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A STRATEGY FOR DEVELOPING AND IMPLEMENTING SUSTAINABLE AGRICULTURAL STRATEGIES IN DEVELOPING COUNTRIES

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ABBREVIATIONS AND ACRONYMS

ACCES	Research on Access to Land, Water and Natural Resources
AFS	Agricultural Focus Statement
A.I.D.	Agency for International Development
AMIS	Agricultural Marketing Improvement Strategies
APAP	Agricultural Policy Analysis Project
BIFAD	Board for International Food and Agricultural Development
CBDP	Conservation of Biological Diversity Project
CGIAR	Consultative Group for International Research
CID	Consortium for International Development
CRP	Collaborative Research Program
CRSP	Collaborative Research Support Program
DESFIL	Development Strategies for Fragile Lands
FAO	Food and Agriculture Organization of the United Nations
F/FRED	Forestry/Fuelwood Research and Development Project
FENR	Office of Forestry, Environment, and Natural Resources, Science Technology Bureau
FRMP	Forest Resources Management Project
FSA	Food Security in Africa
FNRD	Forestry, Natural Resources, and Rural Development
IARC	International Agricultural Research Center
S&T/AGR	Office of Agriculture of the Bureau of Science and Technology
S&T/RD	Office of Rural and Institutional Development, Bureau of Science and Technology
SWAN	Soil and Water Agricultural Network

TAC	Technical Advisory Committee of the CGIAR
WRI	World Resources Institute

EXECUTIVE SUMMARY

. INTRODUCTION

The Mission of S&T/Agriculture

The Agricultural Mission of the Bureau for Science and Technology (S&T/AGR) is to support activities which will increase food production, maintain the natural resource base, and increase incomes in developing countries. As part of this portfolio, the S&T/AGR has the responsibility of supporting research which will improve agriculture in developing countries and providing technical assistance in agriculture to country missions.

The Office has made significant contributions to these aims through its support of a wide range of research projects and CRSPs that have provided commodity and process research in terms of food production, as well as maintenance of natural resources and economic policy analyses which provide support for the Missions. However, there has been a declining budget for agricultural research in real terms, at a time when there is both great pressure for increased food production in the shorter term and a long-term concern for the environment.

The E.T. York Review of S&T/AGR

To address its needs, in 1988 S&T/AGR commissioned a review of its activities by a Committee consisting of Professor E. T. York, Dr. Nigel Smith, and Dr. Roger Fox. The Report of this Committee reviewed trends in world agriculture, rates of population and economic growth, the use of natural resources, and future agricultural needs.

Their Report included recommendations for an appropriate mix of adaptive, applied, strategic, and basic research. It made some criticisms of the overall current organization of the Bureau and its Offices, and although it recommended that the Office pay more attention to degrading natural resources and sustainable agriculture, overall it recommended a continued emphasis on existing commodity and process research, as well as increased financial support for the International Agricultural Research Centers (IARCs) and Collaborative Research Support Programs (CRSPs). It did recommend greater emphasis on vegetables, perennial tree crops, non-food crops, agroforestry, animal agriculture, and aquaculture.

The Report did not emphasize the needs for more interdisciplinary research within and between S&T/AGR and the other S&T Offices and between the Divisions in S&T/AGR. Although it recommended far more attention to sustainable agriculture, the report did not address this issue in detail or make any major recommendations on how this should be done.

Terms of Reference of the Present Review

After review of the York Report, S&T/AGR commissioned a further review of its portfolio, with special reference to sustainable agriculture, maintenance of natural resources, and utilization of marginal lands. A new Committee set up to address these issues was asked to review the literature and to address natural resource management for sustainable agriculture, systems and interdisciplinary approaches to research, opportunities and mechanisms for conducting such research, and the Office's comparative advantages for conducting research into sustainable agriculture, and to make organizational recommendations on how such a program should be set up. This Report is the outcome of that review.

The Concept of Sustainable Agriculture

There have been major successes in South and Southeast Asia in increasing crop yields by the introduction of new high-yielding crop varieties and use of inorganic fertilizers and pesticides which have potential for other areas. However, there is a general perception that agriculture in developing countries is not able to respond to current needs for increased food production, at least partially due to degradation of natural resources--soil erosion, water contamination, deforestation, and desertification. Improved agricultural sustainability, combined with protection of natural resources, is needed to support the rapidly increasing populations in developing countries. At the heart of this concept is the preservation and improvement of fragile tropical soils by adoption of crop production practices that use on-farm resources and biological processes to provide plant nutrients; production systems which respond to low inputs; and integrated pest management for pest, disease, and weed control. There is a need for integrated, lower-input sustainable farming systems that account for interactions between inputs. Such systems apply not only to the poorer lands, but also to prime lands. It is important that these important resources are not allowed to degrade further if we are to provide sufficient food for increased populations in developing countries.

Agricultural sustainability is concerned not only with environmental and ecological issues, but also with economic and social sustainability. The **environmental and ecological principles** of sustainable agricultural systems include use of practices which involve decreases in soil erosion, biological improvement of soil fertility, maximum utilization of plant and animal residues, innovative cultural practices, maintenance of ecological diversity, and combination of crop and animal production. Synthetic chemicals are used only as a supplement to these practices. The **economic and sociological principles** involve adoption of only those practices which are profitable and meet the needs of farm families as well as the community, are resilient enough to ensure rural survival in adverse periods, and produce crops and animals suitable for local markets.

Definitions of Sustainable Agriculture

The various definitions of sustainable agriculture all involve:

adequate economic returns to farmers,

* indefinite maintenance of natural resources and productivity,
* minimization of adverse environmental impacts,
* optimization of production with use of minimal external inputs,
* satisfaction of human needs for food and income, and
* provision for the social needs of farmers and their families.

In other words, they maintain environmental, ecological, economic, and social stability and sustainability.

Inputs into Sustainable Agriculture

Sustainable agriculture systems require combinations of biological, cultural, economic, ecological, and social inputs. They should:

a) Maintain soil fertility and structure, minimize soil erosion, and decrease environmental contamination by combinations of practices such as rotations, polyculture, alley cropping, intercropping, legume rotations, live and dead mulches, agroforestry, animal manures, plant composts, conservation tillage, terracing, and environmentally sound use of inorganic fertilizers and pesticides.

b) Improve economic sustainability and farm income by replacing expensive chemical inputs with biological and cultural inputs, using crop varieties that respond to low inputs, and responding to local market demands and structures.

c) Promote ecological stability by maintaining ecological diversity, diversified and mixed farming systems, and preserving genetic bases.

d) Maintain sociological stability by providing full employment for farm families; providing living space, food and fuel; and promoting commodity support, marketing outlets, and land management.

There are economic reasons why an over-dependency upon chemical inputs may not be sustainable in the long term. These include rising costs of petroleum-based products, possible limited future availability of such products, creation of new pest and disease problems, and development of resistance to pesticides.

ENVIRONMENTAL AND ECOLOGICAL ASPECTS OF SUSTAINABLE AGRICULTURE

The world's natural resource base is deteriorating rapidly as a result of deforestation, soil erosion, water pollution, food contamination, and loss of ecological

diversity. Seven million hectares of land are lost annually and another 20 million degraded to the point of becoming unprofitable. The environment and productive potential in developing countries is degrading so rapidly that there must be a sense of urgency in adopting measures such as sustainable agriculture that will halt this process.

Issues involved include:

Deforestation, due to harvesting wood for fuel, provision of pasture for animal production, and a variety of other purposes, is resulting in loss of 12 to 21 million hectares of forest annually. Another major contribution is the type of "shifting agriculture" common in many developing countries, where the bush is cleared for production of crops for one to three years before fertility falls to an unprofitable level and there is regrowth of the bush.

Soil erosion is occurring at an average of seven tons per hectare per year, with a global loss of soils of up to 25 billion tons annually. This is due to deforestation and heavy cultivation of steeply sloping marginal lands. These soil losses impact not only on soil fertility, but also cause siltation of aquatic resources. They can be minimized by conservation tillage, agroforestry, alley cropping, use of mulches, terracing, and contour planting.

Loss of stability is due to shifting agricultural production in developing countries which were sustainable in the short-term, but are becoming unsustainable in the long term because of increasing population pressures, and inadequate fallowing periods. Additionally, land is degraded by cultivation of steeply sloping land, overstocking and overgrazing with animals, and inappropriate land clearing and use.

Utilization of biological inputs to soils can greatly improve the productivity of marginal soils through use of legumes and other crop rotations, adoption of practices that increase the input of organic matter into soils, use of animal manures, and a variety of cultural and cropping practices.

Promotion of ecological diversity can increase the stability and productivity of marginal lands. Increases in plant diversity improve nutrient cycling and conservation and promote biological control of diseases, pests, and weeds. Increases in animal diversity improve food utilization and productivity.

Minimization of water pollution by agricultural chemicals can be achieved by adoption of sustainable agricultural practices. These chemicals reach water through runoff, careless use of chemicals, improper disposal of their containers, and chemical application to rice paddies. Practices that minimize soil erosion are also effective in decreasing pollution of water by agricultural pesticides.

Maintenance of fish stocks, both freshwater and marine, helps to protect this valuable, renewable source of protein and income. Productivity and the overall stock size are both threatened by overfishing, water pollution, changes in species composition, and destruction of fish habitat.

Effects of agrochemicals on human health can be an important issue since many pesticides have a high mammalian toxicity and there is poor labelling of products, inadequate training and education of applicators, and little use of protective clothing causing many accidents to occur--they are often fatal.

ECONOMIC AND SOCIAL ASPECTS OF SUSTAINABLE AGRICULTURE

Sustainable agriculture can succeed only if it is profitable and provides adequate income for farm families. It is process-oriented with a long-term perspective of sustainability based on maintenance of natural resources, whereas poor farmers operate mainly on a short-term time scale.

The **resource user or farmer** responds to short-term needs and has adopted production systems that spread risks between seasons but do not usually address long-term sustainability. He/she needs policy-based support and/or subsidies to adopt sustainable practices, as well as education in appropriate practices before it becomes economically feasible for him/her to adopt such practices.

There are **opportunities and constraints** in adoption of sustainable agricultural practices. There may be conflicts between national policies and long-term sustainability. Economic analyses of sustainable agricultural systems may need to be designed for particular regions to assess the opportunities and constraints necessary to obtain maximum benefits.

The **availability of non-renewable resources** can influence the economic success of sustainable agricultural systems. Some non-renewable resources, such as fossil fuels, have clear economic limitations on their use and a limited availability in time. Soils have less clearly defined economic value and can be renewed only slowly, if at all. Biological or genetic diversity of plants and animals is not usually thought of as a non-renewable resource but from an economic aspect it is. Although it is difficult to place a long-term value on non-renewable resources, such values must be taken into account in the adoption of sustainable practices and systems.

The **maintenance of renewable resources** is important in economic terms. Biological resources such as fish, animals, plants, and forests are renewable in the long term. When sustainable agricultural systems are suggested they should be considered in terms of their effects on these renewable resources. Although soils are usually managed as if they were non-renewable resources, in the longer term they are renewable when suitable management practices are adopted. The long-term economic impact of sustainable agricultural systems is an essential factor in the adoption of such management systems.

Macroeconomics and international trade can affect the adoption of sustainable agricultural systems. International market forces exert pressures on resource use that

may not be sustainable. International demand can place artificial value on certain products or foods that may justify their incorporation into unsustainable agricultural systems. National governments should examine what they can do to implement economic policies that promote sustainable patterns of use of domestic natural resources.

RESEARCH NEEDS FOR THE PROMOTION OF SUSTAINABLE AGRICULTURE

Research literature on sustainable agriculture has expanded rapidly over the past 10 to 15 years. More scientific papers have been published on sustainable agriculture in the past three years than in the preceding 15 years. There have been a number of reviews, books, and compilations on sustainable agriculture in both developed and developing countries.

