipment really is often not the major limiting factor. Where there is a lack of nutrients, materials to make media, or equipment needed to grow the organisms, these must be obtained before much can be done. But if some simple equipment and materials can be supplied, then the main limiting factor becomes the imagination and creativity of the people involved. In many places, I've been astounded at how much work is being done by people under very limited conditions. So facilities are important in the sense that there must be certain minimal levels, but the biggest limitation, and also the biggest strength, is the creativity of the people doing the work.

We have the challenge to help those working in the farmers' fields and in the local laboratories to determine what can be done with BNF. The labs are not all modern and well-stocked. And the fields are not all moist with lots of rainfall and lush with nice green growth. Some of the labs

are poorly equipped and very primitive, and some of the fields are very rocky and dry. We have a variety of challenges that can be translated into opportunities. The task of discussing personnel, facilities, funding, and so forth in a comprehensive manner needs to be on a country-by-country basis, because each country will have its own problems and its own limitations. The purpose of this brief statement was to provoke thoughts on the subject and to give one concept of how a technology for biological nitrogen fixation might be made useful. We can work together to obtain the personnel and facilities that are so necessary. If we're successful, we might achieve a result with the same beauty as a thistle blooming in a desert.

STRENGTHS AND CONSTRAINTS OF DEVELOPING COUNTRY RESEARCH PROGRAMS

Issue Paper Summary

The development, adaptation, and utilization of BNF technology were outlined. Four phases include:

1. Establishment of a germplasm resource;

2. Development of the necessary biological technology involved in understanding how to grow the appropriate organisms;

3. Development of production technology in order to realize the value of products of BNF; and

4. Proper utilization of the end-products of BNF.

It is valuable to identify the strengths and constraints of developing country BNF research programs in order to assess how a proposed network for testing the performance of various strains of *Rhizobium* under farmers' field conditions could be implemented. It was hoped that the strengths and constraints of BNF research programs in developing countries could be identified specificially, based on the components of each phase as outlined.

Group Discussion Summary

I. Constraints to BNF Research

It was pointed out that there are numerous constraints, actual or perceived, related to BNF research in developing countries. The problems identified were:

A. The major constraints are lack of personnel and adequate facilities in developing countries. This, however, was recognized as non-limiting provided the workers have creativity and imagination and minimum essential equipment is available to them.

B. Problems in each country are site-specific and do need specific resolutions and strategies. Proper identification of the problem is essential to the proper resolution.

C. Each of the tropical countries has its own national priorities which should be recognized.

D. What systems and incentives can the Network

establishment provide to the prospective Cooperator?

II. Issues To Be Considered in Networking

A. Clarification of the objectives of the proposed Network is needed. The following tentative objectives were proposed:

1. Find out whether there is a response to inoculation.

2. See how NifTAL strains compare with other strains.

B. A potential strategy for setting up the Network was proposed:

1. Identify potential Collaborators worldwide.

2. Decide, in terms of available resources, the scale on which experimentation can be undertaken (e.g. 1 per continent, 3 per country, etc.).

3. Assess the state of the art in Collaborators' programs (e.g. What legumes and which nodulation problems are known? What is the staffing and participation rating?).

4. Refine strategy.

5. Describe a tentative project for each site.

6. Visit Cooperator at each site to assess willingness to collaborate, support by the institution, need for institutional approval, and support needed. Ideas of potential Cooperators should be integrated into project.

C. Roles must be allocated to institutions. It was suggested that <u>functions</u> be allocated rather than <u>positions</u> or <u>specialties</u>. Identify potential needs and inputs of institutions.

D. A suggestion was made that needs and inputs from scientists and farmers must be identified so that expected outputs and implementations could be outlined. Critical needs of average farmer to utilize BNF must also be identified.

E. An alternative to on-site visits was proposed.

Regional conferences could be held with each Cooperator attending.

F. A suggestion was made that the approach of the Network should be to use systems with little specialization, more easily adaptable to developing country conditions.

G. It was unclear what decisions have already been made by NifTAL, and what constraints NifTAL has in implementing the Network.

SECOND WORKING SESSION

Considerations Involved in Institutional Networking

Chairman: Martin Alexander
Issue Paper: Roger Ernst
Rapporteur: Donald N. Munns

CONSIDERATIONS INVOLVED IN INSTITUTIONAL NETWORKING

Roger Ernst
Consultant on Development
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Human Resources

Introduction and Charge

We can build on Harrison Brown's statement of the general dimensions of the world scene, Ned Kefford's distillation of scientific methodology, the quick surveys, incomplete as they were, of the work underway around the world, and Lloyd Frederick's dissection of the flow of events involved in mastering BNF. This workshop is being held to plan for an international network to concentrate on biological nitrogen fixation. Biological nitrogen fixation is a function; not a crop; not an "end good," but an elemental ingredient in agriculture. We need, therefore, to canvass a range of questions covering purpose, scope and extent, as well as modalities and costs in developing the plan for the Network. In addition we will need to recognize that a considerable number of other groups are involved in aspects of biological nitrogen fixation or are concerned with specific crops in which the nitrogen fixation process is significant. We shall need to consider how our work is to be linked to the work of these other international, national and private groups.

We have been entrusted with a disproportionately important subject. From the point of view of the developed nations, priority needs to be given to means of both reducing the energy used to produce our foods and fibers, and flattening the unit cost of agricultural products. These priorities are necessities because of limitations on available petroleum and gas supplies; because of prospective exponential growth of demand for those supplies; and perhaps even more critically, because of the formative role which surges in food prices play in worldwide inflation. The effects of these limiting factors are definitely contrary to our hopes for increases in discretionary income! Thus, BNF research and adaptation programs can materially help the advanced nations. And as they succeed in containing their demand for petroleum-based fertilizers in this and other areas, there will also be an easing of the supply situation for the developing countries. The 1977 study by the NAS indicates that 45 million tons of nitrogen are used annually. This amount is but one-third of the amount fixed biologically. Biological nitrogen fixation has not increased substantially in recent years--and this is a prime research goal.

If we are going to have to rely on chemically fixed nitrogen, over the next twenty-five years we need to increase world production two to four fold. One estimate is that 500 large fertilizer plants would have to be built, at a cost of $50 billion. Even if this amount is off by 100%--if only $25 billion is needed--1/10 of 1% would be $25,000,000. Then this is not an unreasonable amount to seek for our work over the next five years!

The appeal of BNF for the developing countries is even more compelling. The promise of NifTAL and associated projects is to fill a void in raising agricultural productivity at costs affordable compared with the costs of man-made nitrogenous fertilizers delivered to the farmers' fields. As we know, in many many areas of the world, the latter is simply not an alternative--there is no availability, no road, no credit, and no benefit to the small farmer under many tenure arrangements. Where fertilizer is not available, inoculant or inoculated seeds can be.

The fact that about five kilograms of inoculant will do the work of up to 500 kilograms of man-made fertilizer ought to convince the most adamant skeptic that we need to press forward at an optimal pace. Then too, we know that costs of inoculant have already declined to perhaps one-quarter the cost of seeds while fertilizer can cost up to five times the value of seed. (Parenthetically, I should add that there is an urgent need for a staff economist to work along with the NifTAL scientists in searching for appropriate, least-cost technologies for inoculant production and delivery.)

We are working on an asymmetrical proposition: BNF may in time be one of the most feasible means available to peasant farmers to increase the productivity of their land and, thus, their food supply; especially when BNF is used in conjunction with other low- or no-cost, improved inputs. We need to search for answers to the question of what contributions we can make to the production level of food grains in the developing countries. For example, India's food grain yields per acre (1969-71) were about 1000 pounds; Sri Lanka produced 2200 pounds; Taiwan produced 3300 and Japan 4500! Infant mortality rates (below the age of five) were 129, 47, 25, and 9 per thousand, respectively. Can we foresee India boosting its small farmer food crop yields to 2000 pounds per acre? Surely this action would provide family nutritional levels which would cut this dreadful 129/1000 infant mortality ratio. Perhaps this is the challenge to be faced by our Network: how to put BNF into the service of the poor and the dying infants--soon.

I want to turn now to the specific task set forth in

the invitation to this workshop. Let me quote: "Form a network of collaborators for the purposes of exchanging germplasm and research information and for cooperative identification and testing of Rhizobium strains." This formulation must be examined closely in our deliberations to ensure that the results of our workshop are fully consistent with that charge. We should also look to see if there are not additional measures which should be instituted among us, and in concert with international and national units concerned with improving small farmer productivity through farming systems research and extension efforts. One such issue is whether it might not be desirable to incorporate other symbiotic and non-symbiotic nitrogen fixation processes, such as Azolla-Anabena, into the scope of our work. A more encompassing approach could be more appealing to the developing countries, and more efficient in use of scarce scientific resources. It is my own view that we need to broaden our charge.

Characteristics of Networks

We can propel ourselves toward defining the most suitable network by taking a look at some main types of networks.

First, there is the type of net which is used to catch fish or butterflies. Two features distinguish it: it is used for catching or gathering-in separate organisms, and it is not constructed for two-way exchange. However, it exhibits two features pertinent to our work: most of the strands have to be linked to each other--big holes markedly decrease its effectiveness--and the net has to be cast out by a person or team working toward a common goal.

Second, there are the networks which are conspicuously present in our lives--McDonalds, Shell gasoline stations, and so forth. Again, we are dealing with one-way systems, designed in these cases to distribute standard commodities. We might want to borrow McDonald's concern for profitability, converting it for our purposes into a set of guidelines for evaluating whether our work is contributing to the production of increased quantities of food, especially by the poorer and smaller farmers in the developing world.

Third, there are communications networks. It would seem that the Network we are seeking will need to have this sort of capability to flow in several directions--of germplasm and research information among those directly involved in Rhizobium-legume interactions, and for planning and executing programs to identify and test Rhizobium strains under field conditions.

However, in light of my earlier observation about "profitability," that is, results in the farmers' fields, we will need to design our Network so it can interact with international, national and private sector entities directly serving farmers. This will mean an aggressive network management style, with a blending of work on specific Rhizobium strains of underutilized crops, with the planning of national agricultural development programs.

Purposes

The purposes of the proposed Network would appear to include the following:

1. Sharing of workloads, with functions allotted to take advantage of comparative strengths, needs, and levels of interest. This sharing--collaboration--should mean that all those who participate have the benefit of the results of all the work done throughout the system. All will have the extra benefits that can flow from such an orderly pooling and "netting"--in the accountant's sense of the word--of the work to be done within a worldwide integrated plan. As NifTAL connects with other parallel work in symbiotic and non-symbiotic nitrogen fixation, the work plans for the Network will need to be appropriately adjusted. A concommitant of collaboration in work is a sharing of leadership policy making. Thus, we may need to bring into being an international board to give direction to all the many disparate but interrelated efforts in BNF and provide guidance in management of the Network.

2. Accelerating localized testing so that strains that work in any given locale can be more rapidly passed along to extension units, inoculant producers and those charged with downstream farming support programs and technology delivery. This testing might include such approaches as "carpet-bombing," patterned delivery of inoculant for areas where there is no capacity to handle inoculated seed as well as no access to fertilizer. Testing will also be needed to assess risks and costs for future decision making on cropping patterns with new, selected rhizobia.

3. Optimizing resources applied to understanding and harnessing the biological nitrogen fixation process. The Network can bring into play existing personnel and facilities and tap additional

resources in ways that solor or bilateral efforts cannot. In many situations, strain testing can, for example, be inserted irto other, ongoing agricultural research and development programs at minimal additional cost.

Level and Pace of Activities of the Network

In dealing with this subject, we should consider the benefits to acrue from early achievement of widespread availability of effective inoculants in the tropics, in correlation with farming or cropping recommendations and practices.

A practical guideline for dealing with this issue may be to try to move as swiftly as human, technical and institutional factors permit--and not consider financial and resources constraints as the critical limiting elements. It would seem that the preliminary economic indicators cited earlier should command the needed resources for the Network, almost on a preemptive basis. In other words, one option is for the managers of the Network to push individual activities along as fast as they can go--item by item, site by site, test by test.

We will need to foresee the need for the involvement of several groups in the Network. Obviously, scientific investigators and technicians, but also specialists in field testing, in farming systems, in statistical extrapolation and in data management and dissemination--all will need to be "netted." Beyond these core groups who will carry out the basic program of scientific work, wherever they may be, there will be a need to involve several other groups: inoculant producers and distributors; extension units, both governmental and private; agricultural planners; national program administrators; and financial decision makers. Each of these groups will require special consideration, and the managers of the Network will, per force, have to create special links--globally, regionally and at the country level--with concerned individuals so that they are prepared, through participation and interchange of information, to play their roles in utilization, as swiftly as the state of the art permits. In short, we can envisage a push-pull situation in which the Network pushes out the results of its work, and users and beneficiaries pull in needed ingredients for incorporation in farming-development programs.

Additionally, the work of parallel units in symbiotic and non-symbiotic nitrogen fixation will demand a high level of attention to ensure strong crosswalks in both the research and applications phases. A first step could be a

special "telephone book" directory of "who is doing what in BNF."

Scope

Another issue is that of scope. There are at least seven elements to be considered and weighted in our final construct of the Network.

The first three are straightforward and borrowed from the current statement of project purpose:

1. To exchange *Rhizobium* germplasm and related documentation.

2. To assemble, index, and exchange research information and published work concerning *Rhizobium* and inoculant technology.

3. To encourage cooperative collection, identification, and testing of *Rhizobium* strains.

In developing specific work plans for these three elements, we shall need to be quite clear about such questions as *who* and *where*: with whom to exchange information, and at which places to assemble information, and so forth. We shall need to ensure that areas of the world, especially the developing countries, which may have limited capabilities to work with the Network, are not excluded on the basis of their limited capabilities. In fact, their inclusion may be a prime *desideratum*.

The remaining four elements of scope grow out of the first three, but will involve different requirements for collaboration with such institutions as the International Agricultural Research Centers, national agricultural development organizations and private-sector inoculant, seed and other producers and distributors.

4. To provide a cadre for direct training of personnel to be involved in BNF and to offer help in developing regional and national training *syllabi* and materials--in short, a central training center with associated, continuing education units scattered around the globe.

5. To assist in developing delivery methodology to permit widening *Rhizobium* applications in the tropics which should be linked to farming systems research, existing Benchmark Soils Project sites and other ongoing activities, as feasible. The

IARCs can play a heavy role in this area. We should try to delineate tasks for each during this workshop.

6. To render supportive services to industrial development elements so that local constraints to inoculant production, shelf-life, distribution, and use are given priority attention by concerned national units. It may be that special symposia, followed up by visits of teams of inoculant production and delivery specialists will be useful. This effort could also incorporate subunits of technical assistance covering questions of inoculant production cost controls, legal and proprietary issues, and socio-cultural questions, where pertinent.

7. To organize periodic evaluations to determine whether sufficient attention is consistently being given to BNF to achieve results in farmers' fields which are of significance in meeting world food and nutrition needs.

This list of seven may seem to some to be too expansive for NifTAL. If so, we should develop recommendations for each of the "rejected" elements so that they are given attention by some institution since achievement of elements 1 to 3 alone will not necessarily provide benefits to poor and small farmers, and we shall have failed to act on the opportunity before us.

Institutional Linkages

The linkages which the Network will need would seem to go in three directions:

1. International entities including the CGIAR and its family of Centers. The IARCs could play critical roles in field testing and in training. The FAO and UNDP, with their extensive systems of projects, can materially assist in the development of inoculant delivery methodologies. Finally, the international financial institutions should be afforded every opportunity to incorporate inoculant technology development and delivery capabilities in new and ongoing agricultural and rural development projects.

2. National entities can be the main "work horses" in the Network since most site-specific research is conducted by national units. Their own BNF

programs, enhanced as may be possible, could constitute the real core of the effort to speed up the process of realizing the benefits of manipulating BNF in the developing countries.

3. Private and public sector producers and distributors of inoculant and seeds need to be so intimately involved that the technology transfer process (from scientist and experiment station to inoculant producer-distributor and farmer) can take place in an unhindered and direct fashion. Special rational programs to make Rhizobium technology attractive to producers should be designed. Action should also be taken by appropriate bodies to help educate governments to legislate against current commercial practice in which Rhizobium cultures that are not viable upon receipt cannot be returned to the distribution. These "no return" policies adversely affect both distribution and usage.

Developing and maintaining these linkages will be a demanding task for a skilled team of scientists and development administrators, backed up by professional help in information management and dissemination.

Constraints to Networking

Several constraints seem apparent, but all are remediable, it would appear:

1. A network cannot "perform" unless most of its "points" are functioning. Constant watch will be needed to ensure against non-functioning which would vitiate the Network.

2. Making use of existing international entities and national programs, including their overheads and activities, is likely to be essential to achieving a critical mass of global effort in BNF. Participation by so many elements will, however, demand significant continuing research management as well as scientific talent in the Network management unit. NifTAL will have to fit into existing structures and programs in a symbiotic way, and this task in itself imposes a burden of awareness which will be a challenge to meet.

