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CLASSIFICATION AND MICROBIOLOGY OF TROPICAL SOILS

Grant AID/csd-2857

FINAL REPORT

1 July 1976 to 31 January 1979

UNIVERSITY OF PUERTO RICO
COLLEGE OF AGRICULTURAL SCIENCES
DEPARTMENT OF AGRONOMY AND SOILS
MAYAGUEZ, PUERTO RICO

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211(d) Annual Report
Date Due: 30 April 1979
Date: 31 May 1979

Grant Title: Classification and Microbiology of Tropical Soils

Grantee: University of Puerto Rico

Grant Program Director: F. H. Beinroth

Aid Sponsoring Technical Office: Development Support Bureau
Office of Agriculture

Statistical Summary

1. Period of Grant : 1 July 1976 to 31 January 1979
2. Amount of Grant : $300,000.00
3. Expenditures : $300,000.00

NARRATIVE SUMMARY

The extension of grant AID/csd-2857 to the University of Puerto Rico (UPR) was effective from 1 July 1976 to 31 January 1979 and had two subject matter areas, classification of tropical soils and biological nitrogen fixation.

The highlight in the area of soil classification was an International Soil Classification Workshop held in Brazil in 1977. The workshop was initiated by the grant and organized with the cooperation of the Servico Nacional de Levantamento e Conservacao de Solos of EMBRAPA. In addition to a large number of Brazilian delegates, there were 24 participants from 11 countries of five continents. This was a uniquely qualified group, representing some of the most distinguished pedologists and outstanding young soil scientists from LDC's. The workshop identified ten problem areas in Soil Taxonomy with respect to tropical soils and revised the definition of Alfisols and Ultisols with low activity clays. Thirty-one critical soils were inspected during eight days of field trips. The success of the workshop precipitated similar meetings in Southeast Asia and the Near East and catalyzed follow-up action regarding the workshop recommendations. In terms of impact, the workshop was clearly the most important grant activity.

A "state-of-the-art" (SOTA) study entitled "Soil Taxonomy in the Tropics" was conducted during the grant extension. The purpose of this study was to establish where and how this system of classification is used in the tropics, and to identify inadequacies of the system relative to tropical soils. Part I of the study dealt with tropical America and Part II with tropical Africa, Southeast Asia and Oceania. The base data were compiled largely through a questionnaire survey. The study showed that Soil Taxonomy is the single most widely used soil classification system in the tropics; it is applied in many countries in Latin America and Southeast Asia but to a much lesser extent in Africa. The study also showed, however, that much remains to be done to fully adapt Soil Taxonomy to the soils of the lower latitudes.

Chemical, physical, mineralogical, and climatic soil characterization data were obtained for key soils of Brazil. These data significantly increased the information content of the Soil Data Bank of the University of Hawaii. In collaboration with the University of Ghent, Belgium, soil micromorphological studies were conducted which generated new knowledge of relevance to the formation and classification of tropical soils.

In the area of biological nitrogen fixation (BNF), four SOTA studies were completed which share the common title: "Factors Affecting Biological Nitrogen Fixation in Tropical Grain Legumes". The studies focused on bean, cowpea, pigeon pea, and mungbean. The overall objective of the studies was to keenly and analytically review the generally accepted facts about crop production and BNF for certain target legumes. Part of the work for these studies was carried out by the Morton Collectanea of the University of Hawaii under a subcontract from the grant. For each of the four legumes investigated, summary statements, recommendations, limitations, steps toward overcoming limitations, and research needs are presented in the detailed report below.

A laboratory and greenhouses for BNF studies were established and experiments on inoculation of pigeon peas were conducted. These resulted on the isolation of 5 effective rhizobium strains which were subsequently tested against 7 commercial strains and compared favorably. Thirteen pigeon pea strains of rhizobium were tested for efficacy in the greenhouse.

The following materials have been investigated as substitute sources for peat as a carrier for inoculant: bagazillo, cachaza, coir, and seaweed. Coir dust proved to be the most promising alternative. However, it contains a substance toxic to rhizobium. If this toxicant is water-soluble tannin, as preliminary research indicates, there is an excellent opportunity that it can be removed from coir by simple water extraction. This is a significant finding of potential impact on the inoculant industry in LDC's.

As a direct result of the grant, UPR's research capacity was improved markedly through the installation of a functional BNF research laboratory. The international scope of the grant also resulted in the establishment of viable linkages with numerous multinational organizations, US and European universities, and LDC institutions as well as with many individuals. An important, although somewhat intangible, grant accomplishment should be seen in the emergence of a new perspective of tropical soils and BNF at UPR and a stronger institutional commitment toward the solution of LDC problems. An indication thereof is the present utilization of UPR's research capacity in soil classification and BNF developed under the grant by AID/DS/AGR through a research contract and three grants.

DETAILED REPORT

I. INTRODUCTION

This is the final report for the University of Puerto Rico's grant AID/csd-2857, Classification and Microbiology of Tropical Soils. Inasmuch as a summary report for the basic grant covering the period from 4 March 1971 to 3 March 1976 was submitted to AID on 20 July 1976, the present report is largely confined to the period of the second grant extension from 1 July 1976 to 31 January 1979. However, reference to the basic grant is made where appropriate.

II. GENERAL BACKGROUND AND DESCRIPTION OF THE PROBLEM

A. REFERENCE BACKGROUND

Less than half of the approximately 2 billion hectares of potentially arable land in the tropics is currently under cultivation. In theory, adequate land resources are, therefore, available for development to meet the present and future food requirements of tropical countries. Such considerations are deceptive, however. It appears that the practical limits to intensified crop production are likely to be economic and socio-political rather than biological. Although soils that can produce food under appropriate management are not yet in short supply, bringing them under cultivation poses formidable problems. Principal among these are: (1) the land not now cultivated is generally inferior as regards inherent productivity to the land presently used, (2) the capital investments required for agricultural development are considerable and compete with other demands for capital, (3) the land areas are remote from the dense populations that need to be fed, (4) infrastructure is usually lacking and agricultural industries would take time to develop, and (5) massive research efforts are needed which are difficult to organize and support. Yet, such have been the problems of developing areas in the past -- they are not insurmountable.

In the general context of this dilemma and considering the economic implications in particular, this grant focuses on a promising approach to economize

agricultural research efforts in terms of time and money and on alleviating the dietary deficiencies in LDC's through improved production of high-protein crops of low fertilizer requirements. Specifically, this grant is addressing the areas of soil classification and biological nitrogen fixation.

B. SOIL CLASSIFICATION

In view of the spiraling growth of population in the tropics, the now idle soil resources must be utilized more intensively and extensively in the near future. This will likely encourage methods of land use which are both more exploitive and more destructive than in the past. The agricultural development of these areas, therefore, requires a careful assessment of the potential of the soils to produce specified crops, the inputs and the level of technology needed and the precautions to be taken to ensure sustained productivity with a minimum of soil degradation.

In recognition of this necessity and in accordance with traditional approaches, most LDC's are engaged in costly soil survey programs the stated purpose of which is to facilitate land resource planning and to increase agricultural production. However, the practical value of the soil maps generated by these soil survey programs is often questionable. This results from the use of inadequate systems of soil classification, or from insufficient analytical data about the map units, or both. Soil maps with these inherent deficiencies are of limited agricultural utility as they cannot be interpreted for purposes of crop production at a reasonable level of reliability. The kind of soil classification system employed is, therefore, a key factor determining the value of a soil map for agricultural interpretations.

The problem with most schemes of soil classification used in the tropics is that they are based to varying degrees on theories of soil genesis. Consequently, the units of these systems are largely pedogenetic rather than agricultural groupings. The challenge is, therefore, to translate this pedogenetic information into meaningful soil agronomic data. If this is accomplished, soil classification, as applied in soil surveys, can be a powerful tool in agricultural development because it facilitates the evaluation of soil potential, the prediction of soil behavior and the extrapolation of soil management experience.

Not all systems of soil classification are equally well suited for making agricultural interpretations, but it is generally agreed that the American system, Soil Taxonomy, has the greatest potential in this respect as experience obtained in the temperate region shows. However, since Soil Taxonomy was developed by the Soil Conservation Service of the USDA primarily for the soils of the United States, it has deficiencies with regard to tropical soils. These inadequacies need to be identified and corrected now. Only then can Soil Taxonomy be effectively employed in agricultural development programs in LDC's. Failure to undertake these efforts will result in a diminishing acceptance of Soil Taxonomy in the tropics which, in turn, will hamper agroproduction technology transfers among tropical countries.