The key question is: What kind of research is needed and how can S&T/AGR provide relevant research and technical assistance support to countries, Missions, and national institutions? Field-level sustainable agriculture projects in developing countries need the following types of research support and technical assistance:

- component-level research on commodities and processes;
- systems research on integrated crop, livestock, and fish production systems;
- methodology and dissemination technologies; and
- information management systems that allow explicit consideration of resource management trade-offs.

Component research has been well covered by past and present S&T/AGR projects on commodities and processes. More emphasis is needed on conservation tillage, biological inputs to soil fertility, agroforestry, alley cropping and strip cropping, weed control, integrated pest management, and crop breeding through genetic engineering (especially breeding drought-tolerant crops and disease-resistant livestock).

Sustainable systems research and development must be based on a conceptual framework that includes both ecological, environmental, and socioeconomic factors. It also depends upon the development of simulation models that can identify constraints and gaps in knowledge. The methodology adopted by a multidisciplinary team will depend on regional requirements; therefore, all site-specific environmental, ecological, and socioeconomic aspects must be integrated. The development of more sustainable systems will require consideration of physical, climatic, biological, economic, and social inputs and will have to be based on suitable cropping patterns, integrated with animal and fish production where appropriate. Macroeconomic and biophysical factors should also be incorporated in the design of such systems.

Production systems research is essential to the final design of regional sustainable agricultural systems. There are considerable amounts of production system-level research but it is often difficult to access. Cropping, livestock, and fish production systems research is being conducted by many institutions in different countries. An inventory of which institutions are doing production systems research suitable for different regions and climates is needed.

The **development of sustainable systems** is a step-wise process. A qualitative description of the current resource use system is the first step, followed by a quantitative analysis of the components and interactions within this system. This should be followed by the design of alternative systems which must be evaluated in terms of both short-term economic viability and long-term sustainability.

Information management is the final stage and critical to the successful implementation of any sustainable agricultural system. There must also be information links between farmers and fishermen and local organizations, and back from farmers and fishermen to the design team. The information management system must allow for the explicit consideration of resource management trade-offs, such as a balance between short-term production and long-term resource maintenance.

THE CURRENT S&T/AGR PORTFOLIO

A thorough analysis of the **Current S&T/AGR portfolio** reveals excellent breadth and depth in component, commodity, and process research which have made major contributions to productivity in tropical agriculture. However, there is definitely potential for more cross-fertilization between the many high-quality projects running in parallel.

If a bold new initiative, organization, and leadership could be set up to promote and enhance interdisciplinary collaboration and foster initiative to conserve natural resources and better utilize functioning of natural ecosystem processes, an impressive Office program in sustainable agriculture could be developed.

Such a **program** should (i) identify local, national, and regional problems and constraints to productivity and environmental sustainability; (ii) encourage collaboration among U.S. scientists, their developing country counterparts, and local farmers in the implementation of sustainable agriculture; (iii) initiate additional component research on commodities and processes where appropriate; (iv) integrate the biological, social, ecological, and agricultural components into sustainable agricultural systems through interdisciplinary research and systems analysis during project design, implementation, and evaluation; and (v) provide a mechanism for dissemination of information.

Research and development in current **S&T/AGR projects** include many of the required components for sustainable agriculture. These focus on improvement of crop and animal production and associated cultural practices, pest management, soil and water management, fisheries, aquaculture, and agricultural policy. In particular, the Soil and Water Agricultural Network (SWAN) and the Trop Soils CRSP are interdisciplinary in nature, although Trop Soils has no inputs from ecologists or social scientists.

Collaboration is common in S&T/AGR within projects, which involve more than 500 scientists from more than 40 countries. Several projects have multidisciplinary components, but few span the range of biological, ecological, economic, and social sciences, and collaboration between projects is rare.

The results of S&T/AGR projects are currently disseminated efficiently through formal networks and informal links between collaborators. Additionally, an interactive information network would be needed in a sustainable agriculture program. This would provide feedback between the design teams and the regional users of the systems.

Of the 33 projects in the S&T/AGR portfolio, many are useful and a number are of considerable importance to sustainable agriculture. These involve utilization of legumes in cropping systems, biotechnology, integrated pest management, soil moisture management, biological nitrogen fixation, pond dynamics, and aquaculture. The Agricultural Policy Analysis Project could also play an important role in a sustainable agriculture program.

There is also great potential for collaboration with other S&T Offices, particularly in agroforestry, protection of natural resources, and agricultural marketing. The considerable resources and expertise in other S&T Offices should be used in a sustainable agriculture program.

ORGANIZATIONAL RECOMMENDATIONS FOR S&T/AGR IN MEETING FUTURE SUSTAINABLE AGRICULTURE RESEARCH CHALLENGES

There is considerable scope for increased **Inter-Directorate interactions**, particularly between the Office of Agriculture (Directorate of Food and Agriculture), Office of Forestry, Environment, and Natural Resources (Directorate of Energy and Natural Resources), and the Office of Rural Development (Directorate of Human Resources), all of which could make major contributions to a sustainable agriculture program as well as avoid duplication and redundancy of their efforts.

Inter-Divisional cross-disciplinary interactions between the three Divisions within S&T/AGR Agricultural Production, Renewable Resources Management, and Economic Policy are as effective as necessary for a good interdisciplinary sustainable agriculture program. This could be improved by incorporating projects in the three Divisions into interdisciplinary technology elements. Alternatively, many of the groups of projects identified in these terms could be formally linked as interdisciplinary programs, each with a leader who would facilitate the interactions essential to sustainable agriculture.

The Office support organization could be reviewed in the light of suggestions made to the Committee by the staff of S&T/AGR. These include more funding for travel for general service staff to visit projects, provision of short-term planning facilities, longer-term staff appointments, improved communications, increased secretarial support, a Directory of world contacts, more conference rooms, and a better information system.

Staff recruitment is needed in certain key areas for a sustainable agriculture program. These include:

(i) an **overall leader for the Sustainable Agriculture Program**, and permanent positions for:
(ii) an **agroecologist,**
(iii) a **systems analyst,**
(iv) **a sociologist/anthropologist,**
(v) an **integrated pest management expert**, and
(vi) a **natural resource economist.**

It would be difficult to run an efficient sustainable agriculture program without at least the first three of these positions. The overall leader could have expertise in any of the key overall areas.

New projects should be considered for certain subjects critical to a sustainable agriculture program. These include **conservation tillage, biological inputs to soil fertility, agroforestry, alley cropping and strip cropping, weed control, integrated pest management, crop breeding through genetic engineering** (including drought resistance), and **post-harvest technology**. If they cannot be set up in the near future as individual projects, they should be incorporated into existing projects since they are all essential to a sustainable agriculture program. Funding could be through reallocations or based on money from the Congressional earmarks for sustainable agriculture.

ORGANIZATION OF A PROGRAM IN SUSTAINABLE AGRICULTURE

The operating procedures and organization of S&T/AGR will need considerable change to implement a sustainable agriculture program. Decisions will be necessary on the extent to which recommended new projects are implemented as part of the overall Office portfolio, and it will also be needed to decide how far the other Directorates will be involved in the sustainable agriculture program. The Divisions should be reviewed to assess whether their current structure is appropriate to a sustainable agriculture program, and, if not, what modifications are needed. New staff appointments are recommended so decisions on which Division(s) they will be attached to will be needed. They should be linked together in a functional group.

Options are discussed for the Organization of the proposed Sustainable Agriculture Program. These include:

* A Sustainable Agriculture Secretariat within S&T Agriculture

  Such a Secretariat would be easy to organize and inexpensive but could be seen as a poor response to the Congress directive and might not be very effective.

* **A Sustainable Agriculture Secretariat outside S&T/AGR**

  Such a Secretariat could access projects in all three S&T Offices but would depend upon continued support by these Offices for long-term viability.

* **A Sustainable Agriculture Program within S&T/AGR**

  This would be a high-profile response to the Congressional directive but might be administratively complicated and slow to implement.

* **A Sustainable Agriculture CRSP within S&T/AGR**

  This would be more complex than existing CRSPs and would have to perform a linking role. It would be a clear response to Congress, easy to administer, and would utilize available funds effectively.

* **A Sustainable Agriculture Center within the Science and Technology Bureau**

  It would be a high-profile response with a primary advantage in that it would combine activities between the three S&T Offices and have independent funds and direct links to the Missions and regional Bureaus. It could be administratively complex and slow to develop.

Each of these options has different advantages and disadvantages associated with it. After considering these in detail, and the current structure of the Science and Technology Bureau and the Office of Agriculture, the Committee decided that their preferred option is for either a new sustainable agriculture CRSP or a Center (or Program). A Sustainable Agriculture Secretariat, either within or outside S&T/AGR, would probably not be effective in creating the types of activities and changes needed to promote sustainable agriculture.

A Sustainable Agriculture CRSP (or Program) has the advantages that all of the present CRSPs have demonstrated: a long-term commitment to research, active collaborators in the U.S. and abroad, the potential for high-quality work, and a very efficient use of funds. However, since sustainable agriculture must be multidisciplinary and embody a systems approach, the traditional scale CRSP would be over-stretched to supervise all of the components. A possible solution is the creation of a super-CRSP that would have an enhanced level of annual funding and a modified structure. In some ways this becomes a de-facto Center, our other preferred option.

A Sustainable Agriculture Center would have the funds and administrative authority to overcome the inherent weaknesses of a Secretariat and would promote projects across the three Offices. As a Center it could provide funding to existing projects and establish new ones. It could operate on both Congressional earmarks and funds made available through S&T/AGR program consolidation.

A Center would add another layer of administration, but this may be the price of having the power to actually effect the required changes. As a super CRSP, a Center could be modeled on the CRSP pattern but with an interdisciplinary team, larger numbers of project officers, staff, and financial inputs from the other Science and Technology Offices (especially FENR and RD).

The creation of a super-CRSP or Center would require major changes. It could, however, build on the existing resources, staff and projects in S&T/AGR and also draw in the other S&T offices (and maybe even Regional Bureaus). A super-CRSP would probably be cheaper and could be based on experience with existing CRSPs. Suitable experience to contribute to such a super-CRSP exists at five U.S. Universities, and many others could contribute in different ways.

The Committee also recommends the establishment of **several interdisciplinary collaborative research sites**. Each site should represent a major agroecological zone and be staffed by an interdisciplinary team of scientists to include at least one social scientist, one ecologist, and one agronomic scientist. Three sites are suggested initially, one in **humid tropical forests**, one in **semi-arid lands**, and one in an **intensive rice producing area.** These are critical zones which require immediate attention as their natural resources and productivity are declining.

Thus, the overall recommendation of the Committee is to create a CRSP, Center, or Program on Sustainable Agriculture that should be independent of the present Divisions (Figure 5) in order to facilitate inter-Divisional cooperation. Since setting up such a Program may take as long as two to three years it might be preferable to adopt a step-wise procedure and set up initially a Secretariat or SWAN-like interdisciplinary activity. This could serve as a planning mechanism to assemble the diversity of expertise that will be necessary to ensure that the Program functions in a truly interdisciplinary manner. Both the interim Secretariat and eventual Program would report directly to the Director of S&T, AGR and have a separate funding line.

Whatever form the sustainable agriculture program finally takes it should reserve significant financial resources to co-sponsor collaborative projects at the interdisciplinary research sites with other S&T/AGR projects and contractors. These funds could be distributed under the guidance of a peer review mechanism to assure that projects funded are those most relevant to the purpose of developing integrated management systems and technology. The on-site staff should devote a portion of its time to facilitating such projects.

In the final analysis, S&T/AGR or the three Offices in the S&T Bureau must adopt one of these options if they wish to be seen as responsive to the various recommendations and directives they have received from Congress, BIFAD, and other sources. Any administrative upheaval caused will be balanced by the attraction of additional funding during a time of declining budgets. Our final recommendation is that the S&T Bureau and S&T/AGR adopt one of the suggestions that we have made and ensure that adequate funding is made available to develop a significant move in the overall Portfolio towards sustainable agriculture. This is an extremely urgent issue since

the environment and productive potential in developing countries is degrading rapidly. Clearly, S&T/AGR, and the capacity that it has built into its current portfolio, are an excellent foundation for a rapid response to this urgent problem, if it is willing to review this portfolio urgently and take steps to implement some form of sustainable agriculture program.