3. Political issues need not arise since participation, blending of national programs and sharing of benefits, would be wholly reserved as a national decision. It would be hoped, however, that the

results and benefits of the work of the Network would be available freely to all entities in the international agricultural community, irrespective of participation in the Network in any formal sense.

4. Patently, not all desirable goals can be served in the same measure at the same time; and although it is hoped that the constraints will be human, institutional, and technical and not financial, we must get our sights up. However, in prioritizing efforts for resource allocations, primary attention should be given to those rhizobia and legumes most suitable for the least developed countries, which in practice means South Asia and the Sahelian and sub-Sahelian areas of Africa. This also includes special attention to those legumes and rhizobia most suitable for small farmer subsistence agriculture, where improvement in subsistence and nutritional status will occur along the curve of farm productivity increases, largely irrespective of market prices of major commodities (i.e. increased farm production for the families' own consumption).

Heavy attention will need to be given to downstream dissemination of the results of the work; especially to outreach efforts to prepare national extension and other units to internalize the results as early as is prudent and possible.

Conclusion

The principal conclusion of this quick survey is that while a functioning network at the scientific and technical level is already emerging, an enhanced, orchestrated effort in testing of *Rhizobium* strains is needed, and an outreach effort still remains to be mounted, along with decisive steps to link NifTAL's work with other work in symbiotic and non-symbiotic nitrogen fixation. All are possible within a network which 'nets' into the CGIAR family, national institutions and the private sector, and which sets for itself goals which encompass the translation of scientific development into an improved food and nutrition posture for the poor and malnourished of the world.

CONSIDERATIONS INVOLVED IN INSTITUTIONAL NETWORKING

Issue Paper Summary

From the point of view of developed nations, we need to flatten the curve of use of resources and cost of production. In less developed countries the potential for lessening demand for petroleum products is compelling. But it is necessary to concentrate on BNF--not as an end, but in the extent, modalities and costs of the Network. Specifically, the objective of the Workshop is to form a Network of Collaborators to test strains and varieties, and the goal is to increase small farmer productivity. We need an aggressive management style to mobilize resources. A first step might be the formation of a working group on developing country clientele and their *Rhizobium* needs, including problems of inoculum delivery. Risks and costs associated with *Rhizobium* testing should be assessed, and output of this group built back into Network design.

Some objectives of the Network should be:

1. Sharing of the workload to take advantage of strengths and overcome weaknesses. (Includes sharing leadership and policy making.)

2. Optimizing resources available for problem-testing, and distributing available funds to maximize productivity.

3. Developing a quality inoculum which is consistent with the needs of the market (i.e. not necessarily the "best possible," but considering time:cost: effectiveness ratio).

4. Sharing data produced with inoculum producers, extension workers, agricultural planners, financial planners, other scientists.

5. Internalizing benefits so that the benefits accrue to the whole populations of the countries involved.

6. Providing the concept of a stable focus, an information source, and a management system.

7. Identifying weak points in training functions and improving training programs.

Group Discussion Summary

I. Motivation

Motivation of individual workers towards collaboration is important, but will be taken up later. The present question is how to get institutions motivated to encourage, support and permit collaboration. This question is not entirely separate from that of the motivation of individuals. For example, several institutions support an individual or a small group working on BNF, and an invitation to participate in international collaboration would greatly enhance the status and support for BNF researchers within the institutions.

Getting people (and institutions) involved in planning, early, is essential to gaining their collaboration. The project must be theirs. The involvement should precede organized regional planning workshops since the latter occur when many decisions have already been made.

Should institutions be involved? Need they be involved? Would it not be sufficient just to gain cooperation of individual researchers (as envisaged in early stages of thinking about the Network and NifTAL)?

Frequently the Director, Minister, or Dean in charge of an institution has his ideas and priorities. He needs reasons to alter these priorities in order to release or encourage a member of his institution to collaborate on an outside project. The process amounts to attempting to influence institutional or national research priorities. An analogy in the US is the influence of federal agencies on the direction of state-supported research. Administrators need not be assumed to lack vision. In this case we would not be introducing new ideas to them, but re-introducing an idea with a background of previous failure. Motivation may be uphill. If the target institution has priorities wildly divergent from the Network project, seeking collaboration is pointless.

In many cases, institutional support for the collaboration is no problem. This is true, at least for the short term, where the individual worker is willing and able to collaborate, and administration of his institution is too chaotic to interfere. More desirably, the institution is already working effectively in the field with BNF, motivation is not needed, and the best kind of participation is likely. Collaborators in such institutions should be sought first to get the Network off the ground.

To get experiments done promptly, the strategy is to choose those cases where it is not necessary to soften up an institution. But getting experiments done is not the only aim. There is also the need to get the results received and put into use. This needs support from governments and institutions. Motivating this support should go hand in hand with initiation of the experimental work.

Two requisites for motivation were noted:

1. At least one set of clear-cut data, acceptably interpreted, to demonstrate the likelihood of worthwhile outcome. (Old data, from the literature, might suffice?)

2. Funds, facilities, or materials otherwise unavailable. A good administrator is unlikely to be moved by the news that we have a good idea. He would have already put ideas he appreciates into action if he could have. He needs to be afforded the opportunity to do something he couldn't do without the collaboration.

There is a need for parallel motivational development of both scientists and institutions. When scientists produce results administrators must have been given the right information so that they will be prepared to accept and use the results.

II. Financing

The need for outside support funds will vary from place to place. In general, national funds in developing countries are unlikely to be abundant. International funding should be sought at some point.

The existing NifTAL funding allows for provision of limited financial support in the implementation of projects at priority sites. But it is hoped that some collaborators may not need fiscal support. NifTAL could supply some materials and services where needed. But at first, the collaborating institutions will obviously be those already working in this field.

Several institutions or collaborators in S. E. Asia could find local funding at this stage--they need only inoculants and other materials. In tropical Latin America many sites exist where the collaborators have a high participation rating and no additional funding would be needed. However, by contrast, most Indian areas would need considerable support (e.g. for labor), and there could be

institutional difficulties in the receipt and auditing of funds. Neighboring countries in this area would need much more help than India. Many countries are "rhizobiologically empty." Heavy funding would be necessary, and no quick returns could occur. For example, it is highly likely that $5,000-$15,000 per year per group would be required to institute worthwhile projects in some African countries.

In short, the network could proceed immediately in many places with only minimal monetary infusion. In others, it would need funding, almost certainly from US or international funds, with a likely two-year delay for funding and even further delay in establishing facilities and projects. The latter group pose the motivational problem--national agencies who think BNF important have already allocated funding.

"Who will finance what; where?" is a pertinent question. Perhaps there is little chance of competing for CGIAR funds.

III. Locating Cooperators

(Short discussion by Chairman) Among members of this meeting there must exist a contact base that could be developed into a large list of collaborators. These scientists and their institutions would be personally known, and this is a facilitating factor.

IV. Making an Impact on Extension and Production

We do not need to produce more results for burial in files.

Some ideas on information dissemination were:

1. FAO (Latin America) projects have successfully used experiments designed as effective demonstrations, placed at "shopwindow" sites.

2. Brief, clear, written messages with illustrative slides have been successfully used by Dr. Obaton, Dijon Cedex, France.

3. Involving extension agronomists in the experiments helps, along with well prepared extension bulletins, has been successful in Argentina.

4. Involvement of institutions through site visits also increases information flow.

5. Accurate, convincing statements we needed describing the practice, costs, and benefits of BNF. These should be backed by states-of-the-art analysis, analysis of marketing and financial requirements, and should be condensable to one page for impact on committees and busy administrators.

THIRD WORKING SESSION

Facilitating Communication, Coordination and Evaluation

Chairman: Noel P. Kefford
Issue Paper: Maurice Fried
Rapporteur: R. Stewart Smith

FACILITATING COMMUNICATION, COORDINATION AND EVALUATION: THE COORDINATION OF AGRICULTURAL RESEARCH WITH REFERENCE TO THE JOINT FAO/IAEA COORDINATED RESEARCH PROGRAMS

Maurice Fried and Carl Lamm
Director and Deputy Director
Joint FAO/IAEA Division of
Atomic Energy in Food and Agriculture

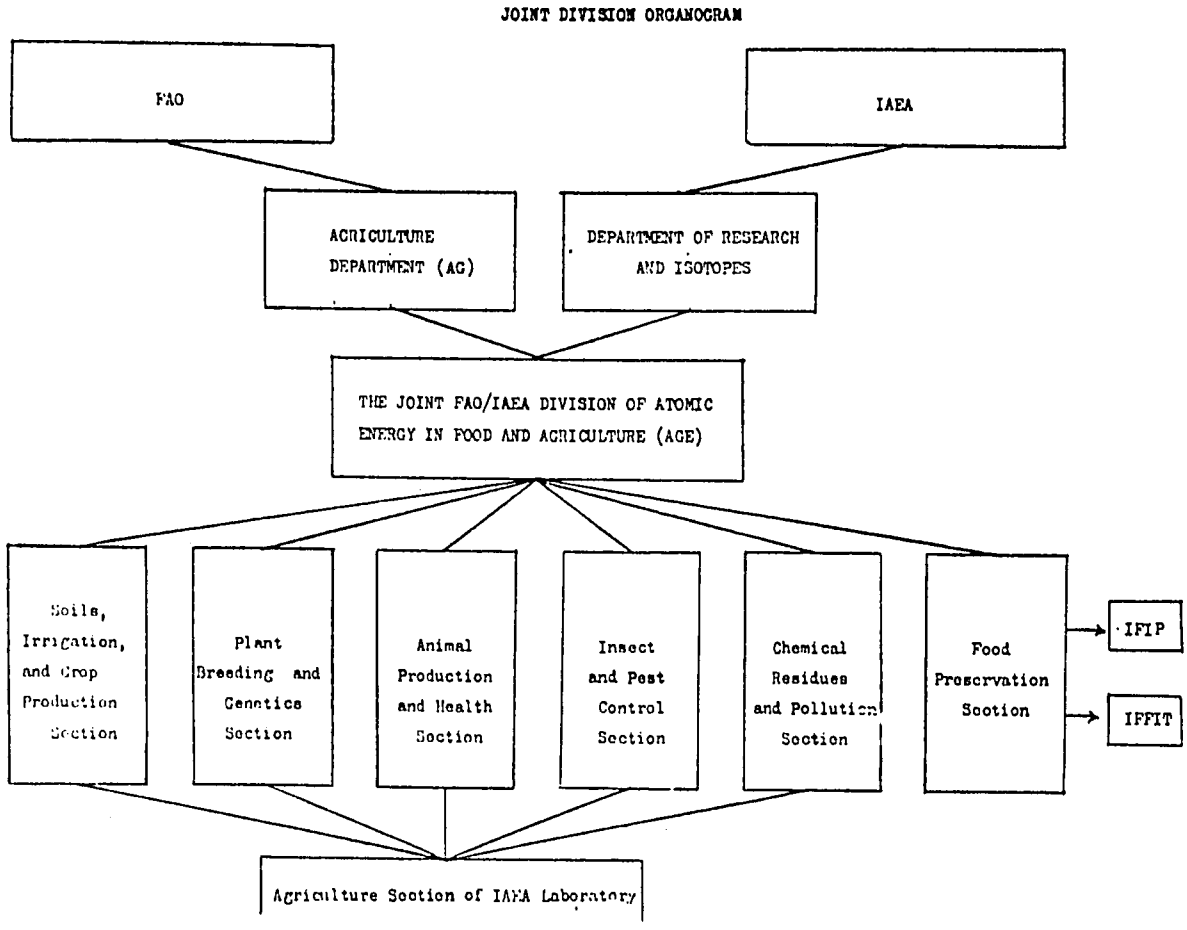
This presentation is confined to the coordination of agricultural research by a mechanism that also seeks to ensure communication, training and evaluation. This mechanism is based on experience with internationally coordinated research programs administered by the International Atomic Energy Agency during the last seventeen years and for which the Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture has the technical responsibility. It, therefore, appears appropriate to spend some words on what the Joint Division is and what it stands for.

Isotopes and radiation techniques have, for more than 30 years, proven their particular value as a strong tool to supplement ongoing conventional agricultural methods to solve particular problems. There are many examples that could be cited here, and we shall only mention a few. Isotope labelling of fertilizers offers a fast and direct method of measuring the efficiency of a fertilizer compound or field practice. Direct measurement of the amount of atmospheric nitrogen fixed by plants under field condition is an evident example. Neutron activation analyses are sometimes the only way of determining elements present in biological samples at extremely low concentrations. Neutron attenuation methods have enabled direct and continuous assessment of water in undisturbed soils during plant growth. The advantages of isotope labelling in most biological studies, whether plant or animal, are also evident, and the use of bio-immunoassay techniques in studies of the physiology of reproduction and pathology or in the tracing of nutrient elements in animal husbandry are well known. Creation of genetic variability in plants by radiation-induced mutation, biological insect control through the sterile-insect technique, and food preservation by irradiation are other examples of applied nuclear methods.

The Joint Division plays its role in assisting and advising developing countries in their decisions on if, when and how to embark on an isotope- or radiation-aided project in agriculture.

The Joint Division was established in 1964 based on an

arrangement between its two parent organizations, FAO and IAEA, and its organization is shown below.



The Joint Division, which is located in Vienna, is comprised of six subject item sections. The Agriculture Section of the IAEA Laboratory assists the Joint Division in offering its services to member countries as needed. The objective of this research-oriented division is to exploit the potential of nuclear techniques in research and development for increasing and stabilizing agricultural production, improving food quality, protecting agricultural products from spoilage and loss, and minimizing pollution of both food and the agricultural environment. In carrying out its task, the coordination of research in member countries is one of the important activities of the Joint Division.

Coordination of research means having different

parties performing research with a common goal. In order to succeed, the investigators must meet certain criteria (step 1):

1. The investigator must have a real interest in the problem and be given a proper incentive.

2. The investigator must be professionally capable of carrying out the research.

3. The investigator must have the necessary tools and facilities available for carrying out the research.

4. The investigator must be mentally disposed toward cooperation with others.

5. The investigator's organization must be willing to support his research.

We believe that the most important part of accomplishing the overall goals is the selection of the individuals who participate in the coordinated (group) activity.

The next step (step 2) in accomplishing a coordinated research program is to bring together all the selected investigators. The research coordination meeting is a crucial part of the coordination. As a minimum, it must accomplish the following:

1. Discuss the coordinated program in its broader framework.

2. Develop a spirit of teamwork.

3. Bring up the level of the group to that of the most competent investigators in the group.

4. Develop an action plan agreeable to all members of the group.

The action plan to be agreed upon can take one of two extreme forms, or it can be a combination of the two forms:

1. Everyone in the group does the same job.

2. Each individual investigator performs a piece of the overall research or plan according to his interest, background and capability.

3. Any combination of 1 and 2.

In case of combination between the two extremes, two approaches can be used.

1. One part of the group does the same job while another part performs supporting research.

2. Certain common research is mandatory to each participant while additional research is optional depending on the interest and relevance to the country situation of the investigator.

After research has been done (step 3) according to the action plan, a new coordination meeting should be convened (step 4). At this meeting, each investigator will present his results which will then be discussed and evaluated. Finally, a new action plan will be agreed upon either for supplementing the information already obtained or for continuing the research within the overall objective and timing of the coordinated program.

The role of the Coordinator in such a program can take many forms, and again one can distinguish between two extremes or any combination of these.

1. The Coordinator provides secretarial focal point and is involved only administrative matters such as:

   a. arranging coordination meetings;
   b. assuring communication with and between the investigators;
   c. providing funds; and
   d. buying supplies.

2. The Coordinator provides technical and administrative leadership of the program. In this case, the Coordinator must be technically, administratively and organizationally capable of providing this leadership.

3. Any combination of 1 and 2.

The advantages of the approach to research coordination as delineated above are:

1. Accomplishes research goals in the shortest possible time.

2. Performs a training function for the investigators in bringing up the level to the best.

3. Sets up working relations between scientists with common problems that last long after the program is terminated.

4. Disseminates information to the scientific communities simultaneously in a wide geographical and political context.

We would like to illustrate the above approach to international research coordination by some examples from the Joint Division.

Coordination and support of research by the Joint Division is furthered through a number of Coordinated Research Programs, each of which is designed to solve a very practical agricultural problem of relevance to the participating member states within its own terms of reference.

The objectives of each program are drawn up by specially convened panels of experts. Competent and interested investigators are then contacted and invited to take part in the program which normally lasts for not more than 5 years.

Investigators in developing countries are normally given research contracts with a nominal financial support (US $1,000 to $5,000 per year), whereas investigators in developed countries usually participate under cost-free research agreements. All participants in such coordinated programs (approximately 15) meet periodically (approximately every 12-18 months) to review results achieved and to discuss and plan future approaches.