C. BIOLOGICAL NITROGEN FIXATION

A second aspect of the grant concerns biological nitrogen fixation, i.e., the process whereby atmospheric nitrogen is fixed or enzymatically reduced in symbiotic biological systems. This phenomenon is characteristically associated with leguminous plants. Grain legumes are important food crops and produce about 20 percent of all plant protein consumed. However, average grain legume yields are relatively low in the tropics. Among the reasons for this is the limited effectiveness of symbiotic nitrogen fixation due to inadequate inoculation or inoculation with inefficient strains of rhizobia. The problem is that very little is known specifically about the intricate *Rhizobium*/host plant interactions in tropical grain legumes. As a consequence, the potential importance of grain legumes in tropical agriculture is subject to conjecture. Therefore, the process of biological nitrogen fixation in tropical grain legumes needs to be scrutinized and optimal *Rhizobium*-grain legume associations have to be developed.

Grain legumes constitute a high-protein food which serves to balance the extensive use of cereals and starchy crops in human diets in LDC's. However, the quantity and quality of grain legumes available in most LDC's is insufficient to correct protein-deficient diets. Yet, to produce the grain legumes needed large inputs of nitrogen are required. Since the small LDC farmer cannot afford the high cost of nitrogenous fertilizers, the increased amount of nitrogen needed must come from biological nitrogen fixation. If grain legume yields

are not increased through biological nitrogen fixation, many people in LDC's will suffer from protein-deficient diets; a problem which will become even more acute in view of the ever-increasing population in most LDC's.

III. PURPOSE OF THE GRANT

The purpose of the grant, as it appears in the grant proposal, is twofold:

(1) To improve the classification of tropical soils to enable prediction of transfer of soil management requirements among tropical countries in order to accelerate the production of more and better quality food for the small farmer in LDC's, and

(2) To develop institutional response capability in biological nitrogen fixation and soil microbiology with emphasis on grain legumes suited for small farms in tropical LDC's.

The two stated grant purposes are different in kind. In the subject matter of soil classification the grant purpose corresponded to a utilization mode, whereas in the area of biological nitrogen fixation the emphasis was on developing institutional competence.

The rationale for focusing part of the grant activities on soil classification relates to the process of extrapolating and transferring agroproduction technology. It has been shown in the temperate region that soil classification, in particular the US Soil Taxonomy, can be a powerful tool for effectuating agrotechnology transfers. There is good reason to believe that Soil Taxonomy can be used with equal success in the tropics provided the system is adapted to the particular conditions unique to tropical soils. The grant proposed to identify present inadequacies of Soil Taxonomy relative to tropical soils through a state-of-the-art study and to correct them so that this system of classification can be effectively employed for predicting and transferring soil management requirements in tropical LDC's. This constitutes a shortcut to agricultural development as direct knowledge transfers significantly reduce the need for costly and time-consuming experiments in LDC's who do not have the human and financial resources to engage in extensive agronomic research.

In the area of biological nitrogen fixation, the grant was designed to develop new competence in a field which has been neglected in the past but is becoming increasingly more important. The recent awareness of the finiteness of fossil energy and the high cost of industrially produced nitrogen dramatically enhance the importance of biological nitrogen fixation by soil microbes. These microbes, rhizobia, are typically associated with legumes some of which produce grain of high protein content. The fact that human diets in LDC's are frequently protein-deficient and that some small farmers in these countries cannot afford the high-priced nitrogen fertilizer needed to grow non-legume crops further accentuates the necessity to develop a knowledge base in the field of biological nitrogen fixation in tropical grain legumes. The second grant purpose is thus directed at improving the nutritional quality of diets in LDC's through low-input agricultural systems conforming to the economic decision environment of small farmers in LDC's.

Major objectively verifiable end-of-project status indicators include the completion of five "state-of-the-art" (SOTA) studies as detailed below; the conduction of two international workshops on soil classification; the analytical characterization of key soils of the tropics; and the development of viable linkages with domestic, multilateral and LDC institutions.

IV. OBJECTIVES OF THE GRANT

A. OBJECTIVES RESTATED

The major objectives as stated in the grant proposal and detailed in the project design worksheets are listed below. The expected outputs were grouped into the following program categories:

I. Expanded Knowledge Base

A. Classification of tropical soils

1. SOTA study: Systems of soil classification used in the tropics and relevance, advantages and problems of Soil Taxonomy.
2. International workshops
3. Pedologic studies
   a. Characterization of key soils of the tropics
   b. Micromorphological studies

B. Biological nitrogen fixation

1. SOTA study: Biological nitrogen fixation in tropical grain legumes and its value to better quality food production

2. Inoculation studies with pigeon peas

   a. Response to Rhizobium inoculation

   b. Residual effect of nitrogen from inoculated and uninoculated pigeon peas.

II. Information Capability

Establish and maintain a reference center of special competence in classification of tropical soils (in coordination with University of Hawaii)

III. Advisory Capacity

Create and strengthen an institutional response capacity in the areas of biological nitrogen fixation and classification of tropical soils aimed at LDC problems

IV. Education, Training and Research Capacity

Enhance relevant capacities by improving research facilities, increasing library holdings and providing staff with educational opportunities

V. Linkages and Networks

Establish and maintain linkages with national and multinational institutions, strengthen linkages with Bureaus of AID, and cooperate with CST institutions in SOTA studies.

B. REVIEW OF OBJECTIVES

Of the major program categories listed above, objective I, expanded knowledge base, received intentionally most emphasis. This is consistent with the project design. However, in a departure from the original workplans, it had been decided to conduct four SOTA studies in the area of biological nitrogen fixation (BNF) rather than only one as previously contemplated. This change was made in consultation with the cognizant Technical Officer of DS/AGR. All other objectives remain essentially unchanged.

C. REVIEW OF CRITICAL ASSUMPTIONS

At the time the workplans were developed, it was assumed that qualified

professional staff would be available when the grant became effective. Unfortunately, unexpected difficulties in obtaining a U.S. visa for a new staff member, Dr. R. Guerrero of Colombia, caused a considerable delay in his appointment. Dr. Guerrero finally joined the UPR faculty in January 1977 and worked in the soil classification component of the grant.

VI. ACCOMPLISHMENTS

Accomplishments are summarized below under the following objectives/outputs: expanded knowledge base; information capability; advisory capacity; education, training and research capacity; and linkages and networks.

A. EXPANDED KNOWLEDGE BASE

1. Soil Classification

a. SOTA Study

A "state-of-the-art" (SOTA) study titled "Soil Taxonomy in the Tropics" was completed during the grant extension. Part 1 of the study deals with tropical America, and part 2 with tropical Africa, Southeast Asia and Oceania. The purpose and intent of this study was to provide conclusive answers to the following questions:

1. What system of soil classification is used in a specific country?
2. To which extent is Soil Taxonomy used or known in tropical countries?
3. What are the deficiencies of Soil Taxonomy with respect to tropical soils?

In order to gather the base data needed for a comprehensive and critical evaluation, a questionnaire was developed. This 26-page questionnaire contained 427 stratified questions which related to (1) field and laboratory procedures used in national soil survey programs, (2) adequacy and deficiencies of Soil Taxonomy relative to tropical soils, and (3) resources and present state of soil survey in tropical countries. Originally developed in Spanish, the questionnaire was subsequently translated into English. The English version was tightened to 116 questions with emphasis on the adequacy and utilization of Soil Taxonomy.

Following the identification of institutions and individuals, 209 copies of the

questionnaire were mailed to 25 countries in Central and South America. Responses were obtained from 17 countries (68%). For tropical Africa, Southeast Asia and Oceania, 157 copies were distributed in 53 countries of which 22 responded (42%). As a follow-up to the questionnaire survey, personal interviews were conducted in Bolivia, Colombia, Ecuador, and Peru.

The results of the study are compiled in the final manuscript of the SOTA report which has been transmitted to AID. Only the salient findings are summarized below.

Regarding present utilization of Soil Taxonomy, the study indicates that the system is widely used in the tropics. In Latin America, ten countries use Soil Taxonomy in lieu of a national system, notably Colombia, Costa Rica, Ecuador, Peru and Venezuela. In four other countries Soil Taxonomy is used in combination with another system. In Southeast Asia, Soil Taxonomy is presently being adopted by the Association of Southeast Asian Nations (ASEAN) as the uniform system of soil classification for the region and is already used in Indonesia, Malaysia, the Philippines, and Thailand. However, Soil Taxonomy is not the prominent system in Africa where a variety of schemes are in use, reflecting the colonial history of the continent.