CHAPTER I

INTRODUCTION

The Office of Agriculture of the Bureau of Science and Technology (S&T/AGR) in the Agency for International Development (A.I.D.) has two primary responsibilities: to support research to benefit and improve developing country agriculture and to provide technical assistance to country Missions.

S&T/AGR has been very successful in both of these areas. It has supervised a large number of well-focused research projects which have made very significant contributions to agriculture in developing countries, not only in terms of food production, but also in economic policy analysis and maintenance of natural resources.

Over the last few years, however, S&T/AGR's budget for agricultural research has declined, while pressure for additional food production has grown in response to increasing human populations and deteriorating natural resources.

S&T/AGR is examining its agenda to assess whether its current research portfolio is appropriate to support its responsibilities of agricultural improvement in developing countries and to address pressures to adopt a research strategy to promote a more sustainable agriculture. Several developments have led to A.I.D.'s interest in sustainable agriculture. The Agricultural Focus Statement emphasized the importance of maintaining renewable natural resources as a foundation for agricultural development. The environmental and university communities have increased pressure upon A.I.D. to make sustainable agriculture integral to its program. Within A.I.D. there is a growing concern to be responsive to these interests, and A.I.D.'s professional staff in agriculture, natural resources and rural development have repeatedly expressed the need for a comprehensive program to provide leadership in this important area where the U.S. has the capability to make a significant contribution. BIFAD published a report entitled "Strategies for Sustainable Agriculture." The report of the House Appropriations Committee directed A.I.D. to consider providing no less than $10 million over three years for a new program in sustainable agriculture and natural resource management. It also recommended provision of an additional $5 million in FY 1990 to increase the scope of current S&T/AGR projects to address issues of sustainable agriculture. This self review of S&T/AGR's portfolio was in response to recommendations from BIFAD (BIFAD, 1988a) and the Committee on Agricultural Sustainability for Developing Countries, as well as S&T/AGR's own comments and discussions on the rapid degradation of natural resources in the tropics and its need to respond to these issues. In a review of S&T/AGR's portfolio at a Conference "Agricultural Development. Today and Tomorrow" (A.I.D., 1988b), it was recommended that agricultural sustainability be given top priority by S&T/AGR. The Conference also recommended that research on agricultural sustainability reflect the site-specific nature of different agroecological environments, consider the needs and foci of different agricultural and national development strategies, and give attention to the knowledge/data gaps which exist in diverse technical as well as non-technical areas, such as institution building, policy issues, and human resource development.

A. Review of the E.T. York Report - S&T/AGR; Research Strategy for the 1990s

In 1988, S&T/AGR contracted with the Consortium for International Development to assemble a Committee to review present and future agricultural research needs in developing countries and suggest how S&T/AGR might best address them. The Committee was headed by Professor E.T. York, Vice Chancellor of the University of Florida, and included Dr. Roger Fox, Professor of Agricultural Economics of the University of Arizona, and Dr. Nigel Smith, Professor of Geography, University of Florida. This Committee produced a Report in February 1989 which provided a review of the historical aspects and future trends in worldwide agriculture and agricultural research and A.I.D.'s role in promoting agriculture in developing countries.

This Report recommended strongly that A.I.D. address the issue of their declining financial support for agricultural research. It reviewed thoroughly the background of general trends in world agriculture and the rates of population and economic growth and made forecasts for agricultural production into the 1990s. It also discussed the availability and use of natural resources and land, particularly in developing countries. It considered the main constraints to accelerated agricultural development to be:

a) biological and physical, in terms of lack of suitable genetic resources, lack of suitable soils, poor water quality and availability, adverse climatic factors, and serious pest and disease problems;

b) institutional and political, in terms of low priority given to agricultural development, economic policies unfavorable to agriculture, inadequate infrastructure, lack of markets, unsuitable financial institutions, problems with land tenure, and poor research and extension, and;

c) human, in terms of training, skills, health, and support institutions.

The York Report summarized the overall agricultural research program conducted by A.I.D., through CGIARs, other IARCs, and S&T/AGR projects, and the amount of funding provided through these institutions and sources. It recommended that commodity research on staple food crops still receive major emphasis by S&T/AGR, through its own projects and through the CRSPs it administered.

In reviewing the kinds of research that are appropriate to improving agricultural production in developing countries, the Report defined four kinds of research: (i) adaptive research, (ii) applied research, (iii) strategic research, and (iv) basic research. An appropriate mix of these research methods was recommended.

The York Report questioned the organizational structure within the Bureau of Science and Technology, particularly the separation of Forestry, Natural Resources, and Rural Development from Agricultural Production and Policy work. For example, there are programs in Agriculture, Natural Resources, Forestry, and Human Nutrition in three

different Directorates and four separate Offices. A further constraint is that the U.S. Congress often earmarks research funds in the Bureau for projects that the Bureau considers to be of relatively low priority. This places constraints on the development of new projects since funding is limited.

The York Report also recommended that sustainable agriculture should be a primary, overreaching priority and goal for the Agency. However, in spite of this recommendation, the Report addressed the issue of agricultural sustainability only briefly. It stated correctly that low-input approaches to agricultural production should not be considered synonymous with efforts to achieve sustainability. However, it also implied that without much greater usage of chemical inputs, increased productivity, and related sustainability, objectives in developing countries could not be achieved. It stated that the low-input approaches being advocated by some offered no panacea for the growing demands for agricultural products in many developing countries.

The York Report's major conclusions and recommendations were for a continued emphasis on existing commodity research, and increased financial support for the International Agricultural Research Center and Collaborative Research Programs, with greater research emphasis on some other commodities not currently studied, including vegetables and perennial tree crops, non-food crops, agroforestry, animal agriculture, and aquaculture. Some of these are important components of sustainable agriculture, but the Report did not emphasize the need for strong interdisciplinary research that is an important prerequisite for sustainable agriculture and sustainable development. Nor did it discuss the serious problems associated with the rapidly diminishing natural resources in the tropics in any depth.

B. The Concept of Sustainable Agriculture

There have been major successes in South and Southeast Asia and in Latin America in increasing crop yields on the better soils by the introduction of new high-yielding crop varieties and use of inorganic fertilizers and pesticides. To increase production in response to population pressures, there will be a continuing need for increased yields. There is relatively little scope for extension of cultivated areas of land; therefore, increased productivity will depend mainly upon increased yields per hectare (Table 1). It has been predicted that pesticide use will continue to increase in both prime lands and fragile soils to nearly 30 percent in all developing countries by 1993, the greatest increases occurring in Latin America (Edwards, 1977, 1986) (Table 2).

However, in both developed and developing countries there is a general perception that agricultural practices are leading to degradation of natural resources in soil erosion, water contamination, deforestation, desertification, and loss of productivity. These trends are emphasized mostly in developing countries, where soils are much poorer and more fragile, susceptible to leaching of nitrogen and fixation of phosphorus, and low in organic matter, as well as being subject to greater pest, disease, and weed problems. There is concern that the increased yields from high chemical inputs, although important in the short term, may not be sustainable in the long term in many tropical soils. Moreover,

even in the prime lands, yields are beginning to decrease, and we must ensure there is no degradation of these valuable resources.

Table 1. Expected Contributions in Production in 90 Developing Countries, 1975-2000.

	Percent Contribution to Increase		
Region	Extension of cultivated areas of land	Farming Intensity	Increased yield/ha.
Africa	27	22	51
Asia	10	14	76
Latin America	55	14	31
Middle East	6	25	69
All 90 Nations	26	14	60

Source: FAO, *Agriculture: Toward 2000* (Rome: Food and Agriculture Organization, 1981).

It must be recognized that the overwhelming majority of the poor farmers in the world are already practicing low-input agriculture without the option of applying high levels of off-farm inputs, such as pesticides and chemical fertilizers, in the foreseeable future. The role of sustainable agriculture is to greatly improve the utilization of available resources. This involves both improving technology, designing farming systems, and addressing the needs for changes in social and macroeconomic policies required to achieve real improvements in income and well-being.

Agricultural sustainability concerns environmental and ecological sustainability as well as economic and sociological sustainability (Steiner et al., 1988; Dixon and Salon, 1989). At the heart of agricultural sustainability is the preservation of soils for future long-term food production. This can be achieved for crop production on both good and fragile soils by adoption of farming practices that are in harmony with utilizing on-farm resources and biological processes to provide as much plant nutrients as possible; by breeding crops which respond to lower inputs of chemicals; and by controlling pests, diseases, and weeds by integrated chemical biological and cultural means. Such lower energy input practices can succeed only within the natural limitations of the region, climate, and soil type and must be tailored to these constraints. Moreover, they will succeed only if they are economically viable and compatible with existing social structures and cultural patterns.

Table 2. Present and future markets for pesticides in developing countries (1978-1993) (Value in $ million).

Year	*1978*		*1983*		*1988*		*1993*	
Country	*Value*	*%*	*Value*	*%*	*Value*	*%*	*Value*	*%*
Africa	115	1.4	150	1.4	240	1.8	480	2.8
Latin America	850	10.2	1,320	12.4	1,900	14.1	2,670	15.8
Middle East	175	2.1	210	2.0	260	2.0	320	1.9
Far East	650	7.9	850	8.0	1,075	8.0	1,350	8.1
Other developing countries	15	0.2	20	0.2	25	0.2	30	0.2
All developing countries	1,805	21.8	2,550	24.0	3,500	26.1	4,850	28.8
Rest of the World	6,445	78.2	8,120	70.0	10,000	73.9	12,000	71.2
Total	8,250	100.0	10,670	100.0	13,500	100.0	16,850	100.0

Source: Edwards (1986)

In addition to sustainable crop production, livestock-based systems and fisheries, both fresh and salt water, capture or captive, also need to be considered within the "sustainable agriculture" framework. Not only do many sustainable farming systems have important livestock or fishery components (e.g. pigs in China, fish ponds in Indonesia, cattle in India and Nepal) but those sectors are where some of the basic principles of sustainable resource maintenance were developed.

Marine fisheries, for example, have yielded valuable models for managing stock and flow resources over time. Marine fisheries, both demersal and pelagic, are also under considerable pressure in many locations resulting in declining fish stocks and degradation in quality of the catch (e.g. smaller average fish size and changed species composition). Land-based fish production systems or aquaculture are also part of sustainable agriculture.

Livestock, either as part of a family farm or as the focus of a major pastoral system, are also important components of the agricultural economy in many developing countries. Although we tend to concentrate on crop production systems in this Report, the philosophy and approach to sustainable agriculture is just as relevant to livestock production and aquaculture as it is for field crops. Indeed, the greatest degree of sustainability can be achieved by thorough integration of crops, livestock, and fish production into whole systems. One of the best examples of this is in Maya Farms in

the Philippines where the waste from 100,000 pigs is used for refeeding to pigs after drying, production of methane for electricity generation, feeding to ducks, producing *Tilapia* and finally adding the residues from these processes to land for crop production (Maramba, 1978).

Lower-input farming systems for crop production tend to be more diverse and complex, require a good information base, and may be more management-intensive than higher-input systems. Development of such systems carries with it a need for a good local extension capacity. The diversity adopted should include high-value horticultural crops that lend themselves to lower-input systems which can be very attractive to poorer farmers.

To achieve long-term sustainability, crop-producing farming systems that can increase net productivity must be based on:

a) Environmental and Ecological Principles

In general more sustainable farming systems should accomplish the following:

* Minimize soil erosion and maintain and improve soil fertility structure and productivity.

* Be designed to achieve the greatest efficiency in utilization of natural resources such as soil, water, sunlight, and energy.