Currently, the Joint Division has technical responsibility for over 25 such coordinated programs, which include investigators from some 300 scientific institutions around the world. These programs are mainly funded by the IAEA regular budget but also enjoy financial support by a number of donor countries. In some cases the provision of fellowship training is an inherent part of a program.

Among the many coordinated programs for which the Joint Division has been technically responsible, two are selected here for illustration.

1. FAO/IAEA coordinated research contract program on the uptake of nitrogen and phosphorus by lowland rice, 1962-68. (Ref. IAEA Technical Report Series, No. 108, Rice Fertilization, Vienna, 1970).

2. The FAO/IAEA/GSF coordinated research contract

program on use of nuclear techniques for seed protein improvement, 1970-1978. (Ref. Sigurbjornsson, B. Brock, R.D., and Hermelin, T.: A joint FAO/IAEA/GSF program on grain protein improvement, IAEA-SM 230/86. "Seed Protein Improvement in Cereals and Grain Legumes," Proceedings FAO/IAEA/GSF Symposium, Neuherberg, FRG, 1978, IAEA Vienna, 1979, in press).

The rice program involved investigators in twelve different countries, mostly in southeast Asia, and was carried out over the time period 1962-1968. The objective was to determine that form, placement, and time of application of phosphate and nitrogenous fertilizer which would result in maximum uptake and utilization of the applied nutrient. The nutrient was labelled with an isotope to enable direct quantitative measurements. All Cooperators performed the identical experiments. The results presented in Tables 1, 2 and 3 indicate the tremendous research potential of this kind of coordinated research.

Table 1: Effect of Placement of Superphosphate on the Uptake of Fertilizer P by Rice Plants (Data as percentage of P in plants that was derived from the fertilizer)

Location	Treatments						
	Surface	Hoeing	Hill 10[a]	Hill 20	Row 10[b]	Row 20	LSD 5%
Philippines (Los Banos)	17	17	6	4	4	3	2
Thailand (Bangkhen)	68	68	50	34	51	38	9
Thailand (Surin)	37	40	22	15	26	23	2
Burma (Gyogon)	11	17	6	4	4	3	2
Burma (Mandalay)	25	25	6	6	6	4	3
E. Pakistan (Dacca)	19	25	22	17	12	7	8
W. Pakistan (Tandojam) (80 days)	48	50	5	4	4	4	5
UAR (Sakha)	64	60	37	38	38	37	10
Hungary (Szarvas)	3	3	2	1	1	1	1

[a] Placement at 10-cm depth in the planting hill.

[b] Placement at 10-cm depth between the rice rows.

Table 1 comprises six different placements of superphosphate at the nine locations that participated. The first two placements were broadcast applications. The two hill placements were put into the hole in which the rice was being transplanted, while the latter two treatments were between the rice rows. Although all of us predicted that putting the superphosphate in the hole at the time of transplanting the rice would be most efficient, the experimental results, which encompassed entirely different varieties of rice and ecological conditions, clearly showed that broadcast treatments of superphosphate were far more effective in getting phosphorus into the rice plant.

Table 2: Effect of Depth of Placement of $(NH_4)_2SO_4$ on the Uptake of Fertilizer N by Rice Plants (Data as percentage of N in the plants that was derived from fertilizer)

Location	Treatments				
	Surface broadcast	Surface rows	5-cm depth in rows	10-cm depth in rows	15-cm depth in rows
	Sampled at primordial initiation				
Ceylon	54.7	49.0	54.5	65.0	67.9
Philippines	8.3	9.5	25.1	33.8	35.2
China, Republic of (Taiwan)	41.5	39.0	44.5	45.4	45.7
Thailand	30.7	34.7	48.8	50.1	44.8
Madagascar	27.1	22.0	45.9	49.2	51.3
	Grain sampling				
Philippines	7.1	8.3	18.5	19.3	21.6
China, Republic of (Taiwan)	20.4	19.3	25.2	26.8	31.2
Thailand	11.8	11.2	32.4	37.0	38.1
Madagascar	11.5	9.1	20.4	29.9	26.5

Table 2 shows the results of nitrogen uptake as a function of placement of $(NH_4)_2SO_4$ for rice. This clearly shows the ineffectiveness of broadcast treatment as a means of supplying nitrogen to the rice plant.

Table 3 shows the results of nitrogen uptake as a function of time application of $(NH_4)_2SO_4$ for rice where all treatments were broadcast in accordance with standard practice. Again it is clear that later broadcast applications are more effective in supplying nitrogen to the rice plants.

Table 3: Effect of Time of Application on the Percentage of Nitrogen in Rice that was Derived from the Fertilizer (Averages of Six Replications), Sampled One Week After Primordial Initiation

Location	Percentage of N derived from fertilizer (mean of six replications)						
	A 60-0-0[a]	B 0-60-0	C 0-0-60	D 30-30-0	E 30-0-30	F 0-30-30	G 20-20-20
Burma (Gyogon)	20	35	40	28	34	41	33
Burma (Mandalay)	16	29	37	25	30	29	24
Ceylon (Gannoruwa Peradeniya)	14	21	27	19	23	24	25
Ceylon (Maha Illuppallama)	32	28	35	32	32	32	29
E. Pakistan (Dacca) I	9	23	37	14	26	27	24
E. Pakistan (Dacca) II	26	31	34	26	38	41	39
Hungary (Szarvas)	18	17	25	13	16	19	16
Korea (Suwon)	33	41	40	36	35	33	37
Madagascar (Tananarive)	18	24	37	18	30	31	25
Philippines (Los Baños) I	10	22	30	14	20	24	20
China, Republic of (Taichung, Taiwan)	32	18	30	24	32	31	26
China, Republic of (Taipei, Taiwan)	16	24	37	22	29	31	22
Thailand (Bangkhen)	16	28	37	21	26	33	28
Thailand (Rangsit)	27	44	46	33	43	40	33
UAR (Sakha)	26	23	31	21	32	29	28
W. Pakistan (Tandojam)	12	28	34	19	29	32	29

[a] 60-0-0, 60 kg N/ha at transplanting, 0 kg N/ha halfway between transplanting and two weeks before primordial initiation and 0 kg N/ha two weeks before primordial initiation.

In all three cases, a specific question was asked. In one year the answer was unequivocally obtained from which generalizations could be made. Not all results are this clear-cut, and part of the reason for this clarity was that the isotope labelling meant that direct measurements of uptake from the fertilizer could be made. Second, the answer to each question was relatively independent of location.

The plant protein improvement program on the other hand was organized entirely differently. The program had better financing, and therefore involved more Cooperators, more plant species and a wider scope of questions examined as shown in Table 4.

The objective was to determine the role that mutation breeding could play in increasing protein quality and quantity in small grains. This included answering questions

Table 4: Classification of Program Activities for Seed Protein Improvement

Type of activity	Number of Cooperators
Plant Breeding	
Wheat	10
Rice	9
Barley	5
Other cereals	2
Grain legumes	15
Techniques	
Analytical	7
Nutritional	2
Breeding methods	8

of whether mutation induction could achieve this objective; if so, how should it be done. A nutritional evaluation of the resultant product was also included. The planning session determined what the Cooperators would do, and how it would be done, but each Cooperator worked essentially independently on one part of the problem. The achievements of this program to date are summarized in Table 5.

Table 5: Achievements

A. PLANT BREEDING
Mutants and hybrids in advanced trials recommended for release.

1. Cereals

Wheat	High protein	Chile, India, Pakistan, Yugoslavia, Austria
Rice	High protein	India, Indonesia, Japan, Tanzania, Korea, Hungary
Barley	High lysine	Denmark, Sweden
	High protein	Sweden, Cyprus

Table 5: Achievements (continued)

A. PLANT BREEDING (continued)

2. Grain legumes
Increased yield with increased or constant protein per cent resulting in increased protein yield.

Mung beans	India, Bangladesh, Pakistan
Lentils	Bangladesh
Pigeon pea	India
Soybean	Uganda
Chickpea	Bangladesh
Field bean	Egypt
Food bean	Uganda
Haricot bean	Uganda

B. TECHNOLOGY
Development and recommendation of techniques for:

1. Mutation plant breeding	Mutagenic treatment Population size Selection systems
2. Protein and lysine assay	Standardization Automation Interlaboratory comparisons
3. Nutritional evaluation	Rat Microbial and Insect assay systems

C. TRAINING
A core of trained and experienced plant breeders and analysts.

Suffice it to say, that after this period of some eight years we are in the position of advising any investigator interested in plant protein improvement of small grains by mutation breeding as to the resources necessary, the chances of success, the population that must be dealt with, the best techniques available (most of which had been worked out under the program) and the likely nutritional value of the product, before the investigator starts his program. All of this information must, of course, be published for it to be

useful to the community at large, and the Coordinator can play a major role in stimulating and subsidizing publication in a suitable form.

One additional item might be mentioned that we feel has contributed markedly to the success of some of our coordinated programs. This is the back-up provided by our laboratory and its staff. This back-up is not just in the nature of being available when problems arise but the laboratory is an intricate part of the overall coordinated program. It does preliminary experiments, participates in the experimental plans, does services of all kinds including analytical, interpretational, intercomparison, etc. and provides technical back-up. The laboratory does not participate in all our coordinated programs, due to lack of resources, but where it does participate we generally find the programs are much more effective. In fact the active participation of the laboratory enables research on problems that could otherwise not be investigated. An example is the methodology worked out for the laboratory screening of a huge number of grain samples produced in the above-mentioned plant breeding program.

This is a quick overview of what can be accomplished without mentioning the myriad of problems associated with maintaining such a program over a period of years.

In summary, we have tried to illustrate one means of carrying out coordination of research on a regional or worldwide basis. We have found this method successfully accomplishes predetermined research and development goals. It is clearly a mechanism based on relatively limited resources and necessary effective inputs from a group of individual collaborators at the scientific level who are highly motivated. In the long run, many of the side effects involving individual interaction, training and extension may be as important as the limited research goal set.

While we have discussed the role of the Coordinator it is clear that the level of success of any program of this kind will depend on the extent and nature of the leadership provided by the individual Coordinator, as well as the already mentioned choice of individual Cooperators. With appropriate and effective leadership and competent and enthusiastic collaborators the type of collaboration can take different forms which will multiply the effectiveness of a program far above the algebraic sum of the individual research inputs.

FACILITATING COMMUNICATION, COORDINATION AND EVALUATION

Issue Paper Summary

Based on the system developed in various programs of the IAEA/FAO in Vienna, five criteria for selection of Cooperators have been developed and successful systems for developing experimental teams have been formulated. There are three options for participation patterns and three options for the role of the Coordinator in the collaboration. Choice of option depends on the problem and the design, as well as the program objectives. The coordinated approach accomplishes research goals in the shortest possible time while setting up relationships between scientists which optimize performance and facilitate dissemination of information to the scientific community. Collaboration can multiply the talents of the investigators beyond the algebraid equivalent of their means.

Some considerations for Network experimentation:

1. Only one question should be addressed in each experiment.

2. Research aims should not be compounded by demonstration aims.

3. Laboratory and other back-up can be critical to success.

4. Terminate project after five years because programs stagnate, priorities change and this prevents investigator dependency.

5. Increased peer respect and participation in the enthusiasm generated by the group are incentives to the experimenters.

Other Existing Network Models - Panel Discussion

Moderator: N. P. Kefford
Panel: M. Fried, S. Ahmed, W. Judy, J. Halliday

I. INPUTS Program (Saleem Ahmed)--Efficiency of Fertilizer Use.

   A. The circumstances of the perceived energy/oil crisis created conditions that generated worldwide interest in the topic of fertilizer efficiency. Field research aimed at increasing efficiency of fertilizer use was a project which drew a lively

response.

B. The EWC is a process-oriented organization and thus supplied coordination to various institutes already capable of performing a specific task. Special materials and services (statistical and chemical analysis) were provided by a number of institutions.

C. The Coordinator:
   1. Did not provide funding,
   2. Did not have laboratory back-up,
   3. Provided information and "back-up" support to Cooperators,
   4. Rapidly assembled workshop proceedings.

D. Approximately 140 agronomic, socio-economic and fertilizer marketing studies have been conducted in 18 countries during the past 5 years.

II. INTSOY (William Judy)--Soybean Variety Development

A. The INTSOY program has been in existence since 1973. It tries to bring Cooperators the best varieties to see how they behave in different environments throughout the world. Collaborators do an adaptability trial and a demonstration of soybean potential.

B. This system was developed with an end objective of direct, in-country human use. There were three levels of variety trials and three levels of Coordinator participation.

   1. SIEVE - (48 varieties in 3 sites) frequent direct contact.

   2. SPOT - (20 varieties in 10 sites) occasional direct contact.

   3. ISVEX - (16 varieties with 100-150 Cooperators in 80 countries and in total 250-350 sites) little direct contact.

C. What made ISVEX Work?

   1. Soybean was a new crop to Cooperators; so they followed instructions.

   2. Cooperators received precise descriptions of the methodology, procedures and development of events.

3. Cooperators received good quality materials.

4. The limits of such researchers are delineated.

5. Increased yield provided a hard output which was the real incentive.

6. Circumstances led to a rapid increase in soybean price and (which induced such an excess of requests that a charge for the materials is now necessary).

7. Experimentation was made personally rewarding for scientists by publication of results.

8. Research was kept separate from demonstrations.

D. Hazards encountered by INTSOY. Hazards were mainly related to:

1. Unreliability of factors such as quarantine and customs.

2. Uncertainty due to uncertainty of researcher tenure, facilities, and availability of services.

3. Natural and man-made catastrophy.

III. CIAT (Jake Halliday)--Forage Legume Strain Evaluation

A. Three sites were involved. With few sites in the network, checks are necessary to ensure that results are not highly site specific.

B. The Coordinator sent a scientist to each site with the materials to initiate the trial and be responsible for correct procedures. This represents a high degree of Coordinator involvement.

C. Helping the Cooperator to solve <u>his</u> problems is a major incentive. The scientists from CIAT and the cooperating institution arrived on site at the same time and together they planned a program of work.

Group Discussion Summary

I. Selection of Cooperators and preparation of team

A. Site selection

Selection of sites may determine Cooperators. Many factors may be involved in the selection of specific Network sites. Ideally, strong site capability and individual expertise and capability coincide. The following criteria for site selection were discussed:

1. Equal regional participation. It may be necessary to include geographic and environmental considerations. An equal number of sites should be chosen in the various regions (Africa, South Asia, South East Asia, Latin America). Hawaii is better able to focus on the Pacific than on Africa, for example. But the Network needs experimental data from all tropical areas.

2. Site-specific research needs. Proposed research must fit the Cooperator's objectives and help answer his research problems.

3. Availability of microbiologists and agronomists. Existing NifTAL-trained personnel are qualified microbiologists, and NifTAL-trained personnel should be target Cooperators, for the following reasons:

   a. This provides a return for NifTAL training-investment monies.

   b. Future trainees could be selected with this experimental collaboration function in mind.

   c. Providing back-up and support for NifTAL-trained people increases their prestige within their institution. Select people with a need.

B. Agronomists

While selecting NifTAL trainees presumes provision of the microbiology component, satisfactory agronomist capability must also be ensured. This may involve recruiting an additional person. Soil microbiologists of Latin America are usually

laboratory trained and may not have field capabilities. A qualified agronomist alone would not be satisfactory.

C. Crop selection

Selection of Cooperators will also depend upon target legumes selected by NifTAL. For example, we might want a 10 point soybean network but an 8 point cowpea network.

D. Site visitation

The need for a site visitation before Cooperator selection may depend upon known level of competence of potential Cooperators. Select Cooperators already involved in research on the problem. FAO/IAEA does not have site visits. If the answer to the question is the issue, site visits are not necessary.

E. Human factor

In the final analysis, it is the human being involved, and his direct personal contact with the Network, that determines success.

II. Leadership and Coordinator's role

A. Time factor

Coordinator leadership may decrease with time, as Network capabilities develop.

B. Group leadership

Group leadership will develop naturally, because of variability in leadership capabilities within the group.

C. Regional expertise

Utilize regional capabilities and expertise to solve specific problems. Coordinator leadership and involvement should not be initiated if Cooperator or institution lack the needed capabilities.

III. Strategy

A. Experimental design

Only one question should be answered per experiment. Keep experimental design simple enough not to endanger the success of the total research. Focus on one area at a time.

B. Number of sites selected

1. The number of sites needed depends upon the number of legumes chosen by NifTAL.

2. The number of sites also depends upon degree of Coordinator supervision and known levels of Cooperator competence. Allow for percentage of site failures.

3. This determination will be influenced by the choice of regional saturation or total world involvement.

C. Crop selection

Avoid crop introduction. Utilize a legume crop that has a previous record at each site and for which agronomic management capabilities exist. For experimentation on response to inoculation, select crops for which the answer is not known.