Several countries expressed a preference of Soil Taxonomy over the system presently used but cited constraints in adopting the US system. These constraints relate to insufficient knowledge of Soil Taxonomy, inadequate laboratory facilities, and lack of official support.

In reference to the adequacy of Soil Taxonomy, most of the correspondents found it appropriate as regards basic principles, hierarchial structure and nomenclature. The operational definitions, differentiae and diagnostic horizons were, in general, recognized as the most valuable characteristics of Soil Taxonomy. But it was also pointed out that several definitions and classes are inadequate to properly accommodate tropical soils.

The results of the SOTA study are encouraging in that Soil Taxonomy is known and used more widely in the tropics than was expected. As in the past no real and consistent effort has been made on the part of the US to divulge the system

abroad, this shows that Soil Taxonomy has gained wide international acceptance on its own merits rather than because of political pressures. However, the study also showed that much remains to be done to refine Soil Taxonomy relative to the classification of the soils of the lower latitudes.

The final manuscript of the SOTA study has been distributed for review. Once the review process is completed, pertinent changes will be made and ways and means will be sought to publish the report.

b. International Soil Classification Workshop

As stipulated in the grant agreement, an international soil classification workshop and correlation tour was held in Brazil in June 1977 under the auspices of the UPR grant. This workshop was initiated by UPR and organized with the cooperation of the Servico Nacional de Levantamento e Conservacao de Solos (SNLCS) of EMBRAPA. The Soil Conservation Service of the USDA and the sister universities of CST provided valuable assistance and cooperation.

Participation in the workshop was by invitation only. There were twenty-four participants from outside brazil, representing eleven countries from all five continents. Many of the delegates were selected from the International Committee on the Classification of Alfisols and Ultisols with Low Activity Clays (ICOMLAC) in consultation with the committee chairman, Dr. F. R. Moormann, the Soil Conservation Service of USDA and AID/W. The participants constituted an exceptional group of some of the most distinguished pedologists and promising young soil scientists from LDC's. Many of the best talents available in the field of classification of tropical soils were convened at the workshop. They included Dr. G. D. Smith, the principal author of Soil Taxonomy, D. R. Dudal, Director of the Land and Water Development Division of FAO; Dr. R. Tavernier, Director of the Geologic Institute of the University of Ghent; Dr. J. E. McClelland, Director of Soil Classification of USDA-SCS; Dr. F. R. Moormann of IITA and various outstanding pedologists from LDC's such as Dr. S. Paramananthan of Malaysia.

Twenty of the twenty-four non-Brazilian participants were financially supported with funds from the UPR grant. SNLCS provided meeting room facilities, bus transportation for the field trips and other logistic and professional support.

The workshop had the following major objectives:

1. To examine the adequacy of Soil Taxonomy with respect to tropical soils,
2. To propose pertinent changes in Soil Taxonomy and to identify relevant knowledge gaps and research needs,
3. To discuss new definitions for certain taxa of Alfisols and Ultisols, and
4. To study critical examples of these soils in the field.

The workshop consisted of four days of conference sessions and eight days of field trips. The indoor sessions were held at the Everest Hotel in Rio de Janeiro from 20 to 23 June, at the Instituto Agrónomico de Paraná on 24 June, and at the Miramar Hotel in Recife on 1 July 1977. During the field trips on 22 June and from 24 through 30 June, a total of 1,850 km were travelled in the states of Rio de Janeiro, Paraná, Sergipe, Alagoas, and Pernanbuco. The workshop provided the first opportunity for key members of ICOMLAC to meet.

The conference sessions emphasized discussion and dialogue rather than the presentation of formal papers. Significant progress was made regarding the redefinition of classes of Alfisols and Ultisols with low activity clays. These soils are very extensive in the tropics and are widely used for subsistence farming but have the potential for commercial crop production if the social and economic handicaps can be removed. The technical problems can now be managed on this particular group of soils and the revised classification permits their identification in the field.

The discussion and elaborations regarding changes in Soil Taxonomy geared to tropical soils resulted in the identification of ten major problem areas the study of which was strongly recommended by the workshop participants. The problem areas, not necessarily in order of priority, are:

1. Revision of the soil moisture regimes with special reference to ustic regimes in tropical and subtropical regions
2. Revision of the Andepts and considerations of establishment of an Andisol order
3. Review of the "trop" concept and its use in Soil Taxonomy
4. Review of the Rhodic subgroups

5. Evaluation of color criteria in Versitols as a function of drainage
6. Review of the criteria for cambic horizons under aguic soil moisture regimes
7. Revision of the Oxisol order
8. Review of plinthite and related features
9. Consideration of the "Kandi" concepts in other orders of Soil Taxonomy
10. Evaluation of diagnostic criteria in terms of their significance for plant growth in general and for a number of major crops in particular.

The field tour, superably planned and organized by SNLCS, was one of the highlights of the workshop. Thirty-one profiles of Alfisols, Oxisols and Ultisols were inspected. The study of these soils allowed to evaluate the proposed new taxonomic concepts in view of the real world of soils and contributed much to the clarification of some controversial issues and to reaching a consensus. The discussions in the field were enhanced by well-prepared pits and by excellent analytical data provided by SNLCS, the Soil Conservation Service of USDA, Cornell University and the University of Hawaii.

The proceedings of the workshop which include the papers presented, a summary of the discussions and recommendations, and all analytical data are now in press as a joint publication of UPR and SNLCS. Upon its release in June 1979 it will be distributed worldwide.

By unanimous agreement of the participants, the workshop was a major success. This is attributed to (1) the high professional caliber of the participants, (2) the specifically defined objective of the meeting, (3) the common language and points of reference provided by Soil Taxonomy, (4) the well prepared and conducted field tour and availability of excellent analytical data, (5) the flawless organization, and (6) the joint efforts of CST, USDA-SCS and EMBRAPA-SNLCS.

The success of the Brazil workshop precipitated another workshop of similar scope and nature that was organized by UPR and held in Malaysia and Thailand in

1978 under grant AID/DSAN-G-003. A third international soil classification workshop in Syria and Lebanon in 1980 has been approved by Aid and is now in preparation under a grant to UPR. In addition, action has been taken regarding most of the recommendations of the Brazil workshop. For example, three additional international committees on Soil Taxonomy have been established to deal with Oxisols, Andisols and soil climatic regimes. The Brazil workshop thus has had an enormous effect upon the improvement and internationalization of Soil Taxonomy. In terms of impact, the workshop was clearly the single most important activity of the grant.

c. Soil micromorphological studies

Nine representative, highly weathered soils of Puerto Rico, including six Oxisols, two Ultisols and one Inceptisol, were investigated micromorphologically using scanning electron microscope and thin-section techniques. The objective of this study was to research the micromorphological features of highly weathered Puerto Rico soils and to relate these properties to soil taxonomic differentiae and to processes of soil formation. Dr. Hari Eswaran, a noted pedologist from the University of Ghent, Belgium, collaborated in this study as a consultant.

The research provided valuable insights into the hitherto unknown micromorphological characteristics of some soils of Puerto Rico. The data obtained proved useful in explaining the genesis of the soils studied. However, they also raised some questions relative to the validity of some criteria currently used in Soil Taxonomy, particularly the argillic and oxic diagnostic horizons.

A paper was prepared on the study and has been accepted for publication in PEDOLOGIE. This paper complements a comprehensive study on the formation, classification, mineralogy and chemistry of the same soils. The latter study was conducted in cooperation with soil scientists from the University of Hawaii under the basic grant and will be published as a special issue of GEODERMA. The two companion studies make a significant contribution to the knowledge of tropical soils.

2. Biological Nitrogen Fixation (BNF)

The University of Puerto Rico's research activities carried out in BNF under the

grant and supported with funds from it may be grouped as follows: SOTA studies, laboratory studies, greenhouse and field studies and thesis research.

a. SOTA Studies

The original grant document somewhat loosely specified that UPR's SOTA study would involve identification of grain legume crops and assessment of over-all yields, identification of rhizobium inoculation responses in grain legumes, evaluation of factors limiting production of grain legumes, and identification of inoculant and seed sources. However, it was decided at a BNF planning meeting held in Honolulu, Hawaii in August 1976 that UPR should channel its efforts into four SOTA studies. These studies would deal with the grain legumes cowpea, pigeon pea, mung bean, and beans, and would share the common title: "Factors Affecting Biological Nitrogen Fixation in Tropical Grain Legumes".