* Make as much use as possible of biological and cultural inputs such as: nitrogen fixation, improved uptake of phosphorus through vesicular arbuscular mycorrhizae, crop rotations, agroforestry, intercropping, and biological control of pests and diseases.

* Fossil fuel-based chemicals should be used as a fully integrated complement to overall agroecosystem management. These include fertilizers, herbicides, insecticides, and fungicides.

* Maintain wherever possible, the maximum ecological diversity of microorganisms, plants, and animals in the agricultural systems.

* Combine crop and animal production wherever appropriate and possible.

These principles certainly do not imply that no external chemical inputs should be used, only that they should be used in combination with alternative methods of nutrient supply and pest control and integrated into more sustainable farming systems. Pesticides can be hazardous to human health and fisheries and cause off-site contamination of water supplies. There are a number of economic reasons why dependency upon chemical inputs may not be sustainable in the long term. These include:

* Progressively rising costs of petroleum-based products.

* Potentially limited future availability of such products. The Council of Agricultural Science and Technology (CAST, 1987) has estimated that future supplies of nitrogen, phosphorus and potassium fertilizers are sufficient for only 51, 41 and 107 years respectively.

* Creation of new pest and disease problems that necessitate continued use of pesticides due to elimination of natural enemies and antagonists.

* Increasing development of cross-linked resistance by pest organisms to insecticides, fungicides, and herbicides.

b) Economic and Sociological Principles

In general, more sustainable farming systems should:

* be profitable and meet the needs of farm families for income and provide energy for cooking and working the land;

* meet the needs of farm families for rent or purchase of the land they use;

* meet community needs and be compatible with indigenous social systems, including the role of women in farming;

* be resilient enough to ensure rural survival in times of famine, drought, poor harvests, and political disasters;

* produce marketable produce suitable for local markets; and

* use expensive chemical input only when it satisfies long-term economic criteria for sustainable productivity.

These principles are applicable to all types of farming, regional, and climatic needs. A major problem is that the poor farmer in developing countries has to respond primarily to the immediate needs for food and income and, unless they are economically viable, cannot afford the luxury of environmentally and ecologically sound practices. Hence, all aspects of sustainability, whether economic, social, ecological, or environmental, must be addressed in the development of sustainable agricultural systems.

The four major inputs into high chemical input-crop production systems are cultivations, cropping patterns, fertilizers, and pesticides. All of these inputs interact strongly with each other and with crop yields. For instance, greater crop diversity lessens needs for fertilizers and pesticides; cultivations affect pest, disease, and weed problems; and fertilizers often make crops more susceptible to pests and diseases. In lower-input

systems the main inputs are conservation tillage or no till, rotations, biological and cultural nutrient inputs, and integrated pest and disease management. These inputs interact in much the same way as the high chemical inputs. To assess the importance of these interactions it is necessary to develop an integrated crop production systems approach integrated with livestock and fish production whenever possible.

C. The Definitions of Sustainable Agriculture

The overall aims of sustainable agriculture are all-embracing and can be expressed in relatively simple terms For instance, the Brundtland Report (World Commission on Environment and Development, 1987) defined sustainability as:

> "Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs."

In an extension of this, Harwood (1987) stated that:

> "sustainable agriculture must make optimal use of the resources available to it to produce an adequate supply of goods at reasonable cost: it must meet social expectations, and it must not overly expend irreplaceable production resources."

BIFAD (1988) suggested that:

> "Sustainable agriculture should conserve and protect natural resources and allow for long-term economic growth by managing all exploited resources for sustainable yields."

The Technical Advisory Committee (TAC) of the CGIAR considered that:

> "Sustainable agriculture should involve the successful management of resources for agriculture, to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources."

The definition recently proposed for S&T/AGR (Grove, 1989) was:

> "Sustainable agriculture is a management system that provides food, income and livelihood for present and future generations and that maintains or improves the economic productivity and ecosystem services of these resources."

Edwards (1987), defined sustainable agriculture in more detail as:

"Integrated systems of agricultural production, with minimum dependence upon high inputs of energy, in the form of synthetic chemicals and cultivation, that substitute cultural and biological techniques for these inputs. They should maintain, or only slightly decrease, overall productivity and maintain or increase the net income for the farmer on a sustainable basis. They must protect the environment in terms of soil and food contamination, maintain ecological diversity and the long-term structure, fertility and productivity of soils. Finally, they must meet the social needs of farmers and their families and strengthen rural communities in a sustainable manner."

Although there are differences in emphasis, there is a clear consensus that sustainable agriculture in developing countries has implications for maintenance of environmental, ecological, economical, and sociological sustainability.

D. Inputs Into Sustainable Agriculture

Based on these definitions, we need to define inputs leading to more sustainable farming systems. These inputs should achieve the following goals:

a) Maintain Soil Fertility and Structure, Minimize Soil Erosion, and Decrease Environmental Contamination by:

* maximizing the use of on-farm resources in crop and animal production;
* using rotations, polyculture, alley cropping, and intercropping wherever possible to provide nutrients;
* growing legumes in the rotation to provide nitrogen for crops;
* improving uptake of phosphorus by plants by promoting vesicular-arbuscular mycorrhizal fungal activity;
* protecting soil from erosion by providing cover with live and dead mulches;
* using mixed cropping and agroforestry wherever appropriate in order to maintain ecological diversity;
* utilizing animal manures and plant composts as plant nutrient sources whenever possible;
* adopting conservation tillage practices to minimize soil erosion;

* minimizing the potential for water contamination from inorganic fertilizers and pesticides; and

* using terraces and similar cultural practices to reduce soil erosion and conserve water.

b) **Improve the Commercial Sustainability and Income of the Farmer by:**

* minimizing the use of costly fossil energy-based chemical fertilizers;

* replacing expensive pesticides, whenever possible, by cheaper biological and cultural pest disease and weed control techniques and by adopting crop varieties resistant to pests;

* using productive new crop varieties that respond to lower nutrient inputs; and

* developing local market structures and cooperative ventures.

c) **Promote Ecological Stability by:**

* utilizing as wide a range of crops as possible;

* developing more sustainable farming systems that minimize forest clearing;

* encouraging diversified and mixed farming systems that involve both crops and animals (including aquaculture); and

* preserving a wide genetic base both on-farm and in surrounding land.

d) **Maintain Sociological Sustainability by:**

* providing fuller and profitable employment for farm families, including women farmers;

* meeting the needs of farming families for living space, food, and fuel from renewable energy sources; and

* protecting the rights of indigenous groups by promoting community support, sharing systems, marketing outlets, management of community-owned land, and resources.

It is not suggested that no chemical inputs should be used in sustainable agriculture; in some situations that would invite catastrophe. In South and Southeast Asia the "Green Revolution," which depended on fertilizer and pesticide inputs combined

with new varieties, has been very successful, at least in the short-term, and has considerable potential for other developing countries (Romeiro, 1987). Nevertheless, the productivity of such systems has been limited to good soils and has been obtained at the cost of high-energy subsidies and some deterioration of soil and water resources, and may not be a major long-term answer to the pressing needs of populations in developing countries. The development of integrated sustainable farming systems on prime lands could maintain yields with lower chemical inputs and minimize degradation of natural resources. Higher inputs appear to be most effective on the better soils so it is not suggested that traditional farming practices in marginal lands be replaced with methods depending heavily on chemical inputs. Instead it is proposed that productivity be improved in these lands by combinations of the biological and cultural inputs listed above with judicious use of chemical supplements. Examples of such improvements have been given by Gliessman (1984).

Many of these lower-input, more sustainable practices need considerable research, particularly in relevant developing countries, before farming systems appropriate to different global regions can be designed and implemented.

E. Aims of the Report

In view of the York *et al.* Committee's recommendation for incorporation of a sustainable agricultural focus into the Office's research program, and after an in-Office review and discussion of its portfolio, the Office decided to solicit a supplement to the York *et al.* Report that would address the needs for research into sustainable agriculture and suggest strategies that the Office might adopt which would promote the adoption of such technologies, taking account of public concern for environmental protection, conservation of natural resources, and particularly for the provision of food and livelihood for the growing populations of poor people subsisting on marginal lands in developing countries. It was asked that the analyses of the S&T/AGR research portfolio address management of natural resources, development of sustainable agriculture systems, the promotion of interdisciplinary approaches to research, and mechanisms by which such research could be conducted. Included in the review would be a discussion of the Office's current portfolio and the Office's comparative advantages for promoting research of this kind.

To achieve this aim the Office contracted a new Committee through Tropical Research and Development, Inc., consisting of the authors of the present Report. This new Committee was specifically asked to address the following issues:

a) To review the current status of research on sustainable agricultural systems, particularly in marginal lands, and to provide a summary of the major environmental issues of sustainable agricultural development, including past and predicted trends in degradation of natural resources that result from agriculture and threaten its future productivity.

b) To review and describe future research needs and opportunities for attainment and promotion of sustainable agriculture in developing countries.

c) To discuss the role of the Office in meeting its future research challenge in sustainable agriculture, taking into account its existing comparative advantages, with a discussion of existing and additional disciplines and expertise that should be represented within the Office staff.

d) To analyze the current portfolio of S&T/AGR and its appropriateness to meeting future challenges by reviewing the York *et al.* Report referenced above, reviewing the Office Annual Plan of July 1989, and interviewing appropriate Bureau staff and especially S&T/AGR Division Chiefs and Project managers.

To respond to these requests, the Committee has reviewed research on sustainable agriculture, particularly in developing countries and marginal lands, summarized the relevant ecological, environmental, and socioeconomic issues; described research needs to promote such agricultural systems; and suggested organizational and programmatic ways in which the S&T/AGR Office can meet these needs by review of its organization, current portfolio and overall program to emphasize sustainability and promote interdisciplinary research between projects, Divisions, and Directorates.

This Report addresses all of these issues and provides detailed recommendations on how S&T/AGR's portfolio, organization, and staffing might be changed and reinforced to enable it to achieve these aims.

CHAPTER II.

ENVIRONMENTAL AND ECOLOGICAL ASPECTS OF SUSTAINABLE AGRICULTURE

As Barney pointed out in the Global 2000 Report (1980), the world's natural resource base is deteriorating rapidly. There are both social and economic causes for this (Hansen and Erbaugh, 1987), discussed in Chapter III, as well as the environmental and ecological aspects addressed here.

Rapidly expanding human populations are the root cause of increasing food and agricultural problems in many developing countries. The world population has been predicted to double from its present level of 5.2 billion to more than 10 billion in 50 to 60 years. Increased agricultural production is needed not only to feed these increased populations, but also to provide a food surplus for the increased demand resulting from higher per capita incomes and alleviation of poverty. In many developing countries, poverty and misguided domestic policies have combined to take a heavy toll on the resource base upon which future generations must depend.

Many of the current agricultural practices in developing countries contribute to and are affected by environmental degradation (Dover and Talbot, 1987). Such practices are associated with deforestation, soil erosion, water pollution, food contamination, loss of ecological diversity, and dependency upon external chemical inputs. Probably the most serious of these is soil erosion (and the need for soil conservation) (Tables 3 and 4).

It has been estimated that the productive potential of seven million hectares of land are lost annually: three million to soil erosion and four million to desertification (Dover and Talbot, 1987). Another 20 million hectares of land are degraded annually to the point of becoming unprofitable. In Africa, 10 times more plant nutrients are being removed from soils annually than are returned through inputs in the form of organic and inorganic fertilizers. It is estimated that more than one-third of the world's agricultural land is overcultivated. Even in developed countries such as the U.S., many soils are being eroded 10 to 20 times faster than they are being formed. The productivity of between one-third and one-half of irrigated land is being decreased by severe waterlogging and salinization. FAO has predicted that the total area of rainfed agriculture in developing countries will be decreased by 18 percent by the year 2000, due to soil erosion, nutrient and organic matter depletion, pollution, and deteriorating soil structure. It has been predicted that there will be a net loss of about 55 million hectares of agricultural land by the year 2000 (Dover and Talbot, 1987).