D. Collaboration planning session

Assemble qualified Cooperators for broad program discussion. This will assist in bringing the level of the group to that of the most competent investigator. It also allows the specific site to be that of the Cooperator's own experiment.

E. Project hard support requirements

1. Respond immediately to Cooperator problems. If necessary, deliver needed items to the site.

2. Do not jeopardize the program within a country by avoiding quarantine and/or customs.

3. Extent of hard support by Coordinator may be determined by country regulations and controls.

4. Degree of Coordinator hard support may decrease as site capabilities develop.

F. Research vs. Demonstration

1. A demonstration illustrates what is already known; research is to provide an answer to a question.

2. Specific research questions may determine whether one site can function as both a research and demonstration site.

3. The research design could be altered to provide for potential demonstration.

4. Demonstration should be situated where it has maximum exposure.

5. Utilize a research site for both functions only if it produces a clear demonstration. Protect the Cooperator.

6. Scientist cooperation in a demonstration will be minimal if he prefers a scientific reward, such as publication, for his efforts.

G. Training

1. A secondary aim is to develop talent in the cooperating countries.

2. Development of research competence, microbiological technology and confidence in BNF would be valuable.

FOURTH WORKING SESSION

Expectations for the Network Experimental Program

Chairman: Peter J. Dart
Issue Paper: Joe C. Burton
Rapporteur: Karl R. Stockinger

EXPECTATIONS OF THE NETWORK EXPERIMENTAL PROGRAM

Joe C. Burton
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The initial phases of the program to utilize biological nitrogen fixation (BNF) to enhance world supplies of food protein have been completed. The latest NifTAL report (June 30, 1978) states that the Rhizobium germplasm bank now includes more than 1,000 strains of rhizobia. The majority of these strains have been tested for nitrogen fixing ability and many have been screened for tolerance to low pH and high concentrations of aluminum and manganese--stresses which may well be prevalent in the soils of many of the tropical and subtropical developing countries.

We have reached the threshold where research must be concentrated on truly evaluating Rhizobium germplasm for its potential to increase food supplies. Requests for cultures of Rhizobium species are being received in ever-increasing numbers, and it is important to have an assessment of their nitrogen fixing abilities under the stress conditions which prevail in many of the developing countries.

Considerable progress has also been made in training rhizobia technicians. Twenty-five have been trained by NifTAL, and all but one of these were from the developing countries. These trained technicians should be very helpful in this second phase of the program to explore more fully the use of BNF to increase the world supply of food protein.

NETWORK EXPERIMENTAL PROGRAM

The objectives of our current workshop are:

1. To discuss and organize an experimental program for the Network, and

2. To study under field conditions the potential of the Rhizobium-leguminous plant association to provide greater quantities of nutritious protein foods in the tropical developing countries.

As I envision the Network it will be an organization of concerned agronomists in tropical developing countries, cooperating in an effort to harness and use the root nodule bacteria to produce food protein in greater quantities for undernourished people. Interest should be concentrated initially on specific grain legumes because of their greater potential. Countries included in the Network will, of

necessity, be restricted to countries adapted to growth of one or more of the particular grain legumes selected and those which have research or interest groups able to carry out the field experimentation. The desired data should be collected by the sponsoring organization for analysis, study and dissemination. Supervision, *Rhizobium* germplasm or appropriate inocula and limited financial support will be provided by NifTAL.

COORDINATION WITH OTHER ORGANIZATIONS HAVING PROGRAMS ON BIOLOGICAL NITROGEN FIXATION IN DEVELOPING COUNTRIES

In order to avoid overlapping of activities and to assure maximum benefit from funds available for research, it is extremely important to establish and maintain communication with all international organizations having programs on BNF. This should include not only field research programs but training and extension activities dealing with the practical problems of inoculum production, storage and usage. We are indeed fortunate in this workshop to have wide representation of international groups which are already involved and which have field experiments designed to explore more vigorously the potential of effectively nodulated leguminous crops to supply food. We had reports on many of the programs in our second plenary session. The knowledge and advice of these representatives will indeed be most helpful in planning the experimental program.

EXPECTATIONS OF THE EXPERIMENTAL PROGRAM

Since we are in the discussion and planning stages, perhaps the title of this session should have been "Objectives of the Network's Experimental Program." Our ultimate objective, of course, is PROTEIN FOR MORE PEOPLE, but before this can be realized there will be numerous intermediate objectives. We will agree that it is time to move from the laboratory and greenhouse to the field for our major effort. A thorough survey of international programs in progress--their objectives, location and the crops involved--is of major importance if wasteful overlapping is to be avoided. The results of this survey should be most helpful in selecting the countries and the particular leguminous crops to be included.

Thus, some of the early decisions are:

1. Which of the developing countries have an interest in an experimental network and which have trained research personnel to carry out the program?

2. Which of the grain legumes have the greatest food production potential in these countries, and which are the most likely to need effective rhizobia?

3. Is it practical to secure adequate seed supplies of the preferred genotype of the leguminous crops selected?

4. What experimental treatments are needed, other than inoculation with rhizobia? (Calcium, phosphorus, sulfur, molybdenum--pesticides?)

5. What are the essential parameters to measure?

There is a session later on experimental procedures but please allow me to make brief mention here of treatments. While progress has been made in characterizing strains of rhizobia for their nitrogen-fixing abilities and tolerance of stresses imposed by low pH and high concentrations of aluminum and manganese, I doubt that we know enough yet to select a single strain of rhizobia for any particular legume. I believe the field experiment should include at least two different single strain inocula. If this is impractical, consideration should certainly be given to using a composite of two or three strains.

The field experimentation at this stage should not involve inoculation methods. The inoculation treatment, either seed or soil, should be selected to provide a great abundance of the desired strain or strains of rhizobia without considering economies of the particular practice. The importance of showing positive results is far too great to risk inadequate numbers. The inocula should be strong and of uniformly good quality. At this stage the inocula for the field studies should be provided by NifTAL.

Consideration should be given also to including two or more genotypes of the selected leguminous species, particularly if there is any question regarding adaptability of a specific genotype to the prevailing soil and climatic conditions in the participating countries.

After the legume or legumes have been selected, the participating research groups determined, and the general plan of the experimentation finalized, it would be highly desirable to organize a training course that could be attended by at least one representative of each of the participating research groups. The purpose of this course would be to completely familiarize the participants with the goals of the Network and the particular field experiments to be conducted. This course should emphasize the

practical aspects of harnessing and using preparations of Rhizobium species of bacteria to enhance nodulation of field grown leguminous crops to greatly increase yields. The objectives of this course should be:

1. To explain the field experiment to be conducted, the treatments, their importance, and the importance of following procedures.

2. To acquaint trainees in the arts of inoculating seeds and/or soils and keeping the beneficial nocule bacteria alive in the inoculum and on the seed until the young seedlings develop.

3. To demonstrate how to sample and recognize effective and ineffective nodules on field grown leguminous plants.

4. To instruct the trainees to recognize potentially valuable Rhizobium germplasm and preserve it for future study.

5. To familiarize trainees with any special equipment or procedures needed to evaluate the experimental treatments.

6. To thoroughly familiarize trainees with the total management picture--including all treatments which may be required for insect or pest control.

The training aspects of the field experimental program are very important and may provide the most important single benefit. In essence, these people will be responsible for relaying the valuable findings of the Network to the farmers who will be using the practices. In addition to a thorough knowledge of the benefits which can be derived, these leaders will need to know how to contact the local farmers and convince them to use the important information developed. It will also be their eventual responsibility to learn how to screen Rhizobium germplasm, and then to produce an inoculum product which will be both thorough and dependable.

EXPECTATIONS FOR THE NETWORK EXPERIMENTAL PROGRAM

Issue Paper Summary

The inital phases of BNF research have been completed. Future research must be concentrated on evaluation of *Rhizobium* germplasm for its potential to increase food supplies. *Rhizobium* species must be assessed for nitrogen fixing abilities under stress conditions.

Initial research should be with grain legumes. Legumes will be chosen by the criteria of local interest, food potential, effectiveness of inoculation, availability of materials, and environmental conditions. Careful strain selection is also important.

Laboratory and greenhouse testing must be followed by pot testing with field soils. The best strains must then be field-tested in order to evaluate effectiveness in a variety of soils and environments. Inoculation methods should not be in question, but should be selected to provide a great abundance of the desired strains.

Also of major importance to the success of the Network are the training aspects of the field experimental program. The people trained in this experimentation phase will later be responsible for teaching methodology to the farmers and other users.

Data should be collected and collated from those institutions in countries which are adapted to the potential of legumes. Communication with BNF researchers worldwide must be maintained to avoid overlap. These institutions and researchers are those in a position to convert research results into food production capabilities.

Discussion Group Summary

I. Production

A. The desired end result of experimentation with the legume-*Rhizobium* symbiosis should be improved food production for the tropics. Some problem areas in food production which might be influenced by Network efforts to promote BNF are:

1. Extension of research efforts into the production cycle and increase of research on unproved potential crops and on food quality. Solid research results demonstrating improved productivity with inoculated seeds and

promotion of BNF research by training and information programs can have a great effect in convincing research administrators, funding agencies and independent businessmen to undertake further programs in this area.

2. Local production and distribution of materials. Both seed and inoculants should be available locally to the legume grower. Promotion of these services engenders additional benefits in promoting economic and agricultural productivity.

3. Diversification and intensification of crop production. Diversification to alternate and previously unrecognized or uneconomic crops which promote efficient energy use while resulting in a high quality food product improves the potential for maximization of farm incomes.

4. The stabilization of production conditions and the improvement of the permanence of production. Improved technological potential, environmentally and economically viable cropping systems, and marketable products are key elements in the stabilization of yields.

B. Inoculant production problems to be considered are:

1. In the US, the universities were the original producers of inoculants. Now there are commercial producers which have taken over this task on a profit making basis. But universities will probably have to play a major role in the developing countries' efforts to promote local inoculant production.

2. NifTAL and the Network should try to set standards for inoculant quality rather than attempting to be a long-term provider of inoculants.

3. Consideration of media delivery systems and carriers is needed--not only for the term of the experimentation, but also for eventual in-country distribution systems.

4. Agronomists and technicians must be trained to experiment on inoculant usage for development of preferred technologies which are appropriate for specific, local cropping systems.

II. Strain Testing

A. Preliminary strain selection and testing in the laboratory is of major importance. The Network must offer its Collaborators the maximum potential for positive results if its desired objectives are to be achieved. The laboratory should also be prepared to identify the strains being field tested by:

1. Reaction to antibiotics.
2. Genetic fingerprinting.
3. Serology.

B. Preliminary laboratory and greenhouse testing should do as much as possible to determine the tolerance of the strains to the following stresses:

1. Acidity. Probably work in this area is most advanced. Strains for soybeans, cowpeas, peanuts, mung beans, and lablab tolerance to acid soils are available for Network testing.

2. Salinity. No quick test is available at present to test tolerance to saline soil conditions.

3. Temperature and moisture. Tolerance to high temperatures and high moisture or wet-dry environments must be determined.

4. Fungicides and pesticides. A critique or State of the Art (SOTA) Report is needed on tolerance of various strains to chemical fungicides and pesticides.

5. Nutrient deficiency. Low availability of phosphorus, zinc, and iron in the soil is a probable stress area for which reactions must be tested.

6. Inoculum survival. The potential of various strains to survive delivery and inoculation procedures is an important consideration in improving productivity.

7. *Rhizobium* motility and saprophytic competence. The ability of the strain to survive and move about in the soil must be assessed if the best strains are to be selected for field experimentation.

III. Mechanisms to link institutions include:

A. Money. Research and training expenses can be shared among institutions. Available funds will be more effectively used--both within the institution and within the total field of BNF research--with cooperative networking.

B. Experience. Technical and scientific experience are at a premium in the tropics. Sharing of expertise not only creates institutional linkages it expands the probability of achieving both short- and long-term goals.

C. Training. Training programs are scarce and are in great demand. Regional or cross-institutional training courses develop technical and technological expertise and build personal and institutional bonds between instructors and trainees.

D. Initial experimental links. Linkages between already established researchers will be developed in the collaborative experiments.

FIFTH WORKING SESSION

Experimental Procedures for the Network Experiments

Chairman: James L. Walker
Issue Paper: Jake Halliday
Rapporteur: William Judy

EXPERIMENTAL PROTOCOL FOR THE NifTAL NETWORK EXPERIMENTS

Jake Halliday
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PREFACE

Experimental protocol, embracing experimental design, methodology and data processing, depends strongly on the objectives being undertaken, the number and professional competence of Collaborators in the proposed Network, and the target species, or more specifically the growth habit of the plant under investigation. In so far as these determinants were undefined at the time of writing and are to be developed over the first few days of the Workshop, this paper was written in a vacuum.

In order to proceed with development of a working document certain assumptions have been made with respect to objectives, scale of the Network and the legume species under test. Development and refinement of these concepts during the early days of the workshop will undoubtedly render redundant some of the point presented.*

INTRODUCTION

The first step in considering the experimental protocol for the Network is clear definition of the objective. This paper proceeds on the assumption that the objective is two-fold.

1. To determine whether a given legume responds to inoculation with Rhizobium at a particular site.

2. To evaluate NifTAL developed strains against other available materials.

The second step is to develop a strategy to achieve the objective, and this could be envisaged as follows:

1. Identify potential Collaborators worldwide and decide, taking into account the resources and time available, the scale of the Network to be undertaken--three sites per continent, one site per

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* The views expressed in this article are those of the author and should not be construed to be those of the management or board of CIAT nor its donor agencies.

country, etc.

2. Assess the state of the art in the Collaborator's program:

   a. What legumes are of interest to him?

   b. Are there known nodulation problems (the author assumes, and would tend to insist, that it is neither the Network's role to promote new legumes, nor to create new problems that do not exist in the region)?

   c. What is the competence within the program?

   d. What is the staffing and organization of the program with respect to execution of Rhizobium testing at the field level?

3. Refine the prospective network erected in paragraph 1 of this Introduction.

4. Formulate a tentative project for each selected site.

5. Visit the Collaborator and determine:

   a. The willingness of the individual to collaborate.

   b. The willingness of the organization to approve the project at an official level.

   c. The need for institutional approval (and at what level the need exists), especially in cases where there is a high probability that such approval will not be forthcoming.

   d. The opinion of, and inputs by, the Collaborator on the proposed project.

   e. The support required from NifTAL or from the Network to achieve execution.

   f. Comparative advantage of NifTAL, as against other agencies, to promote the project at that site.

   g. Participation rating relative to other potential collaborators.

6. Fine-tune the prospective Network erected in 3.

This final refinement will take into account not only the feedback from the visit to the Collaborator with respect to capacity to participate, but also such features as the frequency across the network of projects on cowpea as against Leucaena or peanut.

If the Network has relatively few sites, it becomes important to ensure that the type of project executed at each location is not highly site specific. If, however, the Network is "fine-mesh" then site specificity in the type of project undertaken is not a problem and could be considered an asset.

7. Tailor the site projects to the selected site circumstances and obtain the Collaborators "all-clear."

8. Execute the site project.

9. Visit the site project, preferably at sowing, but as early as possible.

10. Analyze the data from the site project, involving, if possible, the site Collaborator.

11. Synthesize the results of the Network projects.

12. Report the findings giving attention to:

    a. The questions answered by the investigations;
    b. The questions that remain to be resolved.

13. Determine future action.

The foregoing strategy has been presented to give context to the author's approach to the topic of experimental protocol. The ensuing considerations therefore relate to the experimental design component referred to in paragraph 4.

EXPERIMENTAL DESIGN

I have already stated that the design I am concerned with describing relates to the tentative project proposal formulated in advance of visiting the Collaborator to enroll his support and incorporate his ideas. We are not yet talking about such specific features in the design as plot size and number of replications.

In so far as psychology is as essential to the

acceptance of the project by the Collaborator as is its agronomic aspect there are design features that will make the project look attractive to the Collaborator and enhance the probability of its acceptance. This can be referred to simply as flexibility in the design that allows account to be taken of three main inputs:

1. NifTAL's assessment of the questions to be answered and means available to resolve them at a specific site;

2. The Collaborator's experience in cultural practices with the crop under investigation; and

3. The ability and right of a Collaborator to challenge the design, and to question the strains proposed for evaluation at the field level.

This last is the most important and could be called the "human dignity" component. It is normal for only 40 to 45% of Collaborators to return usable data in large networks such as CIAT's, IBYAN's, and INTSOY's international trials. Although this can be attributed in part to non-arrival of the package to the Collaborator, and although many factors can have affected the Collaborator's ability to complete the intended project, if his "heart" is not in the experiment, then his efforts to overcome the often minor impediments to implementation of the project are less than maximal. Where there is a will, there is a way. How do we guarantee that there is a will?