Assessment of library facilities available at UPR resulted in the conclusion that a part of the SOTA work should be subcontracted. In November 1976, contact was made with Dr. Julia Morton of the Morton Collectanea, University of Miami (a research department dedicated to economic botany with emphasis on the tropics) who agreed to enter into a subcontract. After finalizing details of the subcontract with the University of Miami, a meeting with Dr. A. G. Norman was held to define and outline the contents of the SOTA study reports. Soon after this meeting, literature reviews and data collection were initiated.

Close cooperation between the University of Puerto Rico and University of Miami has resulted in the completion and release of the drafts of all SOTA reports (pigeon pea, mung bean, bean and cowpea) for review by BNF representatives of CST during 1978.

The overall objective of the SOTA studies of the University of Puerto Rico was to keenly and analytically review the accumulated and generally accepted facts about crop production and biological nitrogen fixation for certain target legumes and to then publish the results in an easily readable non-technical form for use by decision-makers in developing countries in the tropics. For various reasons, the UPR SOTA reports may have possibly missed the goal with respect to intended purpose and use. However, the SOTA reports have been released for use by Michigan State University in a Title XII bean/cowpea planning grant by Texas A & M University for use in the mungbean planning grant. It is anticipated that

the UPR SOTA's will function as the cornerstone for literature reviews in both of these planning grants. At the present time, AID is in the process of circulating the UPR SOTA reports for peer review with the ultimate goal of publication and release of the reports in the form of literature reviews for the crops concerned.

All of the SOTA reports incompassed the same scope as far as possible and were written using the following outline of the pigeon pea study as a guide.

SOTA STUDY - PIGEON PEA

I. A. Nomenclature
   1. Host legume
   2. Rhizobium

B. Cultivation and Varietal Improvement
   1. Historical development
   2. Plant description
   3. Genotypes and varieties
      a. Germplasm inventory
      b. Induced mutations

C. Identification of Crop Producing Areas and Yields
   1. Individual countries
   2. International scale

D. Value of Pigeon Pea to Small-holder Farmers
   1. For food
   2. For forage and feed
   3. Other

E. Economic Importance
   1. To small farmers
   2. To countries

F. Institutions with Pigeon Pea Programs
   1. Research programs
   2. Extension programs

G. Principal Sources for Seed, Inoculant and Rhizobium Cultures

II. BIOLOGICAL NITROGEN FIXATION

A. Nitrogen from Symbiotic N-fixation

1. Known importance of biological nitrogen fixation
2. Crop not inoculated with Rhizobium
3. Crop inoculated with Rhizobium
   a. Methods of inoculation used
   b. Frequency of inoculation
   c. Strains of Rhizobium used
   d. Responses to inoculation

B. Transfer of Nitrogen to other Crops

1. Using intercropping system
2. Using rotations
3. Using other cropping systems

C. Nitrogen from Fertilizers

1. How much fertilizer-N is recommended
2. How much fertilizer-N is actually used
3. Effectiveness of fertilizer-N

D. Other Factors affecting Production of Pigeon Pea

1. Climatic factors
2. Soil factors
3. Plant factors
4. Diseases and pests
5. Agronomics
6. Human factors

III. LITERATURE CITED

IV. TABLE OF AGRICULTURAL CHEMICALS FOR PIGEON PEA PRODUCTION

V. SCIENTIFIC NAMES OF OTHER PLANTS REFERRED TO IN THIS STUDY

Salient results of the SOTA study are condensed in the Technical Summary section of the reports and culminate in the Recommendations, Limitations, and Steps Toward Overcoming Limitations sections which should be the most useful portions of the reports to decision-makers in developing countries of the tropics. The SOTA reports average 100-150 pages in length and include bibliographies of approximately 100-150 references.

As judged from receipt of favorable comments and request for copies, acceptance

of the SOTA reports for pigeon pea, cowpea, and mung bean has been enthusiastic. It can be anticipated that their ultimate distribution in the tropics will be widespread and their impact on tropical agriculture will be quite large.

As an example of this usefulness, the Recommendations, Limitations, Steps Toward Overcoming Limitations, and Research Needs sections of the technical summaries for each of the SOTA reports are reproduced below.

(1) Bean: Summary Statement and Recommendations

Dry-shell beans occupy a position of great importance quantitatively as a source of protein in low-income populations. Qualitatively, there is room for great improvement. Despite its popularity, the bean is far from being an ideal food. In those countries which are the highest consumers of dry-shell beans, black beans are eaten more commonly than white beans or beans of other colors. It is now known that the phenol content of the seed coat of black and other heavily pigmented beans interferes with the body's utilization of protein. Therefore the bean's role in the nutrition of black bean-consuming countries may not be as great as formerly assumed. In addition, there is a possibility that the heavy intake of tannin from this source may contribute to health problems such as stomach cancer, since there is mounting evidence that tannin ingested regularly over a long period of time is carcinogenic in the digestive tract.

The same phenolic constituents (tannins and anthocyanadins) which give heavily pigmented cultivars resistance to adverse environmental conditions, resistance to diseases and pests, and accordingly contribute to high yields, are undesirable in the human diet. Phenols in heavily pigmented seed-coats are probably also antagonistic to rhizobia and may in this way be a hidden factor in poor nodulation. Phenols, too, cause discoloration in broken snapbeans, which is a major problem in the processing industry.

Dry-shell beans require long soaking and long cooking and consume much energy. They are deficient in certain essential amino acids and a certain amount must be lost during prolonged soaking and cooking. Also, the bean is rich in oligosaccharides which are noted for producing flatulence. Much redesigning of the bean as a food is desirable and much education of farmers and consumers will be necessary to convert them to cultivars of higher nutritional quality.

Great advances have been made in breeding and selecting for resistance to diseases and pests, without which efforts to increase yield are superflous. Tremendous resources of improved cultivars already exist. There is a great need for effective delivery of the best planting material and methods to the small farmer in a simplified package.

As societies develop, there will be increased opportunities for marketing fresh and processed snapbeans. Farmers need to be prepared to meet this demand, and the small farmer may be better able to maintain a pole bean operation on a profitable basis than the large-scale grower in high-wage areas.

LIMITATIONS

1. Susceptibility to light, rust, viruses.
2. Susceptibility to nematodes.
3. Susceptibility to root rot.
4. Late nodulation and nitrogen fixation in some cultivars.
5. Sensitivity to acid soils.
6. High labor requirement in harvesting snapbeans.
7. Sensitivity of snapbeans to damage in mecnanized harvesting.
8. Dehydration of snapbeans because of moisture loss from breaking or rubbing off of pod hairs.
9. Brown-end of broken snapbeans due to phenol content.
10. High content of flatulence-inducing sugars in dry-shell beans.
11. High tannin (and other phenol) content of heavily pigmented, disease-resistant dry-shell bean cultivars -- reducing digestibility of protein.
12. Low methionine content.
13. High percentage of hard seeds in dry-shell beans.
14. Neglect of Rhizobium inoculation because of disbelief in effectiveness and also because of need for chemical seed treatment.
15. Inadequate distribution and high cost of improved, disease-free seed.
16. Scarcity of inoculant known to be effective on specific cultivars.
17. Poor cultural practices, lack of control of weeds, diseases and pests and lack of use of fertilizer by peasant farmer.

STEPS TOWARD OVERCOMING LIMITATIONS (based on existing knowledge)

1. Selection of disease-resistant cultivars; planting of disease-free seed treated with fungicide; use of fungicides in the field; practicing good field hygiene. Control of virus vectors.
2. Selection of nematode-resistant cultivars; soil fumigation; rotation with *Crotalaria* or *Tagetes*.
3. Selection of root-rot resistant cultivars; planting only disease-free seed treated with fungicide.
4. Application of small, initial dose of nitrogen at time of planting to boost seedling vigor prior to initiation of nitrogen-fixation.
5. Encouraging soil testing and liming to achieve favorable pH.
6. Selection of cultivars of uniform maturity permitting once-over picking at optimum stage, either by hand or machine.
7. Development of cultivars which detach readily from plant and are subject to less damage.
8. Development of cultivars with less hairy pods.
9. Development of cultivars with lower phenol content.
10. Development of cultivars low in oligosaccharides.
11. Development of cultivars low in tannin and other phenols, such as the white-seeded mutant NEP-2.
12. Development of cultivars high in methionine -- comparable to the F_1 progeny of BUSH BLUE LAKE X BREEDING LINE 195-4R68.
13. Investigation of hard-seed factor; educating consumers to add sodium bicarbonate to hard water, also to boil dry-shell beans for two minutes before soaking, to reduce soaking and cooking time.
14. Development of techniques for combined safe inoculation and chemical treatment of bean seed.
15. Increasing distribution of improved, disease-free seed, chemically-treated, to growers.
16. Increasing availability of inoculant to growers with instructions for application.
17. Education of growers to the advantages (and profits) of improved cultural practices, including weed-, disease-, and pest-control and proper use of fertilizers.