As much as 160 million hectares of degraded upland watersheds are subject to erosion and declines in crop productivity, downstream silting and flooding, and destruction of fishing grounds. As much as 1.3 billion hectares of land have been moderately or severely desertified. It has been estimated that 1.5 billion people in 63 countries experience some degree of fuelwood scarcity. As a result, many countries that have been exporters of wood now face the possibility of becoming overall importers of forest products. Between 10 and 20 percent of all plant and animal species face extinction by the year 2000. The environment and productive potential in developing countries is

Table 3. **Classification of environmental issues in Agriculture and Rural Development Projects, 1983-1986. (Figures are for percent of issues identified in projects by the region or loan type.)**

	ENVIRONMENTAL ISSUES IDENTIFIED IN WORLD BANK PROJECTS						
REGION	No. of Projects	Soil Conservation	Pollution	Pesticide Use	Waterborne Diseases	Sociai Risk	Miscellaneous Issues
East & South Africa	44	54.6	2.3	4.6	2.3	29.6	81.8
Western Africa	36	33.3	5.6	2.8	5.6	30.6	44.4
Europe, M. East N. Africa	39	35.9	2.6	7.7	7.7	25.6	56.4
Latin America/ Caribbean	38	50.0	7.9	5.3	7.9	26.3	47.4
East Asia & Pacific	46	63.0	8.7	2.2	4.4	28.2	63.0
South Asia	63	36.5	7.9	1.6	9.5	30.2	68.3
TOTAL PROJECTS	266	45.5	6.0	3.8	6.4	28.6	61.7

From: Barnes and Olivares (1988)

Table 4. Soil Erosion Threat: Losses of Rainfed Cropland.

	Potential Loss of Cropland	
Region	Million ha	%
Africa	203	16.5
South America	112	10
Southeast Asia (Near East)	176	36
Central America	40	30

Equivalent land area corresponding to decreased productivity if degradation were to go unchecked.

From: FAO (1986)

degrading so rapidly that there must be a sense of urgency in adopting measures such as sustainable agriculture that will halt this process.

Some "under-developed" countries have already "over-developed" or "over-exploited" their limited resources. A destructive cycle of cause-and-effect is developing in these countries, exacerbating and accelerating degradation of the environment. The scenario may run like this: The limited arable land available for planting crops leads to further deforestation and shorter rotation periods for regrowth. The results are low crop yields, increased erosion, and less wood production. Fuelwood is replaced by animal dung, which reduces the availability of organic fertilizer for crop production, which in turn leads to decreased agricultural productivity and eventually to the need for more cleared land. Such a cycle forces people onto more and more fragile land and complicates efforts to protect the environment and manage natural resources for sustainable yields. To meet the increased demands for food, the productivity of the land must be increased. Fertile land is limited, so both cropping intensity and yields must be increased in the marginal lands (Dudal *et al.*, 1982). The nature of these marginal lands is such that most of the needed increases in productivity will have to be obtained from better use of low inputs and good management (Table 5). The availability of land is such that most of the increased productivity will have to come from increased yield per unit area, on both good and fragile soils, rather than from bringing new land into cultivation (Dudal *et al.*, 1982; Brady, 1986) (Table 6). Treitz and Narain (1988) emphasized the dependence of increased agricultural productivity on better management of natural resources.

Table 5. Number of Countries Considered "Critical" by FAO

	Region					
	Africa	S.W. Asia	S.E. Asia	South America	Central America	TOTAL
Total countries	51	16	16	13	21	117
Population (millions)						
1975	380	136	1118	216	106	1956
2000	780	265	1937	393	215	3589
No. of Critical countries:						
1975						
Inputs**						
Low	22	15	6	—	11	54
Interm.	7	12	1	—	4	24
High	2	9	1	—	1	13
2000						
Inputs						
Low	29	15	6	—	14	64
Interm.	12	15	2	—	7	36
High	4	12	1	—	2	19

*"Critical" means that the country cannot provide adequate nutrition to its population based on FAO/WHO recommended average calorie intake, assuming that *all* cultivable land is in production.

**Inputs refer to the level of agricultural technology applied; "low" indicates no agricultural chemicals or improved seeds and no long-term conservation measures; "intermediate" implies some chemicals and improved seeds, and conservation measures and improved cropping patterns used on half the land; "high" means full use of available technologies—equivalent to Western European levels of farming.

Source: Food and Agriculture Organization, *Land, Food and People* (Rome: Food and Agriculture Organization, 1984).

Table 6. Land Use and Population (area in million ha)

	Developing Countries	Developed Countries	Total World
Land Area	7,619	5,773	13,392
Population (1979) (million)	3,117	1,218	4,335
Potentially cultivable	2,154	877	3,031
% of land area	28	12	22
Presently cultivated	784	677	1,461
% of potential	36	77	48

From: Dudal, Higgins, and Kassam (1982)

A. Deforestation

The world's tropical forests are being lost extremely rapidly. They are cleared for a variety of purposes, including production of pasture for animal farming and harvesting wood for fuel. Many of these uses are related to theoretical increased agricultural productivity after the forest has been cleared (Gregersen and McGaughey, 1987). Sometimes the forests are cleared for purely political reasons (Mahan, 1989; Binswanger, 1989).

Estimates of the amounts of tropical forests lost annually to agriculture range from 12 million hectares reported by the United Nations Environment Program (UNEP) (Tolba, 1983) to 21 million hectares (Myers, 1980), of which half is attributed to shifting agriculture.

The clearing of forests to grow crops is a traditional method of food production in tropical developing countries. This involves cutting and clearing areas of forest, usually by burning, and then growing crops for one to three years. Although nutrients are released from the organic matter by burning, much of the nitrogen is volatilized and lost in the process. After cropping for several seasons the forest is left to regenerate. The time taken for the land to regenerate is variable, but the longer the fallow period the more fertile the land when next used for crops. However, in some tropical soils

cleared for cropping, fallowing for even 15 years is insufficient for phosphorus levels to recover (Arnason, *et al.* 1982) .

Deforestation is unlikely to make any major long-term contribution to agricultural productivity, since most tropical forest soils are low in nutrients and a large proportion of the above-ground nutrients are in the tree biomass which is hauled away for timber or burned. With growing population pressures, the fallow regenerative periods in shifting agriculture decrease in length, so fertility is decreasing progressively and forests do not have time to regenerate. The side effects of deforestation include major contributions to increased drought, change from forest to grassland, eutrophication of lakes, increases in soil erosion, and nutrient run-off. Most serious is the effect on soil erosion, which may increase many times after forests are cleared. For instance, erosion rates increased from 200- to more than 5,000-fold when African forest land was cleared. (Sanchez, 1976)

B. Soil Erosion

Estimates of annual losses of soil due to erosion range from four billion tons annually in the United States to 25 billion tons globally. Quantitative data on the rates of soil erosion for different ecological environments, land uses, and farming systems are not known for most parts of the world, especially for the developing nations. It has been stated that soil erosion in Africa and South America is occurring at annual rates of about seven tons per hectare compared with 0.8 tons per hectare in Europe (Sanchez, 1976). The erosion of soils is a worldwide phenomenon. In developed countries, and in prime land in developing countries, it has been linked mainly with intensive cultivation and cropping. However, in the more fragile soils in developing tropical countries, the rapid rate of deforestation is the major factor contributing to soil erosion. Soil erosion not only affects soil fertility, but causes degradation of aquatic resources through siltation.

Sloping soils in semiarid areas are subject to serious degradation from soil erosion by running water. The effect of this erosion includes reduction of agricultural productivity and off-site harm, such as poorer water quality due to the transported soil particles. Steep slopes and soil erosion are major constraints to crop production in many areas of the tropics, and their influence is compounded where human population densities are high. However, steep slopes may be utilized successfully for crop production by a variety of cultural techniques if the soils and the climate are favorable.

Climatic conditions govern the structure and fertility of tropical soils. More than 50 percent of these soils are highly weathered and extensively leached due to rapid organic matter breakdown and poor nutrient supply from biological sources. Those at particular risk are those with more than 1200 mm of precipitation a year (Greenland and Lal, 1977).

The best soil management technology that has been developed for conservation of soil, organic matter, and decreasing erosion, is no-till, reduced, or conservation tillage. Conservation tillage or no-till, combined with the utilization of the allelopathic properties of plant residues or mulches and/or alley cropping and mulch farming, are beginning to

provide the long-sought-after means for continuous cropping of many of the shallow, fragile, and easily erodible soils in the lowland and humid tropics (Lal, 1987).

Agroforestry or social forestry can help decrease erosion on sloping land (Logan and Cooperband, 1987) through the use of trees and shrub roots, providing a physical barrier to soil movement. Another practice used in semiarid regions to increase the infiltration of water is tied-ridging, which involves planting crops on a contour ridge and then linking the ridges together with small hand-built ridges perpendicular to the contour ridge. This system creates many small reservoirs which trap water, thereby allowing it to infiltrate. Contour terraces, level terraces, contour planting, and tied-ridge systems are used in a variety of ways. Terraces or ridges constructed on the contour are frequently used in areas of lower rainfall to trap water and hold it until it infiltrates into the soil. Soil erosion is probably the major impediment to sustained agricultural production throughout the world and especially in the tropics (Logan and Cooperband, 1987).

C. Dependency On Natural Resources

More than three-quarters of the world's land surface is unsuitable for crops (Table 6). Ten percent of the land is ice-covered, 18 percent is too steep, 9 percent is too shallow soils, and 17 percent of the land is too dry to be used for arable purposes. Much of the land is too cold and has too short a growing season for cultivated crops. One-quarter of the land can support grasses and shrubs suitable for grazing, but is not suitable for cultivation or crop production. Of the 25 percent of the land with physical soil conditions favorable for crop production, more than a third is in developing countries, and worldwide, only about 40 percent of the land suitable for crop production is being used. The estimated use of potential arable land in the developing world in 1975 was only 33 percent of that available (Table 7).

Major increases in yields have been achieved on good tropical soils with high inputs of chemicals. However, one of the great challenges in tropical agriculture is to provide viable alternatives for the shifting cultivation or "slash and burn" farming systems so common in the uplands of Africa, Latin America, and Asia. Some 720 million hectares of forested areas are subject to such systems, and at least 300 million poor people subsist on these systems worldwide (Brady, 1986).

Traditional agricultural practices, such as "slash and burn" as well as bush fallow, mixed cropping, and shifting cultivation, have utilized natural resources relatively efficiently and have been compatible with the soils, climate, and environment. Unfortunately, the stability and ecological compatibility of such systems depend on continuing low human population pressure, improvement in soil structure by root growth, erosion control by covering the soil with plant litter or other kinds of mulch, a continuous canopy, contributions to nutrient supply through recycling of organic matter, availability of ash from burning, deep-rooted perennials and trees, and pest control by maintaining ecological diversity through growing a wide range of plant species. However, such practices tend to have low productivity and cannot respond readily to increased population pressures unless they are managed efficiently as whole farming systems with innovative practices added.

Table 7. Crop Production Constraints of World Land Areas

Type of Constraint	Area (m ha)	Percentage of Total
Ice covered	1,490	10
Too cold	2,235	15
Too dry	2,533	17
Too steep	2,682	18
Too shallow	1,341	9
Too wet	596	4
Too poor	745	5
Subtotal	**11,622**	**78**
Low productive	1,937	13
Medium productive	894	6
Highly productive	447	3
Subtotal	**3,278**	**22**
TOTAL	**14,900**	**100**

From: Buringh (1982)

Most soils of tropical and subtropical regions cannot be cultivated continuously under traditional, low-input farming. One to three years after clearing the bush, yields decline to a level which compels the farmer to stop cultivating his plot and allow the natural vegetation to reestablish itself. The intervals of cropping, before bush fallow is necessary, are usually brief because the stored nutrients in the soil are used rapidly, and productivity soon starts to decline. Chemical fertilizers do not seem able to replace completely the beneficial effects of forest fallow even when they are available. We still have much to learn about the ancient ecological rejuvenation processes of tropical forests. (Arnold, 1988).