First it has to be acknowledged that our Collaborator has been responsible to his institution for a certain area of investigation, which may be recognizable to his institute as a defined problem. Irrespective of whether the Network Project is "sold" to him because of the finance and institutional back-up that accompanies it, it has appeal to the Collaborator only if and when he recognizes that it is tackling his problem. However, it must not be allowed to appear that NifTAL can easily solve the problem with which he has been struggling for so long. The problem is to be tackled jointly and the credit for any success must be shared.

Furthermore the Collaborator who has been evaluating Rhizobium strains over many years may resist imposition of NifTAL strains in the trials. You may say "the Network is not pushing NifTAL strains!" I am afraid I then have to ask what has NifTAL been doing for the last three years if it has not been developing strain recommendations. I have understood that a purpose of the network was to validate

these strains and compare them with other available materials.

The Collaborator has every right to question and to challenge the basis for recommendation of the strains to be used in the project, and some documented history of the performance of the strain in selection procedures should be made available. Human nature dictates that the group in the collaborating project will refer to "their" strains and "our" strains. I can predict almost every Collaborator asking, "What reason is there to suspect that a strain developed in Hawaii under very site-specific soil conditions will perform well in our country?"

One specific case illustrates the type of situation that can arise. A proposed Collaborator was invited to participate in a field test of three Rhizobium strains. His reaction was that he would participate if one of the strains was "his" strain. This type of proposal by a Collaborator ought to be resisted. In this case, the strains proposed for that trial included a commercial control and two strains developed on the basis of exhaustive evaluation in three prior stages of screening. If "his" strain had a similar history of evaluation this would have justified its inclusion, but an irrational inclusion of a strain for patriotic reasons would have detracted from the scientific value of the trial. This issue, the importance of which you ignore at your peril, is not impossible to resolve. It can be resolved through participation of the Collaborator in the selecting process, and by inclusion of "his" strains in earlier stages of selection.

How can we overcome the problem that, in the case of the proposed Network, selection has already been done? First, do check whether strains were sent in to NifTAL by the Collaborator in earlier years or at least whether strains from "his country" were included in evaluations and whether or not these merit validation at the field level. Presumably the documentation of strain histories in the Rhizobium Bank enable you to do this.

Let's assume that the involvement of the Collaborator has been zero. Then, to ensure his participation in the selection process, without jeopardizing the value of the field trial, I propose a two-stage network site project. The field experiment in the first stage will tackle only the first objective of the Network, i.e. is there a response to inoculation or not? The strain used will probably be a commercial or widely used "neutral" strain or composite mixture of several strains. A positive answer in the trial is easily interpreted. A negative answer is less so. No

response could result due to use of inappropriate strains. However the second experiment will tidy this up, because strains selected on the basis of pot experiments in site soil will be used. I remind you of the importance of this stage in strain selection and emphasize the modifying role that soil can play on what soil microbiologists and agronomists would prefer to keep among themselves as a host plant by strain interaction.

The design for A (Figure 1). Your first reaction may be "that's simple." It is hoped that the Collaborator's reaction will be the same. Three treatments involved are:

1. Inoculated,
2. Uninoculated, and
3. A plus-Nitrogen control.

Several workers advocated this design for the IBP experiments, but an alternate and much more complex design by Nutman and Vincent was adopted. Without too much elaboration, time revealed that the simple model would have been much more satisfactory. The IBP design tried to answer too many question at once. Both Brockwell and Date have advocated this simple, three-plot design for many years.

Please regard the unreplicated three plot experiment as the basic module in an expandable design. It will answer the question to a degree. The answer will be more reliable with replication. I have used unreplicated trials to get a "quick and dirty" answer which, if positive, encourages the greater investment in setting up a field trial with a full design that is statistically acceptable.

I consider it an asset of this design that it does not demand too much from the Collaborator too soon. If the experiment is "messed up," there is a second chance. Also NifTAL has the opportunity to re-assess reliability of the Collaborator before the larger investment is made.

Modifications are dependent on the capabilities of the Collaborator, but some possible modifications are:

1. Replication (three desirable, five preferred)
2. Alternate strains
3. Alternate cultivars
4. Alternate fertility levels

I would discourage the inclusion of more than two fertility levels in the experiment. Very few plant nutrition effects on the growth of legumes affect specifically the nitrogen-fixing symbiosis; thus, bigger, better plants permit

a bigger and more effective nodule population. Molybdenum deficiency is, of course, the exception to this general rule.

The design for B (Figure 1). This is not a complicated design either--a pot experiment with positive (+N) and negative (-IN) controls and as many strain treatments as the Collaborator can handle. A minimum of five replications is recommended.

The design for C (Figure 1). A randomized complete block design (3 replications) is recommended, with no more than nine treatments (e.g. 9 strains or three strains x three technologies). In addition to an uninoculated and plus nitrogen control, an absolute (no input) control is sometimes useful.

The Network has to ensure that the basic module is executed, thereby enabling subsequent comparison to be made across the Network between sites. Certain circumstances would argue for the discrete existence of a fixed design around which the satellite experiments reflecting the Collaborator's interest, are arranged. What do I mean here? Let's assume that NifTAL's prime interest is in the cowpea component of trials set up in many sites. If composite designs are permitted, the following circumstances could arise. The cowpeas could find themselves adjacent to, and over-shadowed by, Leucaena in one site, invaded by Centrosema at another site, and independent of the neighboring plots at a third site where the Collaborator's only other interest was a second and third cultivar of cowpea. The issue of compatibility of species in a composite design is a major agenda item for the on-site project development discussions with the Collaborator.

EXPERIMENTAL PROCEDURE

Inoculant. Variation across sites must be minimized. Standardize:

1. The peat base
2. The moisture content
3. The initial viable count
4. The viable count at time of sowing (aim at a minimum of 10,000 rhizobia/seed)
5. Inoculation method (pelleting or granules?)

In view of the very different sowing dates at sites and the scale of the Network there are logistic difficulties in placing a comparable inoculant in the hands of each Collaborator on the day he sows his experiment. The

survival characteristics of the strains in the peat that is used must be known. The biggest unknown in previous inoculation trials in developing countries has been the quality of the inoculum. Phytosanitary regulations of most countries permit relatively unimpeded entry of sterile-peat based inoculum.

Climatic data, or at least observations, are essential to aid in interpretation of results. It is disheartening to attempt to explain, in terms of native strain competition effects, why site seven in a ten-site experiment failed to respond to inoculation, and to learn subsequently that site seven had no rain for eight days after sowing causing loss of viability of rhizobia on the seed coat.

Native rhizobia. Some people place a value on knowing the number of native rhizobia/g of soil at the site--I don't, but it may be the mind of the group to take this datum.

Cross-contamination between plots is the greatest destroyer of field inoculation trials. The risk is greatest at sowing and is minimized by first sowing the uninoculated treatments (-IN and +N), and by surface sterilizing all implements and footwear in Chlorox between strain treatments. Plots should be fenced to exclude animals and tourists. The slope of the site should be studied and observed during rainfall. Appropriate drainage canals should be constructed to prevent surface water flow through plots. Some workers have gone to extreme lengths to prevent contamination, such as sinking metal plates into the ground around the borders of plots, but my experience has been that the acknowledged, relative immotility of *Rhizobium* works in our favor. It is important that all participants in the project (laborers who do weeding, etc.) are aware of the contamination issue.

Cultural practices. The seedbed preparation, fertilization regime, and plant protection measures (except seed treatment) should be those of the region in which the Network site is installed. Preferably these will provide non-limiting growth conditions for the plants.

Plot size. The size of the plot will depend on the species and type of seedbed preparation (drills, beds, etc.). 4 x 2m has proven a satisfactory plot size for most workers.

DATA COLLECTION

The absolute and preferred measurement of the response to inoculation is seed yield in the case of the grain legumes, and dry matter yield in the case of the forages. However, there are many components contributing to the

nitrogen fixation profile that can be described through observations during the course of the experiment:

1. Earliness to nodulation,
2. Nodule number,
3. Nodule weight,
4. Nodule color,
5. Distribution of the nodule population, and
6. Longevity of the nodule population.

It is common for many legumes to show a visual response to inoculation that does not translate into a seed yield response due to genetically programmed self-destruction in the plant variety, premature curtailment of the growing season or other limiting factors. This makes it desirable to rescue some measure of the early response (e.g. plant DM) to distinguish between a true zero-response-to-inoculation and a potential-for-response situation pending resolution of limiting factors.

EXPERIMENTAL PROCEDURES FOR THE NETWORK EXPERIMENTS

Issue Paper Summary

The strategy for proceeding with an experimental network should include determination of network scale; identification of potential Cooperators and assessment of the status of their programs; design and refinement of experiments; initial and sowing-time visits to Cooperators sites; monitoring progress at sites; recovering and analyzing data; synthesis of results; and publication of results.

Certain design features make the project attractive to the potential Cooperator. These include the flexibility to take advantage of the Cooperator's knowledge of his own country and to contribute to solutions to the Cooperator's own research problems.

The proposal is for experiments to take two growth cycles, with two experimental components in the first cycle. A, the first experiment in cycle I, is a field experiment with three plots for each legume to determine whether there is a response to inoculation. B, the second experiment in cycle I, is a strain selection, pot experiment using site soils and ten strains with five replications. Leonard jars allow ranking of strains under optimal conditions, but the best strain in the soil may not have ever ranked highly in Leonard jar tests. C, conducted during the second growth cycle, is a field experiment in a randomized complete block design with three replications and nine treatments.

Inoculant quality and carriers must be standard. Sterile-peat based inoculum is recommended. Cultural practices should be those normal to the site.

Data collected should include climatic data at sowing; earliness to nodulation; nodule number, weight, and color; distribution and longevity of the nodule population; and seed yield for grain legumes or dry matter yield for forage legumes.

Discussion Group Summary

I. Crops, species and cultivars

   A. Some suggested crops: cowpea, lima, mungbean, stylo, peanut, and hyacinth bean, soybean, pea, lentil, broadbean, horsebean and common bean.

   B. Selection of a crop for experimentation provides the opportunity for building a reservoir of material

which can be used to promote local farm practice.

C. If disparate crops are mixed, yield will fluctuate. Different crop groupings in a series of experiments should be avoided. The experiments should be as uniform as possible.

D. Species of grain legumes with wide applicability and economic value in the tropics, and those which will respond to inoculation, should be chosen. These should not be country-specific.

E. Genotype and environmental interactions are factors in cultivar selection. The number of available cultivars is very large.

II. Fertility levels

A. A soil fertility variable to test soil amendments, pH, etc. could be built into the design of the experiment.

B. Varying fertility levels can produce uneven results.

C. Fertility level for the legume crop should be the optimal level suggested by knowledgeable agronomists. The plant must have every chance to live and grow, or it is impossible to judge the effectiveness of inoculation.

D. In the actual crop production situation, N level will be determined by the economics of the situation; not by the agronomist.

E. There are many opinions on how many treatments are manageable in one set of experiments. Zero-N (with 4 strains), zero-N (with no Rhizobium), and plus-N (for maximum yield), were agreed to be desirable treatments. Crops can yield less on N plots than on zero-N, zero-Rhizobium plots where N reduces Rhizobium activity but is not sufficient to produce adequate yield. Many local varieties evolved under no N fertilizer but need native Rhizobium. Observations of yield depression have been made in field work.

III. Strains of Rhizobium

A. Decision on which strains to use needs to be considered for each individual site. In one case,

a successful strain failed on a comparable soil 200 miles away. If a strain fails, it needs to be determined whether it fails in all soils, or whether this is a soil-specific reaction.

B. Strains could be mixed, as long as all strains used were good strains, for the response-to-inoculation trials.

C. How many strains at how many sites is a question to be influenced by the statisticians. Three strains are as many as most would want to handle.

D. Strain selection is influenced by: host strain specificy; effectiveness against soil populations; ability to withstand stresses such as temperatures, acidity, and salinity; saprophytic competence; and motility.

E. Either strains or species should be evaluated; not both.

IV. Carriers, shipping and inoculation methods

A. A standard carrier should be used. Any experimentation with carriers should be done at another time.

B. A point was made that irradiation of peats may affect Rhizobium. One company prefers to autoclave carriers.

C. When the rhizobia are adequately protected, the response to inoculation is different from when they are not.

D. Sometimes in order to get seed into a country the seed must be treated, and often these treatments are not good for the seeds.

E. In 1979, ISVEX plans to send a small packet of inoculant with a temperature disk to measure effects of shipment on Rhizobium. The packet will be returned to ISVEX by the Cooperators.

F. One inoculation method should be chosen, for consistency.

G. Evaluation of inoculation method should include:

1. Sterile vs. non-sterile production?
2. How to count Rhizobium numbers?
3. How to package inoculants?

4. How to inoculate (e.g. seed? granules?)?
5. Should seed be pre-inoculated?
6. How should tests for actual numbers be applied?
7. How and by whom should competition be assessed?

V. Leonard jar and pot studies vs. field studies

A. L-jars are bacteria-controlled, autoclaved and receive optimal nutrition. Strains can be ranked, but further tests of reliability are needed.

B. Pot studies use non-sterile soil, loaded with native rhizobia. The fertility regime is designed to duplicate standard fertilizer treatment, and stresses can be duplicated.

C. Not enough research has been done to know whether, when a strain is effective in L-jar but fails in field studies, this is a site-specific result. In one case the worst strain in L-jar was second best in the field.

D. Lab results in L-jars need to be evaluated under field conditions to see whether test methods are reliable. Then experimentation can continue on reliable strains.

E. Greenhouse work is time-consuming, expensive, and sometimes there are no greenhouse facilities in the tropics. But results are very valuable. Greenhouse facilities could be provided by other Cooperators. Pot studies would be done using soils from the field study sites.

VI. Soils

A. Soil classification needs to be considered in selection of sites--both the relationship of the soil to the experiment and how representative the site soil is of other soils in the country.

B. Information is not presently available on the relationship of crop productivity to soil families or soil groups in the tropics.

C. Benchmark Soils Project has as its objective the overcoming of site specificity. Benchmark can do soil classification (taxonomy) for Network sites. Where soil family is known, data may be transferable.

D. Soil temperature, pH, minoral content, and fertility level also need consideration.

VII. Climate

A. Minimum climatic data should be compiled to include:

1. Rainfall at time of planting,
2. Amount of rain between planting and emergence,
3. Soil temperature--maximum/minimum,
4. Surface water flow.

B. Maximum temperatures have proved useful in evaluating chickpea response. Especially important is soil temperature before a canopy is formed.

C. Radiation level and pan evaporation data are not essential.

D. Data from countries should be checked against past data to see whether the conditions experienced during field trials are "representative" of "usual" data.

E. Benchmark sites have already-installed weather-monitoring equipment available.

VIII. Contamination and security.

A. The greatest risk to the success of the field trials is contamination. This risk can be minimized by:

1. Sterilizing all instruments between plantings,
2. Securing the plots against human and animal pests,
3. Proper drainage to encourage through-plot control.

B. Labor must be convinced of the importance of not transferring bacteria from plot to plot.

IX. Data

A. Data must be in terms of yield rather than in terms of "good" or "poor" response to inoculation. Since all inoculation response is relative, other parameters are needed.

B. The following components of response can be assessed but measures should be done non-destructively.

1. Earliness to nodulation,

2. Duration of nodulation,
3. Number of nodules,
4. Color of nodules

C. Climatic data on evapotranspiration, moisture availability index, etc., produced by government branches, should be compiled and integrated with experimental data.

X. Sites

A. Site selection should be made at three stages in the process.

1. Preselection by specific criteria,
2. On-site visit by NifTAL or other representatives,
3. Refinement of list according to broad Network goals.

B. The plan is for a series of experiments carried out at many sites, and sites should be chosen with this concept in mind.

C. Approximately 20 sites will be needed for each crop.

D. It is likely that, unless many sites are selected, site specificity cannot be ruled out. The importance of this issue will not be obvious until the experiments are done.

E. Site loss of at least 20-25% needs to be expected. Benchmark gets data from approximately 60% of sites due to loss through natural disaster such as floods, droughts, and typhoons.

F. Sites must be in areas where legumes are a viable crop--e.g. soil and environmental conditions are favorable and humans or animals are available and willing to consume them.

G. Sites can be varied to vary conditions. Using specific site selection methods reactions to environment may be quantifiable.