RESEARCH NEEDS

1. Greater use of mutagenic agents to develop white or light-colored mutants having characteristics appropriate for dry-shell bean, snap-bean, pole bean or bush bean production.
2. A maximum effort to identify strains of Rhizobium able to nodulate bush-type cultivars; matching of strains to compatible cultivars.
3. Study of the yield capability of effective inoculation vs. application of fertilizer-N.
4. Investigation of period of initiation and decline of nodule development and N-fixation.
5. Investigation of salt tolerance of bean.

(2) Cowpea: Summary Statement and Recommendations

As a versatile legume, drought-resistant, of wide soil adaptability, somewhat salinity tolerant, requiring a minimum of fertilizer, capable of producing two crops a year in tropical climates, and succeeding in regions unsuitable for the bean or soybean, the cowpea has an unlimited potencial for expansion as a source of human food and animal fodder.

The development of various superior table varieties of different colors and textures of seed coat has already greatly increased the consumer acceptability and market demand for the green-mature or mature dry seeds. Selection and release of compact bush-types with elevated clusters has adapted the crop to large-scale mechanized cultivation and harvesting and has also facilitated manual harvesting.

In African countries where the cowpea is commonl/ grown but poorly managed, improved practices can greatly enrich food supplies and enhance the local economy.

In many areas of the world where the cowpea is not presently grown or is little known, it can be introduced as a productive element in cropping systems. Increased production can lead to opening up of new markets for canned, frozen, or mature-dry cowpeas.

Experimental work and widespread screening and selection for disease-and pest-resistance have already made important contributions toward cowpea improvement. The greatest need is for education of growers to adopt the best planting material and cultural practices.

LIMITATIONS:

1. Susceptibility to seed-borne and insect-borne virus diseases.
2. Susceptibility to *Cercospora* leaf spot.
3. Susceptibility to pod borers.
4. Susceptibility to cowpea curculio.
5. Susceptibility to powdery mildew.
6. Susceptibility to nematodes.
7. Sensitivity to excess moisture.
8. Excessive flower shedding.
9. Non-uniform maturity of most cultivars, requiring repeated harvests.
10. High labor requirement of manual harvesting.
11. Conflict with harvest season of cotton and consequent shortage of labor in cotton-growing areas.
12. Insufficient percentage of green-mature seeds released by green-ripe pods whether harvested manually or mechanically.
13. Resistance of farmers in developing countries to solo-cropping and row-cropping.
14. Susceptibility to weevils in storage.
15. Limited availability of seed of high-yielding cultivars.
16. Limited availability and use of effective inoculants.
17. Insufficient use of appropriate fertilizers in nutrient-deficient soils.
18. Use of fertilizer N in the form of ammonium sulphate which is known to inhibit nodulation.

STEPS TOWARD OVERCOMING LIMITATIONS (based on existing knowledge)

1. Planting of virus-resistant cultivars; chemical seed treatment to destroy virus without affecting viability. Chemical control of aphids and other virus vectors.
2. Planting of cultivars known to be *Cercospora* resistant. Elimination overhead sprinkler irrigation.
3. Encouragement of UVL insecticide applications during flowering period.
4. Planting of cultivars known to be cerculio-resistant; further breeding to develop a wider range of resistant cowpeas for different regions.
5. No cultivars known to be resistant. Control with soil drench, seed treatment of foliar spray of Benomyl.
6. Planting of nematode-resistant cultivars; fumigating soil or rotating cowpea with other crops.

7. Encourage ridge-planting where waterlogging may occur; determine proper planting time to avoid excessive rainfall after vegetative stage.
8. Further research to determine efficacy of anti-shedding chemicals and cost/benefits to the farmer.
9. Planting cultivars with short fruiting period in commercial fields. Further breeding efforts to make available a wider range of cultivars with high percentage of pods maturing at one time.
10. Encouragement of row planing to accommodate available types of mechanical harvesters.
11. Determination of planting time which will result in harvest period which does not compete with cotton; choosing cultivar suitable to the daylength of the growing season.
12. Further research and breeding to develop cultivars less resistant to opening at green-pod stage, for commercial processing, as distinct from cultivars that are shatter-resistant and designed for production of ripe, dry seeds.
13. Convincing farmers of the feasibility of solo-cropping wich permits effective insect control with consequent greatly increased yields.
14. Education of farmers to use anti-weevil treatments and storage techniques; with proof that reduction of weight loss and maintenance of quality brings returns more than compensating for extra costs.
15. Further research and experimentation in matching Phizobium strains to cowpea cultivars and distribution of high-quality, low-cost inoculants in convenient package units bearing precise instructions for use.
16. Encouragement of and making local facilities available for soil-testing to determine fertilizer requirements of field intended for cowpea culture; convincing farmers of the economic benefits of appropriate fertilizer use.
17. Discouragement of use of ammonium sulphate which is now being advocated in some extension programs.

RESEARCH NEEDS

1. Field research to confirm adverse effects of ammonium sulphate.
2. An intensive study of Rhizobium strains and testing of their effectiveness on cowpea cultivars which have been identified as having high resistance to diseases and pests;and preparation of an inventory of Rhizobium inoculants and their matching cultivars.

3. A phytochemical study of cowpea shoots and leaves, immature and mature, to determine the possible physiological effects of habitual consumption of this plant material and whether it should be counseled against or advocated. The health value should be considered in any decision to include or exclude spreading, "spinach" types, or dual-purpose types in breeding programs.
4. Identification of developing areas which would benefit economically and/or nutritionally by pigeon pea introduction.
5. Market surveys in developed countries to determine the export potential for canned, frozen and mature, dry cowpeas of high table quality.

(3) Pigeon Pea: Summary Statement and Recommendations

As a multi-purpose bush legume, drought-resistant, of wide soil adaptability, somewhat salinity tolerant, requiring a minimum of fertilizer and producting edible seeds high in protein, which are popular as food in some areas of the subtropics and tropics and of increasing value in international trade, the pigeon pea is worthy of promotion. Erect growth and non-shattering of seedpods are factors favoring mechanical harvesting, which is becoming more and more necessary in agriculture with spiralling costs of manual labor.

The variability of the plant and its product offer unlimited opportunities for breeders to develop and distribute superior types for home and commercial planting. Much progress has already been made and new research programs are being instituted in countries which have heterofore paid little attentions to this crop.

LIMITATIONS

1. Slow early growth requiring weeding first 4-8 weeks.
2. Inefficiency of nitrogen-fixation by prevalent soil rhizobia.
3. Total transfer of nitrogen to plant, enriching soil only by shed leaves and flowers.
4. Susceptibility to frost.
5. Sensitivity to shade.
6. Susceptibility to wilt and rust diseases.
7. Susceptibility to seed-borne fungi decreasing seed quality.
8. Susceptibility to pod borers.
9. Late maturity of many types.
10. Labor intensive crop; continuous fruiting habit requiring repeated harvestings.
11. Indeterminate habit of many cultivars.
12. Low yield compared to cereal crops.

13. Difficult manual opening of immature pods.
14. Long cooking time of immature and mature seeds.
15. Deficiencies in amino acids.
16. Consumption and market limited to areas where the pigeon pea is already an accepted food (or to people from those areas who have migrated elsewhere).
17. As forage crop, short life (susceptibility to grazing damage and decline after multiple cuttings).
18. Total annual clearing of field to avoid carry-over of pest and diseases.