Exactly how long it takes for soils to recover between crops depends upon population pressures, the availability of other land, the rate of regrowth of forest, the climate, and other factors. In general, the longer the fallow period, the more fertile the land will be when next it is cleared for crops. In Belize for example, using such traditional methods such as decade-long fallows did not restore lost phosphorus to the soil. Many farmers with plots idled for five to 15 years reported crop failures, with plants showing symptoms of phosphorus deficiency (Arnason *et al.*, 1982). In India, rice

and maize yields on lands fallowed for five to 10 years were 98 percent and 48 percent lower, respectively, than yields in plots cleared after a 30-year fallow. At least 10 years of fallow were needed to restore soil carbon, nitrogen, and humus levels after cropping (Ramakrishnan and Tokey, 1981). Several workers have indicated that methods which minimize soil movement are beneficial, whereas plowing is most harmful.

Often the clearing of land for crop production is done without adequate attention to (i) the method used in clearing, (ii) the capability of the land being cleared, or (iii) the practices which must be used to sustain its productivity once it is cleared. (Lal, 1987) Once an area is cleared, the question becomes one of how to protect the soil and keep it productive. However, if the soils are managed well and sustainable practices are incorporated into the farm system, then quite large increases in productivity can occur. In one study in Peru, the acreage needed to support a family under "slash and burn" was reduced from 60 to 5 hectares using such methods (Dover and Talbot, 1987).

The improved utilization of land resources involves correcting many current misuses (FAO, 1986) including:

* use of land for crops for which it is not suited,
* attempted cultivation of steeply sloping lands,
* overstocking and overgrazing with animals,
* complete clearing of lands which require a protective forest cover to be productive,
* excessive fuelwood removal, and
* inappropriate land clearing practices which damage the land and lower its productivity.

The ultimate challenge for land use in developing countries is to replace or improve slash-and-burn systems, which allow cropping for only one to two years every 10 or more years, with modified no-tillage multi-crop systems to enable continuous crop production to occur. Some reduced tillage systems are beginning to meet this challenge. Conservation tillage in various forms is now common, and has been traditionally practiced by subsistence farmers in the tropics without the use of herbicides.

D. Biological Inputs to Soils

To combat such loss of natural resources, a variety of the sustainable practices listed in Chapter I must be used in combination with farming systems appropriate to the needs, soils and climate in the region. There is considerable potential for regeneration of soils with careful management.

Natural ecosystems are mainly self-sustaining. Similarly the production of animals on pasture need few external inputs. However, when land is put into crop production, unless the biological inputs are carefully managed, the soils begin to deteriorate without use of inorganic supplements. This trend is accentuated in many of the fragile and easily-leached tropical soils (Edwards and Veeresh, 1981).

The severity of nutrient deficiencies and elemental toxicities in tropical soils, and the difficulty in providing commercial inorganic fertilizers for low-resource farmers, highlight the need to make maximum use of on-farm biological resources by recycling organic matter and crop rotations. A wide range of cultural practices are available to accomplish this through their influence on biological activity. Crop rotations should include legumes which can fix nitrogen, and use crops which will provide organic residues to provide nutrients when they break down. Cultural systems, such as alley cropping or strip cropping, may be used to provide organic mulches which can enhance nutrient cycling and minimize soil erosion. When livestock are a part of the whole system, crop residues may be used as an important source of the animal feed, and the animal manure can be used to partially offset fertilizer needs. Some low-income farmers who cannot afford commercial fertilizers collect leaves and other plant materials from nearby forests. Some farmers in Central America spread as much as 40 metric tons of such litter per hectare on their vegetable fields (Wilkes, 1977).

Healthy soils are aerobic and can support a large microbial biomass and diverse invertebrate fauna. It is important to maintain the biological activity of tropical soils. The critical key to this is to use cultural techniques that maintain as high a level of organic matter as possible, and cultivation practices that disturb soils as little as possible. However, the breakdown of organic matter to release nutrients essential to plant growth is rapid in such soils; moreover, in some tropical soils which cannot retain nutrients, it is often too rapid (Edwards and Veeresh, 1978).

E. Links with Ecological Diversity

It has long been claimed that since natural habitats have a greater diversity of species, they are more biologically resilient and stable. Many ecologists believe that agricultural ecosystems that have greater diversity also have greater stability. However, it is now generally accepted that this is a great oversimplification, although there may be both qualitative and quantitative benefits in diversity (Norgaard, 1987).

The implications of this conclusion for agriculture are far-reaching. A qualitative basis for stability means that agricultural ecosystems cannot be made more stable simply by increasing their complexity. Instead, the interactions that occur between the components of agroecosystems must be evaluated carefully to determine the stabilizing and destabilizing elements and to design systems accordingly.

However, there seems little doubt that farming systems involving more than one crop (in sequence, in combination, or both) and mixing crop and animal production all act towards increasing the resilience of such systems (American Society of Agronomy, 1983).

Diversity in farming systems can provide benefits in a number of ways:

* The productivity of nutrient cycles is improved, because in interplanted systems, water and nutrients are conserved by the low disturbance level and closed canopy characteristics. Minerals lost by animals and crops or left in their residues are taken up by perennial crops. In this way more organic matter is added to the soil and eventually provides nutrients. Different patterns of roots in mixed cropping can be more efficient at capturing nutrients, because they spread better both laterally and penetrate deeper (Dover and Talbot, 1987).

* Plant diversity decreases susceptibility to crop diseases and delays their rates of spread. Some plant combinations and organic matter can enhance fungistasis and antibiosis against soil-borne diseases (Sumner *et al.* 1981).

* Plant diversity and cropping mixtures can greatly decrease weed problems by providing soil cover which delays weed seed germination, by allelopathy, or the inhibition of one plant by another in other ways (Putnam and Duke, 1978).

* Plant diversity can minimize pest problems through the provision of alternative food for the pests or by providing alternative food and habitat for natural enemies. Weeds can exert these beneficial influence on pest incidence just as efficiently as crop plants (Altieri, 1987).

* Animal diversity can optimize utilization of food resources and productivity, particularly on poor soils.

In Africa, 98 percent of all cowpeas (the continent's most important legume) are grown in combination with other crops. A 1974 survey in northern Nigeria found that more than 80 percent of the cropland was planted to mixed-crop systems. In Latin America beans are grown with maize, potatoes, and other crops; this pattern accounts for 90 percent of bean production in Colombia, 73 percent in Guatemala, and 80 percent in Brazil. Maize is planted with other crops on about 60 percent of all of tropical Latin America's maize-growing area.

F. Minimization of Water Pollution

Water is essential for the survival of humans, plants, and animals, and it is often in short supply. In many parts of the tropics there is heavy seasonal rainfall, that results in massive surface runoff from soils, which can carry particulate matter from the soil surface into bodies of water. Chemicals leach readily through tropical soils at a much faster rate than through those in temperate regions, not only because of increased seasonal rainfall but also because of poor soil structure and low organic matter content. Many pesticides are adsorbed tightly on to organic matter or clay minerals and are not

readily leached under normal climate conditions. However, when there is heavy rainfall and high temperatures as is seasonally common in tropical countries the pesticides become desorbed and become mobile in soils (Edwards, 1966). For these reasons, when inorganic fertilizers and synthetic pesticides are used to increase productivity in developing countries, as in the "Green Revolution" in South and Southeast Asia, there is a much greater potential for contamination of drinking water, through leaching into soils or runoff from sloping land, than there is in temperate countries. This pollution problem is accentuated because drinking water is often taken from wells and ditches, and any form of water purification is minimal. An additional way in which water may become polluted by pesticides is through the careless disposal of pesticide containers, or residual amounts of pesticides spilled into waterways (Edwards, 1986). Moreover, many of the lakes and rivers which receive contaminated drainage or runoff water in developing countries are used for fish production, with resulting contamination of this important food source. A particular problem is when fish production is in rice paddies and pesticides are used to control pests of the rice, a practice which is common in many parts of Southeast Asia (Edwards *et al.*, 1980).

G. Maintenance of Fishstocks

Marine and freshwater fisheries are important sources of animal protein, employment, and income in many developing countries. In much of Asia, for example, fish are the largest source of animal protein in the average diet. International trade in fish, shellfish, and fish products is also large and growing. Whether at the high-value end of the market (e.g. shrimp and tuna) or at the low-value end (e.g. fishmeal for animal feed), the maintenance of fish resources is a major challenge.

In many parts of Asia and Africa, coastal fishstocks are under heavy pressure from overfishing, degrading water quality, and destruction of fish habitat. Traditional freshwater aquaculture systems are threatened by degrading water quality due to chemical runoff from agricultural fields. In some locations conversion of coastal mangroves to aquaculture ponds destroys the long-term mangrove productivity for what may be short-term benefits.

Over-fishing is a classic example of abuse of a natural resource. Driven by poverty as much as by greed, overfishing results in declining production of this valuable protein source. Improved management for more sustainable production is possible, but faces severe social and economic challenges. Integration of fish production into other components of food production should be an essential component of a sustainable agriculture program.

H. Effects of Agrochemicals on Human Health

Many pesticides, being biocides, have a high mammalian toxicity and necessitate considerable precautions in their use. Even in developed countries, there have been many instances of human mortality or side effects on humans, in spite of human precautions and the use of protective clothing during application. In hot and humid

developing countries, with less training in safe application of pesticides, these problems are greatly accentuated (Edwards, 1986).

Some of the most serious effects of pesticides result from accidental exposure to lethal or harmful doses of these chemicals. Such accidents can involve the applicator through exposure during spraying or other treatment operations. Proper protective clothing can minimize such exposure, which is mainly through the skin or by inhalation. However, carelessness in using such clothing, particularly in hot weather when it is uncomfortable, and ignorance as to the importance of such protection causes numerous poisonings to occur on a worldwide basis. In developing countries, the poisonous nature of pesticides may not be understood, protective clothing may not be available, and under tropical conditions one may not expect it to be used conscientiously. This is accentuated where pesticides may not be labelled properly or translated into the local language, and where the applicators are not adequately educated or trained. No reliable statistics exist on the incidence of pesticide poisoning, particularly in developing countries. Many affected people do not associate their illness with pesticides, and deaths often go unreported. In 1972, a WHO Expert Committee on the Safe Use of Pesticides (WHO, 1973) concluded that about half a million cases of accidental poisoning by pesticides occurred per annum. A typical example occurred in 1976 when 2,700 out of 7,500 field workers engaged in malaria control in Pakistan became poisoned by malathion and five of them died.

Other types of accident, which may involve larger numbers of people, are those due to unsafe packing and leakage of pesticides in storage or transport. On a number of occasions food has been contaminated in this way. For instance, over 6000 people in Iraq were admitted to hospitals with symptoms of food poisoning in 1971-72 and more than 500 died, due to eating bread which had been prepared from cereals treated with methyl mercury fungicide. Other accidents have occurred when insecticides that have been found to be effective against one type of pest have been incorrectly and dangerously used for treatment against others--such as bed bugs or body lice--with consequent poisoning of members of whole households. In the tropics, containers that have contained pesticide concentrates are attractive for household use; if such containers are used for carrying or cooking consumables, poisoning may occur. Aerial spraying or drifts have caused clinical effects in people in nearby areas. It is not uncommon for children to drink pesticides kept in inadequately labelled bottles or containers. Such problems are likely to continue to occur in developing countries because of inadequate applicator, education, and training both of farmers and the general public.

CHAPTER III.

ECONOMIC AND SOCIAL ASPECTS OF SUSTAINABLE AGRICULTURE

A. General Principles

Sustainable agriculture is related to both economic profitability and ecological sustainability. Farming can be based on either characteristic by itself in the short run, but sustainable agriculture requires both dimensions to be implemented to reach long-term goals. This simple statement hides the complex interactions between people (resource users), the resources they depend on, and market forces that determine how resources are used.