H. Site selection will also be related to budget and choice of crop.

I. Benchmark sites in Hawaii, the Philippines and Cameroon have been offered to the Network.

SIXTH WORKING SESSION

IMPLEMENTING THE NETWORK PROGRAM

Chairman: James Silva
Issue Paper: S. O. Keya
Rapporteur: B. Ben Bohlool

IMPLEMENTING THE NETWORK PROGRAM: STRENGTHENING RHIZOBIOLOGY THROUGH NETWORKS, CONFERENCES AND TRAINING COURSES

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INTRODUCTION

The contributions of nitrogen-supplying microorganisms are well documented in temperate agriculture. However, in developing countries of Asia, Latin America and Africa, little awareness exists on the usefulness of biologically-furnished nitrogen for crop plants. The emphasis on inorganic fertilizers during the last fifteen years has stimulated greater dependence on synthetic fertilizers, despite escalating costs. Coincidental to this low level of awareness is the paucity of meaningful commitment in terms of programs or financial support geared toward promoting nitrogen fixation involving the rhizobia-legume symbiosis. Consequently, in the developing nations there are very few active center involved in the endeavor to exploit the microbial harnessing of atmospheric nitrogen. Similarly, in Africa, Asia, and Latin America, few trained individuals exist who are in a position to transfer existing technologies of the advanced countries to the developing ones.

If the infrastructure were developed, the cost of transferring this technology would be relatively low. Since little sophisticated equipment and few advanced techniques are needed, the cost of establishment of an economically viable program would be modest once the personnel involved were available. Therefore the major needs appear to be the establishment of regional centers, the training of the requisite personnel, and the creation of an awareness of the importance of biological nitrogen fixation. It is in this regard that judiciously funded networks, conferences and training courses could play crucial roles in the transfer of existing technology from the advanced countries for food production in the developing nations. This transfer would effect valuable savings in energy requirements and industrial investment, and at the same time it would reduce potential environmental pollution of nitrogen compounds that contribute to eutrophication and health hazards.

LIMITATIONS TO BIOLOGICAL NITROGEN FIXATION

Renewed interest in biological nitrogen fixation (BNF) has resulted in a number of conferences, symposia, workshops,

state-of-the-art reports, etc. Consequently many reviews and reports by various organizations have appeared over the last four years. In 1976/77 FAO/UNEP conducted a mission to Latin America and Africa. It was found out that some of the factors constraining nitrogen fixation included the following:

1. Little or scattered research on BNF;

2. Inadequate knowledge of the importance of the legume-rhizobia symbiosis;

3. Inadequate knowledge of magnitude of nitrogen fixed by various systems;

4. Little available information on nutritional requirements for effective nitrogen fixation;

5. Poor laboratory and field facilities due to insufficient funds;

6. Few trained microbiologists and support technicians;

7. Research effort often discontinuous due to rapid staff turnover;

8. Rhizobiologists and agronomists generally isolated due to poor communication and information exchange;

9. Work of legume agronomists and plant breeders done independently of rhizobiologists; and

10. Lack of locally based extension programs which can educate the farmers and promote BNF. Findings of research stations not transmitted to the farm level.

Even in those countries where inoculants are produced, the quality and impact of the cultures leaves a lot to be desired. In Africa microbiological work tends to be concentrated either at the Universities or in institutions such as IITA, and ORSTOM. It therefore becomes necessary that any program, conference or training course must address itself to at least some of these 10 points of constraint.

JUSTIFICATION FOR TRAINING AND MANPOWER DEVELOPMENT

A major need in biological nitrogen fixation is the training of people in:

1. Providing continuity in research and extension programs;

2. Handling rhizobia and nitrogen-fixing microorganisms;

3. Preparation of inoculants;

4. Conducting meaningful inoculation;

5. Creating systems that will fix optimum amounts of nitrogen; and

6. Sound legume management practices.

The training of graduate and postgraduate personnel for implementing rhizobiology programs is an essential prerequisite for the building of the framework of the development of national infrastructures. The training of technicians in culture collections, inoculant production, and deployment is also advisable. The knowledge gained during training courses, conferences, and seminar/workshops will enable young scientists from developing countries to modernize the instruction, research, and extension activities at their home institutions. Also, it has been proven that exposure of local personnel to international experts encourages them to establish and maintain contacts with these experts and their institutions. NifTAL and the Nairobi MIRCEN are examples. The personal contacts brought about through these programs give the developing country scientists easy access to information and a method of obtaining specific advice on special problems. On the other hand, the experts in the developed countries become more aware of, and deeply involved in, the specific rhizobiological problems of the developing areas.

Some guidelines established by the UNEP/UNESCO/ICRO Microbiology Panel over the years, might be useful in regard to training. For example, in recruiting participants, preference should be given to persons younger than 35 years old who are in a position to apply or disseminate the acquired knowledge on their return. If the training is regional in nature, not more than one third of the participants should come from the country hosting the course. The teaching faculty should consist of a few foreign and many local and regional experts.

The study program should include lectures, laboratory benchwork, field trips and seminars and discussion sessions. The participants should be invited to present seminars on their work in their home countries. Lecture notes and laboratory manuals should be made available to the participants during or immediately after the course.

To increase socio-cultural contact and promote discussion, students and faculty should be accommodated in one place and have most meals together. In this way valuable ties can be developed among the participants and between participants and faculty members. The participants should also be encouraged to keep in touch after the end of the study program, by newsletters or other means. Evaluation of the course through a questionnaire and a follow-up on impact of the course and the students' subsequent activities should be encouraged. Involving local authorities, national and international institutions, and industries can be rewarding to participants.

With respect to funding of training courses, major costs are presently borne by the UN agencies (FAO, UNEP, UNESCO), foreign governments (e.g. USAID), etc. However, the host institutions also make substantial contributions, usually in kind, without which direct funding would need to be increased. In some countries local contributions will remain small; yet for others very little outside support might be needed. It is to be hoped that contributions from outside would dwindle as the local institutions mature.

Investment of funds on training activities can only be justified if the long- and short-term impacts of the training can be assessed. It has been argued that the real impact of training will be apparent only when participants are able to initiate their own research and act as foci for development in the applied agricultural microbiology of their own countries and organizations. If course participants are fresh graduates, they are unlikely to immediately find themselves in such positions. Thus, the suggestion that training course participants be graduates or higher degree holders may prove to be unrealistic, because such people are not always available.

REGIONAL AND GLOBAL COORDINATION

Considerable inoculant technology exists in developed countries, especially Australia, the USA, and Europe, which could be transferred through cooperative arrangements. The main objective of the cooperative global program should be to promote national and regional activities which will guide developing countries in establishing permanent institutions involved in BNF technology. Responsibility for fostering a global network of research and training, or advisory and technical assistance activities should be vested with one or two of the UN agencies. These agencies should seek to establish operating linkages between sets of institutions, national research systems in less developed countries, and organizations of the more advanced countries which have

demonstrated the capability to contribute to solving BNF problems.

Coordination of different national and international institutions working on Rhizobium is badly needed in order to avoid overlaps. Representation at this workshop of FAO, ICRISAT, CIAT, INTSOY, USDA, NITROGIN Co. and others, is a positive move toward such collaboration. Since the infrastructure is poorly developed, especially in Africa, benefits of a coordinated system will include the following:

1. Provision of a basic orientation for training in applied laboratory techniques, field investigations, and demonstrations.

2. Generation of national capabilities in developing countries so that permanent programs can be initiated and sustained.

3. Establishment of regional priorities which take cognizance of national goals.

THE ROLE PLAYED BY UNEP/UNESCO/ICRO MICROBIOLOGY PANEL

In view of the wide genetic potential with which microorganism are endowed, UNEP convened a panel in 1974 to examine ways and means of exploiting the useful microbial strains such as rhizobia. This contributed to great recent gains in the field of rhizobiology. A subcommittee on nitrogen fixation was later instituted in 1975. As a result of this subcommittee's activities, an international network of culture collections was established with other organizations such as IAMS, IUBS, WHO, etc. This network has sponsored international conferences covering culture collection, characterization and preservation of microorganisms, maintenance and significance of culture collection, exchange of germplasm, and organization of training courses.

Partially due to the activities of the panel, the World Data Centre (WDC), which contains information about all microbial cultures in collections of the world, has been established at the University of Queensland, Brisbane, Australia. Rhizobium cultures occupy an important part of this Brisbane information setup. Also, in keeping with the objective of conservation of valuable microbial gene pools, support has been sought to establish a World Federation of Culture Collections (WFCC).

It should also be emphasized that the panel encouraged research activities in microbiology, especially in the less

developed nations. Accomplishments in this field include exchange of personnel, provision of fellowships for young scientists, and assistance with limited facilities and equipment.

Microbiologists and their national institutions have been encouraged to team up in seeking solutions to problems indigenous to their own areas. A shining example is the South East Asia Regional Network for Microbiology, in which scientists from ten countries are cooperating admirably in various microbiological areas.

The panel has played a crucial role in organizing conferences on Global Impacts of Applied Microbiology (GIAM). The basic philosophy of GIAM conferences is the promotion of exchange of ideas and cooperation between persons working in the technologically advanced countries and those in the less technologically advanced countries. The aim is to take microbiology to the developing countries. Accordingly, the first GIAM conference was held in Stockholm in 1963, and the other four were held in developing countries. The sixth is due to be held in Nigeria in 1980. The second GIAM conference, held in Addis Ababa, Ethiopia, in 1967, offered a rare opportunity for many African microbiologists to meet their colleagues and exchange ideas. Similarly GIAM III, IV and V, held in Bombay, Sao Paulo and Bangkok respectively, gave local participants a chance to meet their counterparts. It is noteworthy that the last three GIAM conferences have attracted more than 80% of all participants from the developing countries. In Bangkok, the African participants formed a Regional Network on Microbiology for Africa.

GIAM conference topics are tailored to discuss problematic issues of the developing world. During the last GIAM Conference, held in Bangkok, Thailand in 1977, a good proportion of the time was devoted to the role of microorganisms in the nitrogen economy of soils. Thus, the conferences have helped to draw the attention of microbiologists of developed nations to problems in the developing world.

Every GIAM conference is usually either preceded or organized concurrently with a training course or symposium. This sort of arrangement brings notable speakers not only to the GIAM conference but also to the coinciding training activity.

Short training courses, lasting approximately 3 weeks and catering to about 20 participants, have been significantly featured among the panel's activities. Under the auspices of the panel, approximately 500 young microbiolo-

gists from developing countries have undergone training courses on subjects important to their own countries. Nitrogen fixation has received attention in some of these courses. Between 1961 and 1974, about 30 regional training courses were held in more than twenty countries. Plans are now underway for more courses in 1979 and the 1980's. Additional activities now under consideration include special refresher courses, technician training courses, and expansion of the small fellowship program.

In addition to executing the programs on training, survey-task force missions, and coordination activities, the panel has played a pivotal role in instituting and implementing the Microbial Resources Centers (MIRCENs). In adopting a more specific approach, a plan was developed for concentrating support on a number of MIRCENs. In the 1976/77 biennium a pilot project was initiated involving two MIRCENs specializing in biotechnology/biogas and waste utilization (Bangkok and Cairo) and two specializing in nitrogen fixation (Porto Alegre and Nairobi). (What were originally referred to as "Supporting MIRCENs," at Stockholm and Brisbane, will no longer be called MIRCENs.)

Objectives of the Nairobi MIRCEN described here are very similar to those of the MIRCEN at Porto Alegre.

The functions envisaged for a nitrogen fixation MIRCEN broadly include the following:

1. Collection, identification, maintenance, and distribution of Rhizobium cultures that are environmentally relevant to the region.

2. Identification of problems pertinent to the development of local rhizobia inoculant technology and promotion of research aimed at the solution of such problems.

3. Provision of advice and guidance to individuals and institutions engaged in research in Rhizobium technology.

4. Development, through long- and short-term training courses, of scientific and technical manpower required for the use of Rhizobium inoculants.

5. Dissemination of information to agricultural workers and microbiologists in the region, through demonstrations, bulletins and newsletters.

6. Development of infrastructure required to seek and maintain collaboration and liaison with appropriate microbiologists and institutions.

Achievements of the Nairobi MIRCEN include the successful completion of a three-week training course on "Basic Research Techniques in Industrial and Environmental Microbiology," August 22 - September 10, 1977. The course was sponsored by the UNEP/UNESCO/ICRO Microbiology Panel and the University of Nairobi. One week was devoted to information on nitrogen fixation. It was attended by 18 participants from 9 African countries. The second regional training course, entitled "Better Exploitation of the Legume-*Rhizobium* Symbiosis," is planned at the University of Nairobi for August 5 - September 15, 1979, in collaboration with the NifTAL Project of the University of Hawaii. A symposium: "Grain Legume Improvement in Eastern Africa," August 20-24, 1979, will run concurrently with the course. Currently 4 postgraduate students are involved in the M.Sc. degree program, while 4 other persons have attended relevant rhizobiology courses at IITA, NifTAL and other institutions.

COMMON PROBLEMS IN IMPLEMENTING NETWORKS AND CONFERENCES

Lack of appropriately qualified students is often denoted by the same people turning up at every training course or by course participants having extremely varied backgrounds. Similarly, a shortage of experienced personnel within a region might necessitate that the majority of teachers or conference speakers be outsiders.

Language barriers generally aggravate the communication problem. Although English is acceptable at most meetings, often there is a significant segment of French, Portuguese or Spanish speaking persons who have a meager working knowledge of the English language. Even when translation facilities are available, it is not always a happy compromise.

Since air and road transportation are weakly developed, travel arrangements must be made many months in advance. It is always advisable to double check that money and tickets have been received.

Due to poor infrastructure, announcements never reach all of the right people in time. Telecommunications systems are generally slow and undependable.

Foreign exchange regulations in developing countries call for early planning. The regulations sometimes make it difficult for scientists to subscribe to journals, buy books, or purchase essential experimental materials. Receipt of materials through customs, quarantine, etc. takes time.

In order to avoid failure, advance knowledge of and

planning for conditions at the site is essential.

These are only a few of the commonly encountered problems and there are others which could be country and area specific. On the other hand there are some pleasant aspects of working in developing countries. For instance, labor is cheap and running a field experiment is not likely to be too expensive. Cost of living being low, it is possible to train one M.Sc. student, or to run a short training course for 15 participants at a cost of only US $10,000.

IMPLEMENTING THE NETWORK PROGRAM

Issue Paper Summary

An urgent need exists in developing countries to create awareness of the significance of the biological nitrogen fixation potential of the legume-rhizobia system. Simultaneously effective programs should be mounted to remove the obstacles hampering exploitation of this type of atmospheric nitrogen fixation. It is suggested that training of personnel and strengthening of the infrastructure for research and dissemination of inoculant technology on a national and international basis are crucial in the implementation of the program. Important instruments ammendable to use in the execution of the program include conferences, training courses, networks, MIRCENs and coordination activities. The necessity for changing the location of these instruments from developed to developing countries, and the promotion of developing country participation in international and regional activities, are viewed as stimulating technical cooperation among developing countries.

A. Limitations to biological nitrogen fixation include little research on, and inadequate knowledge of, the legume-rhizobia symbiosis; little knowledge of nutritional requirements; poor lab and field facilities; inadequate staffing and isolation of staff; and lack of communication of results.

B. Justification for Training and Manpower Development

A major need in biological nitrogen fixation is the training of people in sound legume production, handling rhizobia, inoculant production, inoculation technology, systems for BNF production, and continuity of research and extension programs.

Some of the guides established by UNEP/UNESCO/ICRO microbiology panel might be useful with regard to training include giving preference to younger staff members, with not more than 1/3 of participants from host country; teaching staff consisting of a few foreign and many local experts; involvement of local authorities and national and international institutions and industries; course work including lectures, laboratories, field trips, discussions, and seminars; and encouragement of long-term linkages by socio-cultural contacts and newsletters, etc.

C. Regional and Global Cooperation

The main objective of the cooperative global program should be to promote national and regional activities which will guide developing countries in establishing institutions on nitrogen fixation.

Representatives from CIAT, ICRISAT, INTSOY, FAO, NifTAL, NITRAGIN Co. at the workshop may form the core of a possible Network.

D. The UNEP/UNESCO/ICRO Microbiology Panel organizes conferences such as Global IMPACT of Applied Microbiology (GIAM) with the aim of taking microbiology to the developing countries; organizing short training courses (3 weeks); providing task force missions and coordination; and instituting and implementing the Microbial Resources Centers (MIRCENs).

E. Common problems in implementing networks and conferences are the lack of qualified students; the shortage of experienced local teachers; the time constraints (e.g. plans should be made far in advance); the language barriers; the problems in publicizing the course; and the diversity of restrictions on customs and currency matters.

Questions on Issue Paper

Q. What role do women play in food production in Africa?

A. Women play an increasingly important role in agriculture, although this role is often unrepresented in training courses. Female enrollment in the University B.Sc. program has increased. In the field the woman has the major role, and the man is in the background.

Q. Should training courses be organized for specialized groups with similar backgrounds or for general groups with diverse backgrounds?

A. A great deal of work goes into the course when the group is one of diverse backgrounds and this is frequently not justified. But it could work; especially for a group with individual specialty backgrounds.