STEPS TOWARD OVERCOMING LIMITATIONS (based on existent knowledge)

1. Use of pre-emergence herbicides. Compare costs with alternative of plastic or paper mulch, apparently not yet applied to pigeon pea culture.
2. Matching of effective *Rhizobium* strains to pigeon pea cultivars to enhance nodulation and nitrogen fixation.
3. Determining appropriate fertilizer formula (low nitrogen, high phosphorus, moderate sulphur, plus trace elements) for maximum nitrogen fixation, good plant growth and high seed yield in low fertility soils.
4. Selection of early-maturing types and determining best planting date to avoid frost in subtropical areas.
5. Informing farmers of profitable intercropping systems and of yield reduction by unfavorable intercrops.
6. Selection of cultivars resistant to rust and wilt.
7. Timely harvesting of seed for planting to avoid fungus invasion of seed.
8. Development of cultivars resistant to pod borers (such as LASIBA of Trinidad; thick-walled pod).
9. Selection and distribution of early-maturing types to shorten growing season and reduce per-day cost of production; also to permit two crops per year, except where established dietary patterns demand interplanting of late-maturing pigeon peas with tall, early-maturing intercrops.
10. Selection of cultivars with short-cropping season. Adoption of practice of harvesting at one time when majority of green pods are full (for processing plants). Develop better machinery for mechanical harvesting.
11. Development (for commercial plantings and mechanical harvesting) truly dwarf cultivars, not over 60 cm tall, with plant-to-plant variation not exceeding 15 cm, of determinate habit (pods all at top of plant).
12. Selection and distribution of prolific cultivars capable of producing high yields at high density per hectare. (Determination of maximum feasible

density beyond which yield per hectare declines.) These cultivars should have large pods containing 6 o more seeds.

13. Development of simple device for shelling immature pigeon peas.
14. Selection of cultivars with good cooking quality. Adoption of hulling and flaking process to greatly reduce cooking time of mature, dry seeds.
15. Improvement of nutritional quality through breeding and fertilization.
16. Increasing production of fresh-frozen, shelled, immature pigeon peas which should find ready acceptance in many markets where they are now totally unknown.
17. Continuation of breeding efforts (now in progress in Queensland, Australia) to develop hybrids of pigeon pea and related Atylosia grandiflora which may prove superior for forage and fodder. Consideration should be given to limitation of grazing and recovery of plant for subsequent seed production. (See single management system as tested in Australia; SOTA study page 75.)
18. Chipping stalks for mulch (only if disease and pest control adequate).

An overall aim of current research programs is to develop cultivars which are daylength insensitive, of predictable height and dates of maturity when planted at all seasons, to permit pigeon pea production in all months of the year. Early-maturing cultivars, grown as annuals, can extend pigeon pea culture into marginal dry land and poor coastal soils unfavorable for other food crops.

Essential to coordination of pigeon pea improvement programs is the expansion of FAO's TAXIR system as a universal data bank of pigeon pea genotypes, varieties, strains, lines and cultivars; and of Rhizobium strains which nodulate the pigeon pea.

An ultimate goal should be widespread availability of inoculated, pelleted seed of named cultivars of known performance and suitability for various needs and situations, in order to assure the success of both the smaller farmer and the commercial producer of pigeon peas and elevate this crop to the status it merits in the world food picture.

RESEARCH NEEDS

1. Field research needed to verify response to inoculation.
2. Field research needed to verify response to fertilizer-N.

3. Identification of developing areas which would benefit economically and/or nutritionally by pigeon pea introduction.

(4) Mungbean: Summary Statement and Recommendations

The mungbean is a nutritionally desirable and versatile legume, utilized as a cooked vegetable, a source of high-protein flour, vegetable milk, and as bean sprouts. It has potential for greatly expanded use in the world diet.

As a relative short-duration crop, it fits well as an interim planting where land might otherwise remain idle, adding to the fool supply and providing extra income. It can be grown at various seasons of the year. The domestic and foreign demand is high and wholesale and retail prices are steadily rising. There are excellent opportunities for increasing growing areas and exports.

Properly managed, yields and revenues could be greatly increased. The wide variation in plant habit and behavior offers promise for selection of strains resistant to the numerous cultural problems which are presently aggravated by neglect.

LIMITATIONS

1. Low yield. "Each year fewer Asian farmers are willing to invest in mungbeans".
2. Low pod count in high-density plantings.
3. Sensitivity to shade when intercropped.
4. Poor crop management.
5. Farmers' inadequate use or non-use of fertilizers.
6. Weak competition with weeds.
7. Susceptibility to diseases and insects, not usually recognized by farmers.
8. Farmers' inadequate use of pesticides and fungicides.
9. Non-uniform ripening and consequent high-labor requirement. (Old varieties require 3 to 6 hand harvestings; newer varieties, 2).
10. Adverse effects of early wet conditions, or late-drought stress in late-maturing varieties.
11. Tendency of some types to lodge.
12. Tendency of some types to shatter readily, requiring frequent pickings.
13. Tendency of seeds to germinate in the pods in rainy conditions.
14. Lack of adequate improved seed supply and distribution.
15. Limited availability and use of high quality inoculants.

STEPS TOWARD OVERCOMING LIMITATIONS (based on existent knowledge)

1. Breeding for high yield (high pod number per plant and large seeds).
2. Breeding for short plant stature and upright growth to permit high density per hectare.
3. Screening for shade-tolerance (for intercropping with tall crops).
4. Introduction of effective cropping system patterns.
5. Education of farmers in effective fertilization practices.
6. Selection for good competition against weeds and promotion of early weed control.
7. Selection for disease - and pest - resistance and education of farmers in recognition of serious diseases and major pests.
8. Encouragement of farmers to use best means of disease - and pest - control.
9. Selection for uniform maturity to reduce hand-harvest labor requirement.
10. Selection for tolerance of early wet conditions, and for early maturity--less than 65 days.
11. Selection for non-lodging types to facilitate harvesting.
12. Selection for non-shattering types to reduce number of harvests and losses from delayed harvesting.
13. Selection for early seed dormancy to avoid germination in the pod.
14. Increasing the availability of seed of improved cultivars.
15. Development of programs to encourage local production of high-quality *Rhizobium* inoculants and encouragement of farmers to use them.

RESEARCH NEEDS

1. Investigation of molybdenum and other minor-element levels in soils of mungbean-producting areas.
2. Determination of best tillage methods.
3. Determination of best planting methods; depth of planting and seeding rates.
4. Determination of best plant density for maximum yield.
5. Determination of value of rice straw mulch vs. plastic mulch (effects on pests, diseases and rat invasions; volume needed; costs vs. benefits).
6. Determination of best planting time vs. coincidence of pest and diseases.
7. Study of growth stages in relation to excess soil water.
8. Study of climatic conditions, including solar radiation, conducive to high yield.
9. Recommendations as to management and harvesting of rice crop to best accommodate succeeding mungbean crop.

10. Selection of effective Rhizobium strains and matching of Rhizobium strains to selected strains of mungbean.
11. Evaluation of response of mungbean to Rhizobium inoculation.

b. Laboratory Studies

During the first year of the grant, a functional laboratory for research concerning BNF in tropical legumes was installed and equipped. Further development of this laboratory facility was continued well into the second grant year. During this period valuable contributions to the laboratory were made by Dr. R. Stewart Smith of the INTSOY project. Although the laboratory is now in a fully functional state, continued utilization will require continuing financial support and commitment.

During 1978 laboratory work included a long-term Rhizobium longevity experiment. This experiment included both cowpea and soybean rhizobia in peat, soil, and coir-dust carriers and was executed in cooperation with the INTSOY project. The remainder of laboratory work for the year was devoted to collecting analytical data such as plant mass, nodule mass, nodule number, % protein, % N, and yields for a series of four field experiments which were designed to show the need for and response to Rhizobium inoculation of bean (P. vulgaris) in Puerto Rico. Analytical data were developed using procedures developed in the BNF laboratory by personnel trained in the course of the grant. Actual data are not presented in the report but details of the Rhizobium longevity experiment are reported in a paper entitled "Longevity of Cowpea and Soybean Rhizobium Strains in Peat, Soil, and Coir-based Legume Inoculants" which was presented at the Reunion Latinoamericana Sobre Rhizobium in October 1978. Although approximately one year of work will be required to complete the study, results indicate that coir-dust carriers may provide better Rhizobium longevity than the traditional peat carriers. A certain amount of effort was directed toward preservation of all our laboratory strains of rhizobia on beads. UPR now maintain, on beads, a collection of approximately 30 strains of Rhizobium.

c. Greenhouse Studies

Because of difficulties encountered in overcoming excessively high temperatures, greenhouse work was kept to a minimum. Although last year's modifications of the greenhouse sufficiently lowered the ambient temperature so that nodulation tests

involving cowpea strains could be done at any time of the year, efforts at greenhouse work were limited to strain selection and inoculant evaluation.

d. Field Work

During 1977 and 1978, five field experiments were conducted to evaluate response to Rhizobium inoculation of field bean (P. vulgaris). Discussion of field results in this report will be limited to the two experiments finished during 1978.