Sustainable agriculture is process-orientated, requiring a long-term perspective on human interaction with the land and water resource base and the plants and animals produced. Component research, into production of commodities and understanding processes, can provide the foundation of this systems but is not sufficient in itself to guarantee the long-term sustainability, for which a systems approach is needed. Any system must explicitly recognize both the economic and social dimensions for it to be successful.

The distinction between economics and sociology is somewhat artificial. Economics studies should always take social/cultural dimensions into account. Since economics is a science that tries to explain observed behavior, it must consider the cultural setting within which decisions are made as well as the influence of observable market forces. Failure to pay attention to social factors, especially in agricultural production in developing countries, frequently leads to poor economic analyses.

Economics can be called upon to serve two roles in the promotion of sustainable agriculture. Firstly, it can explain what is happening currently, why available resources are used in any given manner, and why certain technologies or approaches are adopted while others are not. Secondly, economics can be used to build on this knowledge to design policies and programs designed to change patterns of resource use and to promote desirable environmental and other changes. The first role is commonly referred to as descriptive (or positive) economics whereas the second role is the realm of prescriptive (or normative) economics. As Mishan (1981) states, normative economics implies "ought" propositions that derive ultimately from the ethics of society.

Obviously, sustainable agriculture requires both descriptive and prescriptive economics. One has to be able to understand what is occurring currently, and why it is happening, before it is possible to suggest strategies leading to a more sustainable production pattern of resource use. Both approaches go back to the individual resource user: the farmer, pastoralist, or fisherman. Without an understanding of their world and needs, it is folly to design new technology and expect quick adoption into agricultural systems.

B. The Resource User Perspective

It is essential for any attempt to promote sustainable agriculture to begin with research aimed at ecological-sociological-economic understanding of individual farming, pastoral or fishing systems. Since sustainable agriculture is a process, not an exogenous technology or practice that can be added, it must fit within the overall complexities of the existing farming system. A minor change in inputs from one component may have major impacts and implications for other components. The farmer (used here as a shorthand for farmer, pastoralist, or fisherman of either gender) is often a better source of information on these interactions and their impacts on the farming system than the outside expert or consultant. The farmer, after all, has to live with the consequences of any change that is introduced.

A few examples from Asia point out some of these initially unforeseen interactions. The new HYV rice varieties tend to have shorter, stiffer straws. This reduces lodging of the heavier grain heads, but also means reduced quantities of straw for thatch or forage and, in some countries, a need for a change in harvesting technology from the use of a small hand knife to that of the sickle. This occurred in Indonesia and had a major social impact in many rice-growing areas. Whereas traditional varieties were harvested by women using the "ani-ani" hand knife, sickle harvesting is almost entirely done by men. Moreover, groups of professional sickle harvesters now follow the harvest, displacing the local women formerly employed. Thus, a technological change (introduction of the HYV variety) has had a significant social impact that is detrimental to local women.

Another example lies in the economics of utilization of animal wastes. Where there is a shortage of fuel there may be strong social pressure to use the manure for this purpose instead of as a source of nutrients for crop production.

Increased use of fertilizers and pesticides on crops may result in contaminated irrigation return-flow or storm runoff and cause decreased fish production in on-farm and nearby waterbodies. The loss or contamination of this important source of animal protein may have important impacts on human health and cost of food. Overfishing of marine fish is an all-too-common phenomenon in many parts of the world. Growing coastal and inland populations lead to increasing demands for fish which is a low-cost source of animal protein. Degradation of fish spawning grounds and reefs leads to decreased availability of biomass. More fishermen chasing fewer fish results in declining catch per unit effort and negative changes in species composition and populations. The development of commercial trawling operation in offshore areas puts increased pressure on pelagic species.

As the spiral of over-exploitation, decreased resource stock, and increased fishing effort grows, increasingly destructive methods (e.g. blast fishing, push nets) are used to catch the remaining fish, leading to even further resource degradation. Poverty drives the short-term system and creates the environmental and resource degradation that exacerbates long-term poverty. This pattern is seen in the Gulf of Thailand demersal fishery and in coastal waters in the Philippines. There is no easy solution to this

problem since reducing the level of fishing is only possible if alternative income-producing activities for the fishermen are available. A linked terrestrial-aquatic system may offer a partial solution, since it may provide alternative forms of income.

Risk and uncertainty are another set of important factors that influence agricultural production decisions. Small farmers, especially in marginal areas and in poorer countries, have often evolved, complex production systems that spread the risks between seasons and help to avoid the calamitous results of crop failure in any one year. Several different varieties of a single crop may be grown and intercropping with other crops is very common. Farmers may be reluctant to grow new cultivars in monoculture. While this may seem to lead to inefficient patterns of use of resources, these decisions are based on knowledge of the dire personal consequences of crop failures. In some societies, those who guess wrong do not survive to the next season.

Uncertainty over property rights can also lead to resource use decisions with greater short-term returns, but major long-term costs, either to the environment or even to the farmer. Land tenure and property rights issues become very important in the introduction of perennial crops, forestry, or agroforestry systems and in the decision to undertake long-term and expensive soil conservation practices. In order to have a commitment to making long-term investments, farmers need assurance that they will be able to reap the benefits of their efforts.

A final set of socioeconomic issues revolve around poverty and short planning horizons. These issues are especially important in marginal areas. Very poor people use high implicit discount rates. Benefits or losses that are three, five, or ten years away may be totally ignored. This often results in very unsustainable patterns of agriculture or resource use. While the causes are understandable, the solutions are very difficult. Overgrazing in the Sahel, overfishing in the Philippines and deforestation in Brazil or Haiti are all examples of short-term planning causing serious economic and environmental losses in the long term.

In all instances, a thorough understanding of the systems that are used, both in terms of the component parts and how they interact, is essential to suggesting realistic alternatives to these systems. Of course, if a new technology or variety can be adopted which increases yields as much as 30 percent, with everything else unchanged, it will normally be adopted immediately. Most changes, however, are rarely so simple and are slow to be adopted.

For the farmer to adopt sustainable agricultural practices, he/she will need national policy-based support and/or subsidies, as well as education in appropriate practices, before it is economically feasible for him/her to adopt such practices.

C. Opportunities and Constraints

Economic analyses can assist in promoting sustainable practices by identifying the best opportunities for technological change and interventions, as well as potential constraints. Formal analysis of the potential profitability of new components is needed

to establish the economic as well as physical superiority of the new technology. Such work is already included in a number of existing S&T/AGR projects, as in various crop-specific CRSPs or under the Agricultural Policy Analysis Project (APAP) umbrella.

Policy analysis may be equally important in the successful transition to a more sustainable agriculture. Since sustainable agriculture is a process, it is essential to examine the policy framework within which the process must take place. Not infrequently, different units of local and national governments send conflicting signals through the policy framework. For example, terracing and soil-conserving cultivation techniques may be promoted by one unit while at the same time fertilizer subsidies may reduce the cost of agrochemicals, with their use resulting in increased erosion and increased costs for the fertilizer subsidies. An example of this occurred in Indonesia. In Brazil, policies to promote improved forest resource utilization in the Amazon conflicted with other government policies that promoted rapid land clearing in order to receive land title and government subsidies (Mahar, 1989; Binswanger, 1989). As Bromley (1983) pointed out, a policy of integrated management of renewable resources may raise more political opposition than making an investment to ameliorate symptoms of environmental degradation.

Economic analysis will not solve these policy problems. Each individual policy is usually designed for laudable purposes, even if it conflicts with other goals of the same government. A broader systems analysis should help to identify such inconsistencies and help to lead to more consistent and rational policymaking. Component-focused research is unlikely to do this by itself since it usually concentrates on a commodity or process to the exclusion of interaction with other inputs and impacts.

The way in which the S&T/AGR Office can address economic questions associated with sustainable agriculture will depend in part on what approach is taken. Program options will be discussed in Chapter VI when the final recommendations are made.

The present pattern in S&T/AGR of handling economic questions on a project by project basis may defeat its aims of promoting sustainable agriculture. Since sustainable agriculture is by definition a systems approach to rural economics, the physical linkages between projects and their economic manifestations must be considered if realistic systems are to be developed and adopted. With millions of individual decision makers involved (the farmers, pastoralists, or fishermen), only by developing component technology or policies that make economic sense, <u>within the broader system</u>, can we hope to succeed using a systems approach to identify the more important issues.

D. The Relationship of Sustainable Agriculture to Non-Renewable Resources

Most of the major increases in crop production in developing countries has been by the use of inorganic fertilizers and synthetic pesticides which are largely oil-based. Fossil fuels are finite and non-renewable with an availability of only 50-100 years into the future. Hence, sustainable agriculture cannot depend upon these non-renewable

resources in the long-term. Moreover, by its name, sustainable agriculture is designed to be a renewable process. Agriculture in general, however, is very dependent on the management of non-renewable resources, and sustainable agriculture is no exception. Whereas, inputs of sunlight and moisture are renewable daily, seasonally, or yearly, soil is virtually non-renewable within the time frame normally used for analysis. Some forms of ground water (fossil water) may also be non-renewable. There are other resources important to agriculture that are also non-renewable; of these, genetic diversity and petroleum are of particular importance.

We do not usually think of biological or genetic diversity as a non-renewable resource. However, from an economic perspective it is. Once a species becomes extinct, the time required for generation of new or equivalent species to those lost may be very long. Consequently, the growing international concern with preservation of biological diversity is, at one level, a concern with management of a finite non-renewable stock. Agriculture, of course, is very dependent on this genetic resource for the development of new products, new strains or seeds, or as a base material for sophisticated genetic engineering. Much of future productivity gains and the development of disease and pest resistance in crop varieties will come from this source. Sustainable agriculture is particularly dependent on this resource, since it is built on the principle of an integrated systems approach to production.

Although it is not possible to place monetary values on such things as genetic diversity, and attempts to place a value on the costs of soil erosion and sedimentation only capture part of the costs involved, it is generally realized that the ultimate cost of losing genetic or soil resources will be very large. This is particularly true since future production alternatives would be lost, and with it, our ability to respond to perturbations in the agriculture system.

Petroleum-derived products, notably, chemical fertilizers, pesticides, and insecticides, are all important to agriculture. Since petroleum and minerals (e.g. phosphates) are well understood to be non-renewable resources, their present and future availability or supply are reflected, although only in part, in their market prices. Immediate or potential scarcity of these materials should result in higher prices and increasing scarcity is reflected in further price increases. Governments, however, commonly subsidize the use of fertilizers and agricultural chemicals and thereby send wrong signals through the market. As a result, these inputs appear "cheap" rather than expensive. The danger is that production techniques will evolve that depend more on increasingly large doses of subsidized fertilizers and chemicals to maintain yields than on improved agricultural practices. As a result, sustainable agriculture may appear less economically attractive in comparison, when in fact, the high-input alternative is heavily subsidized, expensive to society, and non-sustainable (economically or physically) over time.

Sustainable agriculture is not synonymous with organic agriculture. There is an important role in sustainable agriculture for petroleum-based inputs, but a role that should be tempered by a recognition of the shorter-term benefits and the longer-term costs of heavily subsidized, "high-technology" agriculture. A careful economic analysis

often shows that there will be major long-term costs to high-input agriculture. In addition, as petroleum resources decline in abundance and prices of petroleum-based inputs go up, the "high-technology" option looms increasingly expensive. With current reserves of fossil fuels, the future of inorganic fertilizers may be limited to 50-100 years (CAST, 1987).

E. The Relationship of Sustainable Agriculture to Maintenance of a Stock of Renewable Resources

Since soil, and some types of groundwater, are non-renewable resources, we should also point out that it is possible to manage soil and water resources in a manner similar to the way "classic" renewable resources, such as forests or fish populations, are handled. That is, we can use the "interest" (soil formation) accruing each year without depleting the "capital" stock (existing soil) of the renewable resource.