Discussion Group Summary

I. Training

It was generally agreed that, given the constraints of time, money and resources, the only kind of training necessary for the short-term implementation of the Network program is the technical one--an "updating" of the techniques of all the Collaborators. However, in the long-term, training was identified by the majority of the participants as one of the major constraints to food production in the tropics, and as one of the most important functions NifTAL could perform. The focus was on the NifTAL project as the likely center for major training activities in the future. It was suggested that NifTAL has a comparative advantage because of its track record in training and its University affiliation. Furthermore, NifTAL is not commodity-oriented like many other institutions.

If all international research programs have access to NifTAL's training course, trainees could return to the institution involved for further, in-depth training.

If training modules were designed, within two years training courses could be conducted by the major research institutions. These could be designed to have different course emphases and to employ different methods at different levels as needed.

Early training could be aimed at implementation of experimental goals. A regional planning meeting could provide this sort of training. This is one reason that such meetings have some advantages over on-site visits.

It was suggested that training programs be aimed at creating the "critical mass" for nitrogen fixation activities, either by training of groups from the same area, or by instilling in the trainees the importance of generating a critical mass in their region. Additionally, the trainee should receive materials which help him to illustrate the importance of BNF and build BNF influence within his administration and institution.

It was proposed that NifTAL create an internship program, whereby interns from the developing countries could get involved over a 6-month period in the various activities of NifTAL. If the intern is involved in the day-to-day activities of the project, he may not get all the information in logical order, but more informa-

tion is available to him and he gets "on-the job" experience.

II. Coordination

It was proposed that due to time constraints for the start of the Network activity, an initial network could be formed by personal contact by cooperating centers in the area with regional Collaborators (i.e. International Centers). This would establish several sub-networks, linked to each other and with NifTAL, for the execution of the first experiments. Following this, regional coordinating conferences would be held to reinforce the linkages, discuss results, involve new Collaborators, and plan for the succeeding series of experiments. However, the conclusion was that NifTAL should capitalize on the already existing linkages with former trainees in the initial phase of the development of the Network.

III. Conferences/Workshops with Collaborators

The following questions arose:

1. When?
   a. Prior to experiment?
   b. Annually?

2. Where?
   a. Hawaii?
   b. Regional?
   c. Other?

3. Information Dissemination Techniques
   a. Report results at conference?
   b. Report periodically to workers in field?
   c. Periodic newsletter?

4. Information Storage and Exchange Types
   a. World Data Center?
   b. MIRCEN?
   c. Bibliographic sources and programs?
   d. Computerized retrieval programs?

TASK GROUP MEETINGS

I. Experimental Design Group
   Chairman: James Silva

II. Network Implementation Group
   Chairman: Roger Ernst

Group A - Experimental Design Group

Discussion of the experimental design covered the following points:

I. Experiments
   A. Response to inoculation
   B. Evaluation of strain on site soils
   C. Strain X culture

II. Site characteristics

III. Legume selection
   A. How many legumes?
   B. Soybean
   C. Other legumes
      1. Cowpea
      2. Leucaena

IV. Strain selection
   A. Criteria
   B. Source

V. Supply and delivery of strains to sites
   A. Carriers
   B. Viability

VI. Management level of experiments

VII. Measurement of parameters
   A. Plant
   B. Soil
   C. Weather

VIII. Analysis of data

IX. Time frame
   A. 3 seasons
   B. Long-term

(See Experimental Procedures, Appendix 3, pages 232-241.)

Group B - Network Implementation Group

I. Kinds of agreements and contracts

A "memo of agreement" can serve as a contract. However drafting a memo of agreement can cause bureaucratic delays and other problems. An exchange of letters may be enough. USDA also has a simple contract form. A "grant" offers some advantages over a "contract" and probably agreements with Cooperators should be framed as grants.

II. Coordination with USAID Missions

If AID money is used for travel, clearances must be obtained in advance from USAID and from AID Missions in the countries to be visited, as well as from the governments of countries themselves. This takes at least one month, but is valuable because the AID Mission can coordinate the objectives of the visit with local objectives.

III. Assessment of needs

As soon as feasible, a profile of the fiscal patterns and contract needs of potential Cooperators should be drawn up.

Some possible material needs were discussed: lab equipment, fencing for plots, a greenhouse.

Training needs were recognized in many areas. NifTAL will continue to fund training programs.

In some areas inoculum would have to be provided since there is no local source. Strain identification will continue to be available through NifTAL.

IV. Cooperative support patterns

An Advisory Board on Rhizobium--a talent pool of senior people in the field to provide steering and scientific consultation--was suggested.

Meetings in Egypt, Nairobi, Vienna, and Puerto Rico provide opportunities to exchange scientific information and develop network strategies.

Verbal support in dealing with research administrations and funding agencies was discussed as one of

the more valuable kinds of cooperative support.

A newsletter to increase communication among researchers, administrators and workers in *Rhizobium* technologies was agreed to be worthwhile undertaking for which information and support could be generated.

V. Potential Collaborators and selection criteria

62 potential sites in 20 countries were named.

A list of selection criteria was drawn up and the most important criteria for each experiment were selected (see Figure 1).

VI. Design of the Network

Several schematics and outlines were presented by group members to use in discussion of the design of the Network (see Figures 2-6).

Figure 1. Criteria for selection of cooperators:

		Experiment I	Experiment II
*1.	Personal knowledge or recommendation	5	7
*2.	Existing competence and experimental potential	8	8
3.	Existing local interest (importance?)/Wide base (using? growing?)	---	---
4.	Not duplicating institutional support	---	1
5.	Powerful institution	1	---
6.	Institutional support available	3	5
*7.	Existing facilities	4	6
8.	Government interest	3	3
9.	Geographical distribution (within tropics? representative?)	5	3
10.	Diversity in soil and climate conditions	5	3
11.	Logistics (i.e. not hostile country)	1	1
12.	Time and money available	1	1
13.	Ability to support quality control	1	1
14.	Areas of greatest need	---	---

Figure 2. Checklist for assigning functions

Functions	Type Activity	Who	When	Other
Decisions				
Goals				
Objectives				
Resources				
$ Level				
Professional				
Needs				
Constraints				
Technical				
Decision				
Action				
Facilitative				
Support				
Sites				
Lists of collaborators				
Meetings				

Figure 3. A schema for functions: To implement Experimental Network

Function to be Implemented

Level of Implementation	DECISIONS ON POLICY	TYPES OF PLANNING	COORDINATION	CONTROL	RESPONSIBILITIES FOR IMPLEMENTATION
NifTAL	•Experimental design •Data to be collected •Time frame •Trouble shooting	•New funding •Year-to-year operations •Training program design	•Result sharing •Problem sharing •Response time •Mailing and correspondence •Conferences	•Quality •Time •Design •Funds	•Training •Strain choice •Screening •Packaging •Management of supply •Manual preparation
LOCAL SITE	•Experimental factors left to local discretion	•Input to planning •Constraints •Preparation of sites	•Primarily one-way •Regional conferences	•Funds (locally)	•Conduct experiment •Transmit results •Local bureaucratic management

Questions:

1. Level of Manpower
   -coordination?
   -experiment?

2. Travel
   -planning?
   -control?

3. Authority location
   -NifTAL
   -local discretion

4. Initial design
   -control?

5. Desirability of Conferences

Figure 4. Experimental functions to be considered in the design of the Experimental Network.

What is Purpose of Experiment	What Will NifTAL do	What Will Cooper. do	Crop Species How Many? Why?	Soil Charac. Which? Why?	Area Country Which? Why?	NifTAL Input $ Man Months	Conclusions Expected	So What Farmer View	Cooperator How Many? Where? Who? Specialty?	Design Experiment Complexity Analysis
Is there crop species response to Rhizobium	Design Procedures Rhizob strain Seed Analyze Interpret	Seed Plant Harvest Observe Eval. Interpret	Many	Many	Many	Few	Crop "X" responds Crop "Y" does not		Many Any	Simple
Are there superior strains	Design Procedures Strains Seed Analyze Interpret Visit	Strains Observe Interpret	Few	Few	Few	Many	Strains "X","Y", "Z" are superior		Few Microb.	Complex
Manage X Inoc X strains Alt: Carrier X Method	Design Procedures Strains Carriers Method Seed Interpret Visit	Procedure Carrier Method Seed Interpret	Few	Few	Few	Many			Few Microb. Agron.	Complex
Variety X Strains	Design Procedures Variety (Seed) Strains Seed Interpret Visit	Strains Variety Seed Interpret	V. Few	None	V. Few	Mod.	Variety "A" is not strain specific Variety "B" is str spec		Few Pl. Breeder Microb.	Complex

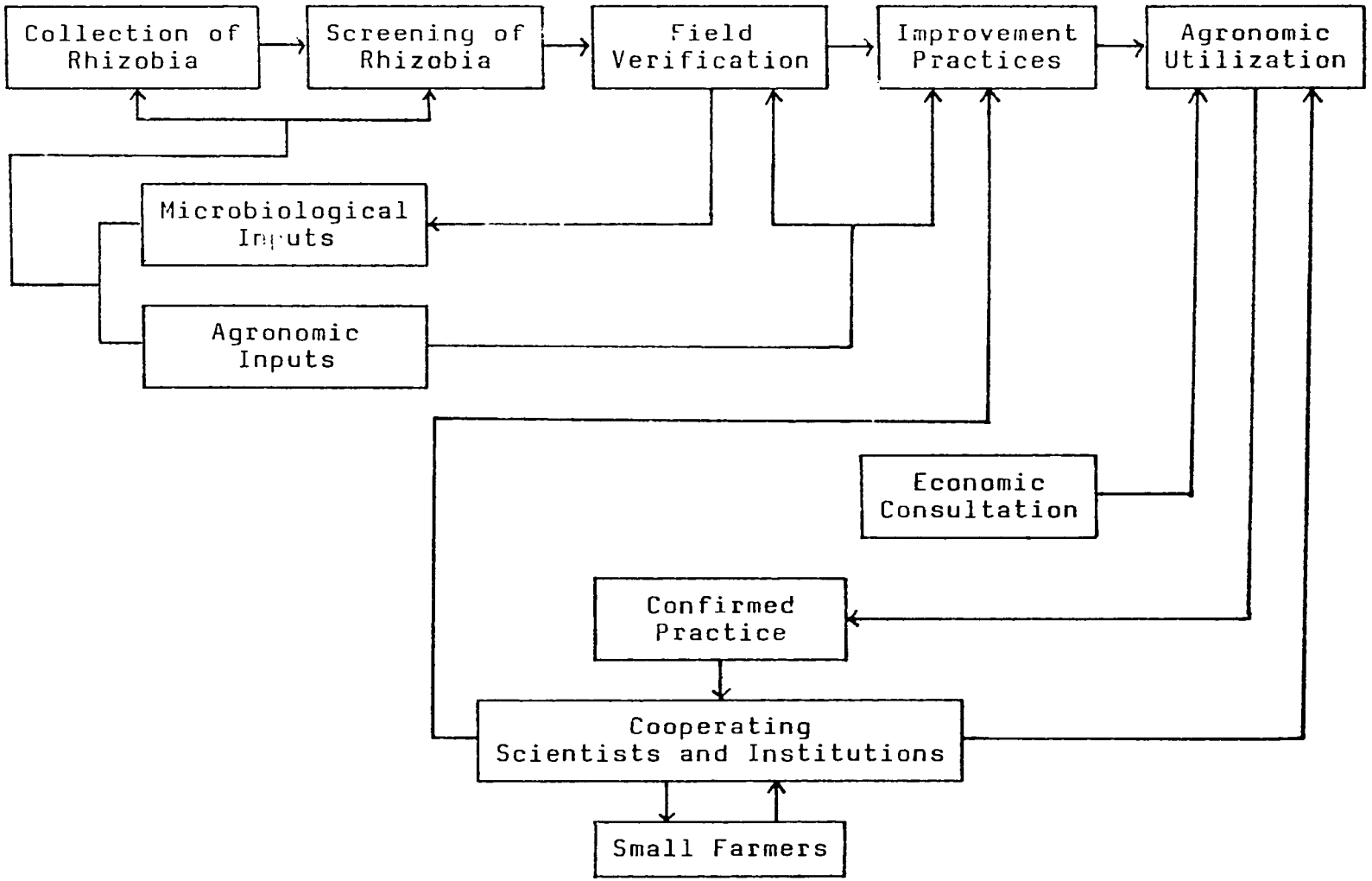
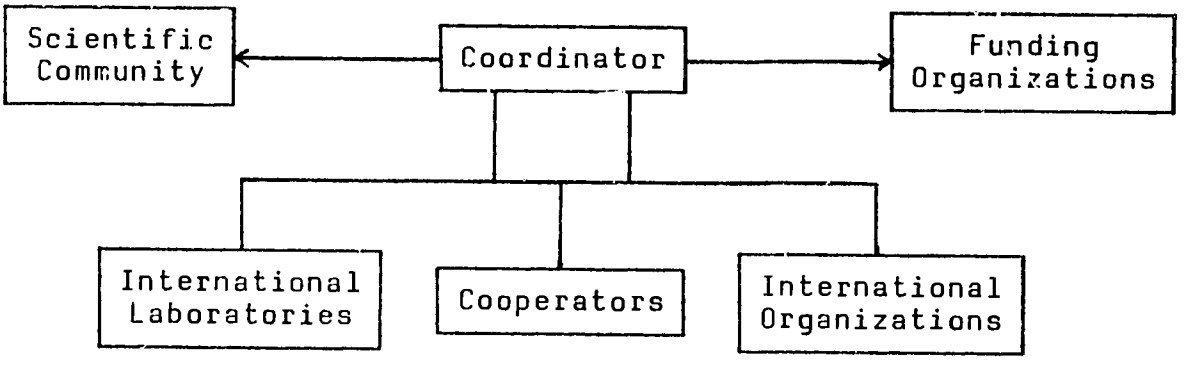


Figure 5. Schematic of design for Experimental Network.

Figure 6. Possible structure for management of the Experimental Network



FINAL REVIEW SESSION

Resolutions of the Participants

Chairman: Wallace G. Sanford

RESOLUTION OF THE INTERNATIONAL NETWORK PLANNING WORKSHOP

WHEREAS, the International Network Planning Workshop of the Project on Nitrogen Fixation in Tropical Agricultural Legumes (NifTAL) met in Hawaii, January 15-19, 1979, and discussed the role of biological nitrogen fixation in the food and farming systems of developing countries in the tropics, and

WHEREAS, the Workshop recognized the critical importance of field verification of the effects of the inoculation of legume crops with rhizobia upon food yield, and

WHEREAS, the Workshop produced a plan for NifTAL to initiate a field testing program in certain areas of the tropics,

BE IT THEREFORE RESOLVED that the participants of the Workshop endorse the plan and recommend its support by individuals and institutions that can contribute to the objectives of the plan, and

BE IT FURTHER RESOLVED that this resolution be recorded in the Proceedings of the Workshop.

January 19, 1979
Wailuku, Maui, Hawaii

RESOLUTION OF THE INTERNATIONAL NETWORK PLANNING WORKSHOP

WHEREAS, the Food and Agriculture Organization and the United Nations Environmental Program have a Biological Nitrogen Fixation Project to enhance the use of this natural plant pathway by farmers in the food and farming systems of developing countries, and

WHEREAS, Phase I of this program has produced recommendations for field programs to determine the response of legume crops to rhizobium inoculation and to select the strains best adapted to crops and environments, and

WHEREAS, the need for implementation of field verification programs exists in developing countries, collaborators are ready to be involved, and testing procedures have been defined, and

WHEREAS, the International Network Planning Workshop of the Project on Maximizing Symbiotic Fixation of Nitrogen by Grain and Forage Legumes in the Tropics, meeting in Hawaii, January 15-19, 1979, endorsed the need for field verification programs throughout the developing areas of the world.

BE IT THEREFORE RESOLVED that other programs represented at this workshop use their resources to foster field verification programs to enhance the utility and use of biological nitrogen fixation in farming systems, and

BE IT FURTHER RESOLVED that this resolution be incorporated in the Proceedings of the Workshop.