Experiment 1 was performed at the Isabela Substation using standard cultural practices. Experiment 2 was identical with the exception that bagasse (10 tons dry weight per acre) was incorporated into the soil prior to planting to immobilize residual soil nitrogen. Both experiments were inoculated at approximately the same rate which was equivalent to 1.48×10^{10} viable rhizobia per plot as liquid soil inoculant plus 8.9×10^{12} rhizobia per plot pelletted to the seed with gum arabic sticker.

In both experiments, Rhizobium inoculation lead to increased nodule number and dry weight. In the second experiment, inoculation lead to increased plant weight. Yield, and percent protein were increased by inoculation in the first experiment. Yield results for the second experiment have not yet been statistically analized.

B. Information Capability

To increase the information capability of CST relative to soil resources, characterization data and profile descriptions for 31 key soils of Brazil generated by the grant were made available for entry into the Soil Data Bank of the University of Hawaii. The acquisition of some 60 text and reference books, soil maps and soil survey reports enhanced the information content and the number of critical holdings in the departmental library.

Information capability was further expressed through communications via the CST Newsletter and technical presentations at professional meetings.

C. Advisory Capacity

UPR's advisory capacity has been further increased during the grant extension

by the recruitment of two new staff members. They are Dr. R. Guerrero, a soil scientist with more than twenty years experience in the tropics, and Dr. R. E. Smith, a microbiologist with a background in the inoculant industry. Through their involvement in grant activities, they acquired new knowledge and a proper perspective of LDC problems in relevant areas of BNF and soil classification. Upon termination of the grant, Dr. Guerrero was retained by UPR as a staff member of the Department of Agronomy and Soils. Unfortunately, Dr. Smith resigned to return to private industry. However, efforts are being made to fill the vacant position.

Advisory capacity in the area of BNF was developed during the first year of the grant extension and then made available to LDC's. Output under advisory capacity was limited during 1978, but significant new contacts were developed in Mexico and Panama. As a result of these contacts, a replicated field experiment concerning need for inoculation on commercial plantings of pigeon pea has been established in Panama. This work represents a joint effort between UPR grant personnel and the Universidad de Panama. It is anticipated that this initial effort may be greatly expanded in the future.

D. Education, Training, and Research Capacity

The installation of a functional soil microbiology laboratory marks a significant improvement of institutional research capacity at UPR's Mayaguez Campus. Prior to this grant extension, such facilities were not available. Through the presence of the BNF research facility, UPR was able to offer laboratory and office space to support the INTSOY microbiology program for BNF in soybean.

During the both years of the grant extension, the BNF project has helped support the thesis work graduate students by supplying laboratory space, technical assistance, and funds for laboratory and field experiments concerning inoculation response in field beans.

Regarding curriculum development, Dr. Smith prepared an undergraduate course in soil microbiology. The course is entitled "Experimental Soil Ecology" and emphasizes isolation and experimentation with microorganisms active in carbon, nitrogen and sulfur cycles in soils, antibiosis, and pesticide degradation. The course was announced for the second semester of the 1978/79 academic year

and met with considerable student interest. The offering had to be suspended, however, due to Dr. Smith's resignation but will be taught when a replacement has been recruited.

E. Linkages and Networks

The linkages with the sister universities of CST have been further strengthened through cooperative efforts. Cornell University and the University of Hawaii assisted UPR by providing mineralogical and soil climatological data for the Brazil workshop. Conversely, Dr. R. Guerrero participated in and presented a paper at the Soil Resource Inventory Workshop organized by Cornell University.

In the area of BNF, the University of Hawaii collaborated with UPR by running current awareness literature searches. Both Cornell University and North Carolina State University offered the use of their library facilities for completion of UPR's SOTA studies. BNF workers at all CST universities were involved in the review of the SOTA study manuscripts.

During the second year of the grant extension the subcontract with the Morton Collectanea, University of Miami was brought to fruition with the release of four SOTA study reports co-authored by Dr. Julia Morton of the University of Miami and Dr. Roger E. Smith of UPR. This linkage with the University of Miami was extremely productive but was terminated in 1978.

UPR's excellent linkages with the Servico Nacional de Levantamento e Conservacao de Solos of EMBRAPA, Brazil and the Soil Conservation Service of the USDA were instrumental in making the international soil classification workshop in Brazil possible.

A close working relationship with the INTSOY program resulted in the locating of the INTSOY microbiologist, Dr. Stewart Smith, in the new BNF facility at UPR. This linkage has strengthened the BNF efforts of and communication between both programs.

Other linkages not involving collaborative efforts exist with numerous institutions in the US, Europe, and in developing countries. These include CIAT, ICRISAT, IITA, FAO, CSIRO (Australia), ORSTOM (France), DSIR (New Zealand), and

PCARR (Philippines). Personal contacts have been established with pedologists and microbiologists in most tropical countries.

The grant is intimately linked with UPR's Benchmark Soils Project (contract AID/ta-C-1158). Under this research contract, UPR, in collaboration with the University of Hawaii, is testing a hypothesis of agrotechnology transfer on the basis of soil taxonomic units. Grant activities in soil classification complement the Benchmark Soils Project and will facilitate the utilization of project concepts and findings.

VI. IMPACT OF GRANT-SUPPORTED ACTIVITIES IN ACHIEVING GRANT PURPOSE

A. Soil Classification

Implementation of grant activities in this area suffered considerable delay due to the fact a new staff member, Dr. R. Guerrero, could not assume his responsibilities in Puerto Rico until January 1977. Also, the response to the questionnaire survey initiated in March 1977 to gather basic information for the SOTA study was rather slow and caused delays in the preparation of the manuscript. This may be attributed, in part, to the lengthy questionnaire which required considerable effort on the part of the respondents.

With reference to university policy, it had been expected that the institution would assume 50 percent of the salary of the newly hired pedologist. However, due to a severe financial crisis afflicting UPR, this contribution did only materialize in July 1977. Similarly, the grant program director who spent 25 percent of his time on the grant was to be supported by UPR but has been paid by the grant. This resulted in reduced funds available for the soil classification component of the grant.

B. Biological Nitrogen Fixation

Contrary to the soil classification part of the grant, which is utilization-oriented, the BNF component has as a major purpose the development of institutional response capability. It is felt that the accomplishments reported above constitute good progress toward this end.

The establishment of a BNF research laboratory through acquisition of equipment and materials will now allow investigations in many areas of BNF and soil microbiology. This research capacity can be more fully explored as the grant moves into the utilization mode.

It is anticipated that the grant will ultimately influence UPR's teaching program through creation of student interest in biological nitrogen fixation and also through provision of laboratory space, library resources, and faculty for offering new courses in soil microbiology. The current grant has already supported the thesis research of two graduate students.

Grant funds have also been used to provide travel support for staff members which has substantially broadened the professional experience and perspective of the faculty. The grant has further promoted establishment of contacts with scientists from CST universities and abroad which have resulted in establishment of new functional working relationships. An example of such a relationship is the subcontract with the University of Miami for the purpose of completing certain parts of UPR's SOTA studies. Since initiation of the grant, dialogue with both domestic and foreign scientists has increased.

VII. OTHER SOURCES FOR GRANT-RELATED ACTIVITIES

As a direct contribution to the grant program, the University of Puerto Rico provided 50 percent of the salary of the soil microbiologist and, for some time, of the pedologist although both devoted all of their time to the grant. UPR also payed the salary of a technician who worked full-time in the BNF laboratory and greenhouses. UPR further provides the grant with office, laboratory and greenhouse space. In addition, the grant carries no overhead cost which constitutes an indirect UPR support of the grant program.

The BNF laboratory benefited from the INTSOY program by mutual sharing of costly equipment. It would be difficult to place a dollar value on such support but substantial savings through sharing of equipment occurred regularly. In addition, the INTSOY microbiologist had a certain amount of funds earmarked for laboratory equipment and supplies some of which were spent in direct or indirect

support of the grant program.

VIII. UTILIZATION OF INSTITUTIONAL RESPONSE CAPABILITIES IN DEVELOPMENT PROGRAMS

During the grant extension no requests for assistance in development programs were received.