January 19, 1979
Wailuku, Maui, Hawaii

APPENDICES

NifTAL NETWORK PLANNING WORKSHOP

January 15-19, 1979

Program

MONDAY, January 15, 1979

First Plenary Session

9:00 - 10:00	Registration and Coffee
10:00 - 10:10	Welcome
10:10 - 11:10	Keynote Address - "Technology Change, Food, and World Security": H. Brown
11:10 - 11:40	"Tackling Problems through Research and Development--a Hawaiian Model": N. P. Kefford
11:40 - 12:00	"Goals and Methodology for the Workshop": A. S. Whitney
12:00 - 12:45	Lunch (then proceed to NifTAL Laboratories for afternoon session)

Second Plenary Session

1:15 - 4:45	"Current BNF Research in the Tropics" Short reports by the participants
4:45 - 6:00	Refreshments in Office Area and Poster Board Displays by NifTAL Researchers

TUESDAY, January 16, 1979

First Working Session

"Strengths and Constraints of Developing Country Research Programs in Symbiotic Nitrogen Fixation"

Chairman: F. Riveros
Rapporteur: V. G. Reyes

8:30 - 9:30	Issue Paper: L. R. Frederick
9:30 - 10:30	Discussion
10:30 - 10:45	Coffee

Second Working Session

"Considerations Involved in Institutional Networking"

Chairman: M. Alexander
Rapporteur: D. N. Munns

10:45 - 11:45 Issue Paper: R. Ernst

11:45 - 12:45 Discussion

12:45 - 1:45 Lunch

Third Working Session

"Facilitating Communication, Coordination and Evaluation"

Chairman: N. P. Kefford
Rapporteur: R. S. Smith

1:45 - 2:45 Issue Paper: M. Fried

2:45 - 3:15 Panel Discussion

Moderator: N. P. Kefford
Panel: M. Fried, S. Ahmed, W. Judy, J. Halliday

3:15 - 3:40 Coffee

3:40 - 5:45 Discussion

WEDNESDAY, January 17, 1979

Fourth Working Session

"Expectations for the Network Experimental Program"

Chairman: P. J. Dart
Rapporteur: K. R. Stockinger

9:00 - 10:00 Issue Paper: J. C. Burton

10:00 - 10:30 Discussion

10:30 - 10:50 Coffee

10:50 - 12:00 Discussion

12:00 - 1:30 Lunch

Fifth Working Session

"Experimental Procedures for the Network Experiments"

Chairman: J. L. Walker
Rapporteur: W. Judy

1:00 - 2:00	Issue Paper: J. Halliday
2:00 - 2:30	Discussion
2:30 - 3:00	Coffee
3:00 - 5:00	Discussion
6:30 - 8:30	Oriental Buffet Dinner and Cocktails for Participants

THURSDAY, January 18, 1979

Sixth Working Session

"Implementing the Network Program"

Chairman: J. Silva
Rapporteur: B. Bohlool

8:30 - 9:30	Issue Paper: S. O. Keya
9:30 - 10:00	Discussion
10:00 - 10:30	Coffee
10:30 - 12:00	Task Group Meetings

I. Experimental Design Group
II. Network Implementation Group

12:00 - 1:00	Lunch
1:00 - 5:30	Continuation of Task Group Meetings

FRIDAY, January 19, 1979

Final Review Session

Chairman: W. Sanford

8:30 - 10:00	Presentation of Reports from Task Groups I. J. Silva II. R. Ernst
10:00 - 12:00	Discussion
12:00	Close of Workshop

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EXPERIMENTAL PROCEDURES FOR TESTING OF *RHIZOBIUM* STRAINS BY THE INTERNATIONAL NETWORK OF COLLABORATORS

These experiments were developed for the systematic testing of *Rhizobium* strains in the tropics. They are the product of the efforts of the following cooperators in special committee meeting at the Network Planning Workshop held on Maui, Hawaii, January 15-19, 1979.

Dr. Ben Bohlool
Dr. Joe Burton
Dr. Peter Dart
Dr. Maurice Fried
Dr. Jake Halliday
Dr. Donald Munns
Dr. Victor Reyes
Dr. James Silva
Dr. Stewart Smith
Dr. Padma Somasegaran
Dr. Karl Stockinger
Dr. Sheldon Whitney

The schedule was drawn up by participants at the time of the workshop. It was sent out for international review in March. Amendments integrating comments and suggestions reflecting the expertise of a larger group than could be present at the Network Workshop can be expected.

Note to Reviewers:

1. Table on page 239 is not complete, and suggestions are welcome.

2. Please check sidedress nitrogen application schedule.

3. Check site rejection factors carefully.

OVERALL OBJECTIVES AND APPROACH

I. Response to Inoculation: Do legumes of economic importance in the tropics respond to inoculation with *Rhizobium* under two or more levels of agronomic inputs?

Experiment A: To demonstrate response to inoculation with *Rhizobium*. A small field experiment using six treatments for each legume to be tested: Three inoculation treatments (Inoculated, Uninoculated, Uninoculated plus Nitrogen) plus two fertility levels ("adequate" and "local"). In situations where farmer's fertility levels approach the optimum, only one fertility level will be used.

II. Evaluation of Strains on Sites: Are certain *Rhizobium* strains better than others with a given legume at a specific site?

Experiment B: To test strain differences. A pot experiment using field soil. The treatments will consist of a variable number of strains, Uninoculated Control and Uninoculated plus Nitrogen; each replicated five times.

III. Strain/Cultivar/Environment Interactions: Are there interactions among inoculum strains, legume varieties and environment?

Experiment C: To evaluate strain differences and their performance in the field. A full-scale experiment in the field consisting of seven strains plus Uninoculated Control and Uninoculated plus Nitrogen (total nine treatments), each replicated four times.

OUTLINE

I. Experiment A: Response to Inoculation with *Rhizobium*

A. Treatments (four replicates)

1. Adequate Fertility

a. Uninoculated
b. Uninoculated plus Nitrogen
c. Inoculated: Mixture of three strains

2. Local Practice

a. Uninoculated
b. Uninoculated plus Nitrogen
c. Inoculated: Mixture of three strains

B. Choice of Legumes

C. Inoculation

D. Plot Dimensions and Arrangements

E. Management of Experiment

F. Plant Density

G. Parameters to be Measured

II. Experiment B: Evaluation of *Rhizobium* Strains on Site Soil

A. Treatments (five replicates)

1. Uninoculated
2. Uninoculated plus Nitrogen

B. Choice of Legumes

C. Inoculation

D. Pot Size and Arrangements

E. Management of Experiment

F. Plant Density

G. Parameters to be Measured

III. Experiment C: Assessment of the Most Effective Strains

A. Treatments

1. Uninoculated
2. Uninoculated plus Nitrogen
3-9. Inoculated: Seven strains or mixtures

B. Choice of Legumes

C. Inoculation

D. Plot Dimensions and Arrangements

E. Management of Experiment

F. Plant Density

G. Parameters to be Measured

H. Site Pre-requisites

I. Site Characteristics

superior strains. Inoculum will be peat-based (granular if feasible).

D. Plot Dimensions and Arrangements: same as Experiment C.

E. Management of Experiment: same as Experiment C.

F. Plant Density: same as Experiment C.

G. Parameters to be Measured: same as Experiment C.

II. Experiment B: Evaluation of Strains on Site Soils: a pot experiment

This will be a pot experiment using soil from the field and carried out under the best conditions available at the collaborator's location (greenhouse, screenhouse, or outside). Not all collaborators need to carry out Experiment B. However, it should be carried out by all who intend to perform Experiment C.

A. Treatments

1. Uninoculated
2. Uninoculated plus Nitrogen (equivalent to 50 Kg N/ha as Urea at planting plus 150 Kg N/ha at 4-5 weeks after planting.

3-x. Inoculated: At least five inoculated treatments including the mixture of three strains (from Experiment A), individual components of the mixture, and other strains from collaborator or other sources.

B. Choice of Legumes: same as Experiment A.

C. Inoculation: Peat based inoculum will be used with Gum Arabic as sticker. Both components will be sent as a package to collaborators.

D. Pot Size and Arrangements: Minimum of three liters (provided by NifTAL, if required). The experiment will be laid out in a randomized complete block design with five replicates.

E. Management of Experiment: Soils should be adjusted to appropriate (optimal) levels of fertility and pH using the results of Experiment A if the information is available.

DETAILS OF EXPERIMENTAL PROCEDURES

I. Experiment A: Response to Inoculation: a field experiment

A. Treatments: There will be a total of six treatments with a minimum of four replicates.

Fertility / Inoculation	Adequate[1]	Local Farmer's Practice[2]
Uninoculated	"	"
Uninoc. + Nitrogen[3]	"	"
Inoculated	"	"

B. Choice of the Legume

1. Soybean (Davis variety) will be grown at all sites

2. At least one legume from the following groups will be chosen, depending on the location and the collaborator:

Group a: Chickpeas (*Cicer arietinum*), lentils (*Lens culinaris*), and beans (*Phaseolus vulgaris*).

Group b: Peanuts (*Arachis hypogaea*), cowpeas (*Vigna unguiculata*), and mungbeans (*Vigna radiata*).

Group c: *Leucaena leucocephala*

C. Inoculation: Inoculum will be a mixture of three

---

[1] Adequate: Application of P, K, Mo, Zn, S, as recommended by NifTAL in consultation with the experimenter. Lime should be applied to correct pH problems, if necessary.

[2] Local Farmer's Practice: Applications to be made according to local practices. Lime should not be applied unless it is a standard practice locally.

[3] Uninoculated + Nitrogen: Nitrogen to be applied as Urea:
50 Kg N/ha at planting
150 Kg N/ha side-dress 4-5 weeks after planting

F. Plant Density

Plant	Plant No./Pot	Thin to* No./Pot
Soybeans	10	5
Cowpeas	10	5
Chickpeas	10	5
P. vulgaris	10	5
Peanuts	10	5
Mungbeans	15	10
Lentils	15	10
Leucaena	20	10

*Thin after two weeks by *cutting* at pot surface. Thin *Leucaena* after five weeks.

G. Parameters to be Measured

1. Color Assessment: Assessment of color response should be done when it occurs (the date must be recorded), or prior to dry matter harvest. The color will be recorded as dark green, green, yellow-green, and yellow.

2. Dry Matter: All legumes, except *Leucaena*, will be harvested when they show differences or at six weeks. *Leucaena* will be harvested when it shows differences or at twelve weeks. Cut plants from each pot at surface of soil and dry in oven. Record dry weight and harvest data.

3. Nodule Sampling: Carefully dig up roots shortly after dry matter harvest from all pots. Record nodulation pattern and nodule weight. *If uninoculated controls are heavily nodulated*, collect nodules from all plants in each pot and store those from the same pot in a vial containing dessicant (provided by NifTAL) to be airmailed to NifTAL.

III. *Experiment C*: Assessment of the Most Effective Strains for a Particular Legume Growing under a Variety of Conditions: a field experiment

A. Treatments: There will be a total of nine treatments (seven of which will be inoculated treatments) with four replications. Only one cultivar will be used.

1. Uninoculated
2. Uninoculated plus Nitrogen as Urea (50 Kg/ha at planting, 150 Kg/ha side-dress)

3-9. Inoculated: seven inoculated treatments

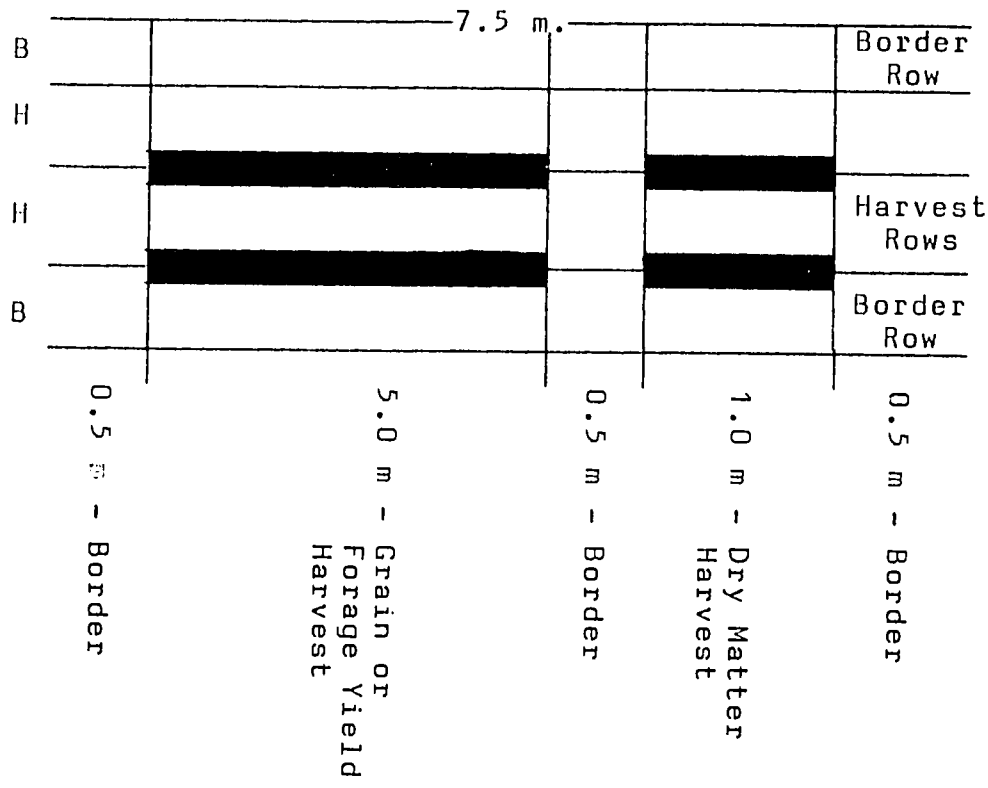
B. Choice of Legumes: same as in Experiment B.

C. Inoculation: Strains for this experiment will be chosen from Experiment B and/or the NifTAL list of recommended strains. If the mixed inoculum is one of the best, it will become one of the treatments in Experiment C.

D. Plot Dimensions and Arrangements: The experiment will be laid out in a randomized complete block design with four replications. The rows will be 7.5 m. long. There will be four rows per plot. Width of plot will be 2-4 m. varying with legume species.

Rows will be marked adequately for recognition of treatments. Any plot not adjacent to another plot should have an extra border row.

Plot Diagram:



E. Management of Experiment: Fertility will be adjusted only to allow adequate growth of the plant. Blanket application of a known amount of Mo (to be provided by NifTAL if required) will be carried out.

Irrigation, pesticide/fungicide, etc., will depend on local cultural practice. Irrigation is critical at initial sowing for uniform germination of seeds and to reduce the mortality rate of the inoculated *Rhizobium*.

For soybean, cultural practice will be detailed in collaboration with INTSOY. The planting time will depend on practice at collaborator's location.

F. Plant Density: Thin 2-3 weeks after planting by cutting at ground level to achieve plant density shown in table. For *Leucaena*, a longer period (5-6 weeks) should be allowed before thinning.

Plant Density

Plant	Plant no./m	Thin to no./m	Row Spacing cm
Soybeans			
Cowpeas			
Chickpeas			
P. vulgaris	(Parameters being sought from international reviewers)		
Peanuts			
Mungbeans			
Lentils			
Leucaena			

G. Parameters to be Measured (in chronological order)

1. Earliness of nodulation (at thinning, 2-3 weeks after planting). Carefully dig up ten plants/plot from the border rows which are inoculated

and record extent of nodulation (nodule weight, if possible). Pool nodules from same treatments and store in small vials containing dessicant (provided by NifTAL) to be airmailed to NifTAL.

2. Dry Matter (when 50% of plants are flowering). See plot diagram (page 8) for area to collect dry matter sample. Cut plants at ground level and dry oven. Record dry weight and harvest date. If dry weight measurements are not possible (i.e., no drying oven), then fresh weight should be measured.

3. Nodule Sampling (at step 2). Carefully dig up ten plants/plot at the time of sampling for dry matter, from same area where dry matter samples are taken. Record nodulation, pattern nodule color, and nodule weight. Collect nodules from all plants of the same treatment (keep replicates separate) and store in a vial containing dessicant (provided by NifTAL), to be airmailed to NifTAL.

4. Color Assessment. Observation of color response should be done when it occurs (the date must be recorded). The color will be recorded as dark green, green, yellow-green and yellow.

5. Grain Yield. See plot diagram (page 8) for place to harvest for grain yield. Grain yield should be reported on oven dry weight basis where possible; alternately as constant air-dry weight.

6. Optional Measurements. Acetylene (C_2H_2) reduction at thinning at step 2, total nitrogen of dry matter at step 2, and determination of native rhizobial population by MPN-method.

H. Site Prerequisites: The site will be <u>rejected</u> based on the following observations:

1. Where nitrogen is not limiting;

2. Where any cultivated legume has been grown in the past;

3. Where it is known that the soil contains more than 10^3/g. of effective rhizobia;

4. Where there is salinity problem, waterlogging and/or water movement across the plot area.

I. Site Characteristics

1. Soil characteristics: Soil may be characterized using soil taxonomy by Benchmark Soils Project. The soil profile must be described by an expert soil surveyor to qualify for this analysis.

2. Soil Fertility: Soil to be collected (0-15 or 0-20 cm) to determine fertility. This may be done at the initial site visit by the NifTAL representative if feasible. For nitrogen, exchangeable $N(NH_4 + NO_3)$ will be done. Phosphorus may be determined by Bray #1 modification. Soil pH by H_2O and KCl. Ca, K and Mg levels need to be determined as well as organic matter content and trace elements where possible. Exchangeable Al and Mn should be determined for soils below pH 5.5.

3. Weather Variables

   a. Maximum and minimum temperatures of air and soil should be recorded until canopy cover.

   b. Rainfall observed daily.

   c. Optional: Wind (qualitative assessment)
      Solar radiation and sunshine hours
      Other weather station data