IX. INVOLVEMENT OF MINORITY PERSONNEL AND WOMEN

In addition to two female secretaries, the grant employed Mrs. Aida L. Mendez de Vargas as an Assistant Microbiologist. A total of six US citizens considered as Spanish-Americans participated in the grant program, they are Puerto Ricans of varied ethnic extraction. The grant further employed two expatriates.

Table I

Distribution of 211(d) Grant Funds and Contributions from Other Sources of Funding*

Reporting Period: 1 July 1976 to 31 January 1979

Grant Objectives/ Outputs	211(d) Expenditures			Non-211(d) Funding**
	1 Jul 76-30 Jun 77	1 Jul 77-31 Jan 79	Total	
Expanded Knowledge Base	83,400	151,900	235,300	128,800
Information Capability	1,400	1,500	2,900	
Education and Research Capacity	15,700	18,500	34,200	
Linkages and Networks	13,100	14,500	27,600	
TOTAL	113,600	186,400	300,000	128, 000

* These figures are our best estimates

**Overhead costs (60% of salaries), 50% of salary of microbiologist (30 months), 50% of salary of pedologist (7 months), 100% of salary of laboratory aid (10 months), and corresponding fringe benefits

Table II - A

Summary 211(d) Expenditure Report

Institutional Grant # AID/csd-2857

Reporting Period: 1 July 1976 to 31 January 1977

Line Item	Expenditures 1 Jul 76- 30 Jun 77	Expenditures 1 Jul 77- 31 Jan 79	Total
Salaries	44,338.00	105,809.91	150,147.91
Consultants	-	990.00	990.00
Fringe Benefits	3,081.06	13,070.14 *)	16,151.20 *)
Travel	46,588.74	23,836.19 *)	70,424.93 *)
Equipment	4,357.72	9,544.64	13,902.36
Material, Supplies and Services	4,275.75	18,241.34 *)	22,517.09 *)
Library	828.74	1,145.27 *)	1,974.01 *)
Publication Costs	106.00	3,786.50 *)	3,892.50 *)
Subcontracts	10,000.00	10,000.00	20,000.00
TOTAL	113,576.01	186,423.99	300,000.00

*) includes firm obligations

Table II - B

211(d) Expenditure Report
Reporting Year Detail
Institutional Grant # AID/csd-2857
Reporting Period: 1 July 1977 to 31 January 1979

I. Salaries and Allowances

A. Professional Salaries

Name	% of Time	Man-Months	Amount
F. H. Beinroth	25	4.75	9,411.11
H. E. Flores Merino	50	1.00	720.00
R. Guerrero	100	19.00	28,213.00
A. L. Méndez Vargas	100	19.00	18,145.00
R. E. Smith	100	18.50	17,195.00
J. A. Vega López	50	7.00	5,600.00

B. Clerical Salaries

Name	% of Time	Man-Months	Amount
S. Padilla	100	19.00	8,000.00
L. M. Vélez	100	19.00	11,780.00

C. Nonprofessional Salaries

Name	% of Time	Man-Months	Amount
R. García	25	4.75	1,300.00
M. Rivera	100	19.00	5,445.80

D. Fringe Benefits 13,070.14

II. Student Support -None-

III. Consultants

H. Eswaran, soil micromorphologist 750.00
R. T. Sherwin, editor 240.00

IV. Travel

	No. of Trips	Amount
A. Travel in Puerto Rico	-	557.94
B. Domestic Travel	10	7,645.96
C. International Travel	7	14,241.79
D. Consultant Travel	1	1,390.50

V. Equipment 9,544.64

VI. Library Aquisitions 1,145.27

VII. Publication Costs 3,786.50

VIII. Subcontracts 10,000.00

IX. Other

A. Materials & Supplies 15,467.61

B. Communication Costs 2,722.38

C. Freight Charges 51.35

TOTAL 186,423.99

PUBLICATIONS

The following publications and manuscripts have been generated with full or partial support from the grant.

Abrams, R., L. Cruz Pérez, R. Pietri, and F. J. Juliá, 1974. The influence of different levels of N, P, K, Mg, Ca, and Si on yield of tomatoes in an Oxisol. Proceedings 22nd Annual Meeting Amer. Soc. Hort. Sci., Trop. Region (in press).

Badillo Feliciano, J., R. Abrams and R. Pietri Oms, 1976: Effect of foliar-applied fertilizers on pigeon peas (Cajanus cajan). J. Agr. Univ. Puerto Rico. (Submitted for publication).

Beinroth, F. H., 1972. The Natural Environment of Puerto Rico. Univ. Puerto Rico, CAAM, Agronomy Dept., 30 pp. (mimeo).

Beinroth, F. H., 1972. Field Guide to the Soils of Puerto Rico. Univ. Puerto Rico, CAAM, Agronomy Dept., 120 pp. (mimeo).

Beinroth, F. H. and V. A. Snyder, 1973. General pedology of tropical savannas. Proc. 1st Int. Symp. on Soils of Trop. Savannas, Santo Domingo, D. R.; Prairie View A & M University, Prairie View, Texas, pp. 20-38.

Beinroth, F. H., 1973. Oxisols - Highly weathered, red soils of the tropics. In: Soils of the Southern States and Puerto Rico. S. W. Buol, editor. South Coop. Ser. Bull. No. 174, North Carolina State University Press, pp. 87-91.

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Beinroth, F. H., 1976. Soil classification and the transfer of agrotechnology. AID Soil and Water Management Workshop, Washington, D. C.

Beinroth, F. H. and G. L. Spain, 1977. Clasificación de suelos y la transferencia de experiencia en el manejo de suelos. Suelos Equatoriales, VIII, No. 1: 401-405.

Beinroth, F. H., 1977. Some general aspects of soil formation in the tropics. In: Teaching Introductory Soil Science (R. E. Green and H. Ikawa, eds.). Hawaii Agr. Exp. Sta., Misc. Publ. 169, pp. 51-62.

Beinroth, F. H., 1978. Some fundamentals of soil classification. In: Soil-Resource Data for Agricultural Development (L. D. Swindale, ed.). Hawaii Agr. Exp. Sta., pp. 12-19.

Beinroth, F. H., 1979. A study of highly weathered soils of Puerto Rico. Part I: Formation, morphology and classification. Geoderma (in press).

Beinroth, F. H., 1979. Some considerations on soil classification and Soil Taxonomy in particular. Proc. Workshop on Experimental Design. Univ. Hawaii Agr. Exp. Sta. (in press).

Daniels, R. B., F. H. Beinroth, L. H. Rivera, and R. B. Grossman, 1979. Landscape and soils in an area of east-central Puerto Rico. U. S. Dept. Agr., Soil Cons. Serv., Soil Survey Inv. Report (in press).

Eswaran, H., A. Van Wambeke and F. H. Beinroth, 1979. A study of highly weathered soils of Puerto Rico; micromorphological properties. Pedologie (in press).

Fassbender, H. W. and F. H. Beinroth, 1975. Bodenentwicklung und Eigenschaften von Ultisolen und Oxisolen von Puerto Rico. Proc. Tropentagung Deutsche Bodenkundl. Ges.

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Jordan Molero, J. E., 1973. Effect of different levels of nitrogen and potassium, population density and planting time on the production of Brassica oleracea, var. capitata L. M. S. thesis, Agronomy Dept., Univ. Puerto Rico, Mayaguez, P. R.

Name Tuñon, B., 1976. Correlation of the soil units of the FAO/UNESCO Legend with taxa of the U. S. Taxonomy. M. S. thesis, Agronomy Dept., Univ. Puerto Rico, Mayaguez, P. R.

Pietri Oms, R., 1973. Changing pattern in land use. Paper presented at Soils Workshop, Prairie View A & M Univ. (mimeo, 42 pp).

Smith, R. E., R. S. Smith, A. M. Vargas, and M. Z. Alameda, 1978. Longevity of cowpea and soybean Rhizobium strains in peat, soil, and coir-based legume inoculants. Paper presented at the 9th Latin American Meeting on Rhizobium, Mexico, D. F.

Smith, R. S., M. A. Ellis and R. E. Smith, 1978. Effect of Rhizobium japonicum inoculation rates on nodulation establishment in a tropical soil. Paper presented at 1978 Annual Meeting of the American Society of Agronomy.

Silva, J. A., and F. H. Beinroth, 1975. Report of the Workshop on Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs. Hawaii Agr. Exp. Sta., Univ. Hawaii, Departmental Paper 26, 50 pp.