Surface water and groundwater are both cases of potentially renewable physical resources. Their management in a sustainable manner is a key to the development of a sustainable agriculture; several of the current S&T/AGR projects deal with these issues.

Although soils are physically renewable only over long periods of natural development there is no doubt that they can be managed in a renewable manner. Many classic agricultural systems (e.g. the Nile delta, Java rice fields) have sustained agricultural production over hundreds or thousands of years. Proper water control plays an important part, both in regulating the quantity and speed of water movement, and in carrying nutrients from upstream for deposition in downstream areas. Agricultural practices, such as the use of fallow periods, mulching, and return of organic material and organic fertilizers to the soil, all make major contributions to the renewal of soil resources. Much of modern sustainable agricultural research examines these interactions and how the various components of the agricultural system interact.

A major challenge for those designing sustainable agricultural systems (whether for field or tree crops, forestry or fisheries) is to develop ways of encouraging sustainable use patterns of potentially renewable resources while still meeting short-term economic goals. Since losses of renewable resources are well-illustrated by the capital-in-the bank/yearly interest analogy, the temptation is to use some of the capital as well as the interest. One may hope to pay back the "borrowed" capital in the future, but we know that for renewable resources that may be very difficult, if not impossible to do. Nevertheless, the pressures for immediate resource development and use remain and cannot be ignored.

Economic signals are very important in influencing the patterns of resource use. In the same way that subsidizing heavily the use of non-renewable resources (chemical fertilizers and agricultural chemicals) discourages the adoption of alternative soil-conserving practices, the rape of the forestry and fishery resources in many countries is also a result of a "give away the capital" syndrome. Immediate gains are large, but long-term costs to society may be much larger.

In some cases, the incorrect signals become noticed by local or national governments and, once proper policy analysis is carried out, can be corrected. In other cases, the signals are sent by the international market and may require international realization and cooperation to correct. The subsidization of petroleum-based products in Indonesia or misallocation of forestry concessions in many Southeast Asian countries are examples of misguided national policies. The ivory trade or the European CAP-corn-cassava link that stretches from the U.S., to the EEC, to northeast Thailand are examples of undesirable global links that can be corrected only by international actions.

F. International Trade and the Macroeconomics of Sustainable Agriculture

International market forces help to create patterns of local resource uses that may or may not be sustainable. Since international agreements on such issues are difficult to reach, it may not be effective to spend too much time at the international level, rather than focus more on the forces influencing decision-making within a country. Sustainable agriculture is usually about smaller farmers and private decision-making. (There are, of course, notable exceptions such as large ranching operations in Latin America). Mahar (1989) provides an excellent discussion of the interactions between government policies, the activities of large and small entrepreneurs, and the extent of deforestation in the Amazon.

With rare exceptions, such as diminishing populations of whales and more recently the killing of elephants for ivory, the countries of the world have been very reluctant to take measures that would limit unsustainable use of resources in other countries (particularly developing countries). The appetite of developed countries for woods, fiber, and other natural products is large, and there is often little attention paid to how these products are obtained.

For instance, tropical fish may be collected from the ocean by use of various poisons, and their en route mortality to the market may be very high, but the purchasers in developed countries are unconcerned about what is left behind on the tropical reef. Similar stories apply to shells, exotic birds, tropical hardwoods or forest products.

These types of events are not new. In the last century the Chinese demand for sandalwood and the greed of Hawaiian chiefs resulted in the almost complete eradication of sandalwood from the Hawaiian Islands (still called Sandalwood Island by the Chinese).

Although international market forces are powerful, and international agreements on issues which oppose these forces difficult to obtain, this dimension should not be completely ignored. There are cases where international forces can have positive effects and where trade can be used to promote sustainable resource use. Some profitable perennial tree crops (such as coffee and rubber) provide fairly good ground cover, can reduce erosion in upland areas, and can yield a reasonable income to farmers. Policies promoting these crops may yield ecological and economic benefits in some countries.

However, it is usually best for national governments to examine what they can do to implement economic policies that promote sustainable patterns of use of domestic natural resources. When external markets can help to support such activities they should be explored and used. When external markets promote inappropriate patterns of use of resources, other policies can be used to help buffer the national economy. "Laissez-faire" systems may be efficient in one sense, but they often result in over-exploitation or resource-degradation, particularly when local populations are poor, have short planning horizons, and few alternatives.

Poverty is the greatest cause of unsustainable use of resources and, therefore, must be addressed if we are to promote more sustainable patterns of long-term resource management.

CHAPTER IV.

RESEARCH NEEDS FOR THE PROMOTION OF SUSTAINABLE AGRICULTURE

A. A Review of the Current Literature on Sustainable Agriculture

The whole concept of sustainable agriculture is relatively new. For more than a decade, consciousness of the adverse environmental effects of conventional agriculture has led to a growing public movement in developed countries, that has been directed towards promoting more sustainable agricultural practices, by finding means of decreasing chemical and other energy-based inputs into agriculture, and substituting them with biological and cultural inputs. During the last two years, these activities have increased dramatically in the U.S.A., with a number of States setting up lower input/sustainable agriculture programs and many others doing increasing amounts of relevant research. At the same time, it has been realized that although significant increases in overall yields have been achieved through the use of pesticides and fertilizers in developing countries, such techniques may have similar or even more serious environmental impacts in the long-term, and other practices are raising major long-term issues in terms of sustainability of agriculture in developing countries.

More scientific papers have been published on sustainable agriculture in the past three years than in the preceding fifteen years. The issues concerned have been discussed at length in a number of review publications published during the last five years such as those by Edens *et al.* Douglas (1984), Harvey *et al.*, (1986), CSPI, (1989), and Edwards *et al.* (1990) which summarize the concepts in developed countries and those by Dover and Talbot (1987) BIFAD (1988, 1989) A.I.D. (1989), OTA (1988), USDA (1988), World Resources Institute (1988), Southgate and Disinger (1987), Sands (1986), Javier and Renborg (1988), and Allen and Dusen (1988), all of which discuss the needs for sustainable agriculture and development in developing countries and the relevant, concepts and needs for cultural and biological research and interdisciplinary work on lower input, more sustainable farming systems.

Some publications have addressed the issues of increasing productivity in the better soils in the tropics directly (O.T.A., 1985; Rambo and Sajise, 1985, Ramakrishnan and Toky, 1981, Allen & Dusen, 1988). However, other research considered the methods of increasing productivity in the poorer more fragile soils using cultural and biological inputs and agroecological principles (Altieri, 1983; Gliessman, 1984; Lawrence *et al.*, 1984; Conway, 1984; Edens, and Koenig, 1980, Sanchez, 1983, Steiner *et al.*, 1988, Papendick *et al.*, 1988, Gow, 1987; Jayne *et al.*, 1989).

There have been reports of how fragile soils can be made to become more productive through adoption of mixed farming systems (Trenbath, 1974; Stelly, 1983; Gliessman and Armador, 1980; Sanchez, 1976; McIntosh *et al.*, 1980; Gliessman *et al.*, 1987, agroforestry (Vergara, 1981; 1982; Nair, 1982; Farrell, 1987; McGuahey, 1986; Andriesse, 1979; McDonald, 1981; Gregson and McGauhey, 1987, Behmel and Neumann, 1981), mulch farming (Wittwer, 1988; Lal, 1987), reduced tillage (Lal, 1986, 1987; Sprague and Triplett, 1986), multiple cropping (Sands, 1984; Altieri, 1987; Kang *et al.*

(1984) integrated pest management (Altieri, 1987; Risch *et al.*, 1983; Reichelderfer 1987; Andow, 1983), use of low levels of fertilizer and lime (Sanchez, 1983), and by the use of biotechnology in plant breeding (Bunders, 1988; Cohen *et al.*, 1988).

There is a considerable literature on individual examples of improved productivity on both good and marginal soils in developing countries, using practices that are appropriate to sustainable agriculture. However, these are regional in nature and rarely take a whole farming system approach, so it seems inappropriate to discuss these in detail here.

B. The Kinds of Research Needed in Sustainable Agriculture

The key question that needs to be addressed is: "what kind of new research needs to be undertaken in order to promote the development of sustainable agriculture?" We plan to identify both the general and specific research needs for an integrated program. We shall compare these research needs with the existing current portfolio of S&T/AGR and its research capabilities, and identify those research areas that need to be added to or given more emphasis. This should provide S&T/AGR with the capability to provide research and technical assistance support to Country Missions and National Institutions that are developing sustainable agricultural systems. Finally, we shall describe the different organizational options that could be implemented in order to give S&T/AGR the capability to respond effectively to demands for its services and carry out its technical assistance and research mandate, in terms of agricultural sustainability.

The approach we have taken to identify the research needs, has been to begin with some assumptions about the type of sustainable agriculture development projects that are likely to be implemented by A.I.D. Missions and national research and extension institutions. From this perspective, four basic types of research needs emerge:

* Research is needed to develop component-level technologies on commodities and processes that can make farming systems both more productive as well as more sustainable.

* Research is needed to develop integrated and sustainable crop, livestock, and fish production systems based on sound agroecological principles and taking account of all interactions between inputs.

* Research is needed on methodologies (integrated sets of optional methods and techniques) to develop and disseminate the principles of sustainable agricultural systems.

* Research is needed to develop information management systems, that include methods to analyze the complex resource management trade-off questions inherent in the development of sustainable agricultural systems.

Much more than general concepts and abstract definitions of sustainable agricultural systems are required to design and implement a research and development

process that promotes their adoption and use on a wide scale. While there is general agreement on the definitions of sustainable farming systems described in Chapter I and on the importance of the environmental, ecological, and socioeconomic aspects described in Chapters II and III, there is no agreed-upon methodology to develop and promote sustainable agricultural systems. However, there is considerable experience and methodology available for the development and promotion of many of the component technologies often associated with sustainable systems (e.g. minimum tillage, multi-species cropping systems or IPM). Also, methodologies that evolved from agroforestry research, crop/livestock systems research, and farmer-participatory research can definitely contribute to the development of a Sustainable Agriculture Research and Extension Methodology (SAREM).

C. Component Research

The need for component research on commodities or processes has always been recognized as a key requirement in international development. The commodity orientation of the CGIAR network is a response to the recognition that without new technology development, projects often become little more than well-intentioned social science studies. S&T/AGR has assembled an imposing inventory of commodity and component research, much of which is relevant to sustainable agriculture.

There is no suggestion in this Report that component and commodity research should be de-emphasized, although we stress the urgent additional need for systems research, with specific reference to Sustainable Agricultural Systems. Keys to the development of more sustainable agricultural systems are likely to be the development of more drought-tolerant varieties of crops, disease-resistant livestock, improved soil manageme[illegible] integrated pest and weed management technologies. More emphasis is also [illegible] onservation tillage, biological inputs to soil fertility, agroforestry, alley-[illegible] cropping, weed control, integrated pest management, and crop breedi[illegible] enetic engineering (especially breeding drought-resistant crops and disease[illegible] estock). Nevertheless, commodity research will remain critical to the sustainability of world agriculture, and should continue to be an important activity of S&T/AGR. Indeed, it became clear to the Committee that there is relatively little commodity research related to production of horticultural crops. Such crops fit well into sustainable production systems, and more emphasis should be considered in this area.

D. General Systems Framework

The fundamental basis of sustainable agriculture is a systems approach. Associated with this is the use of mathematical models as a means of identifying major constraints and gaps in knowledge. At an early stage, any multi-disciplinary research and extension team that attempts to develop a sustainable agriculture methodology, must first agree upon a common conceptual framework. The methodology that the committee agrees upon must include a systematic sequence of steps that, over time, will result in the development and promotion of integrated agricultural systems, that are both economically and socially viable in the short-term and ecologically viable in the long-term as being sustainable over long periods. While the conceptual framework and the methodology

adopted by a multi-disciplinary team will depend on the specific characteristic of the relevant site (including regional, physical, climatic, biological, economic, and social characteristics where they are working), the fact that both environmental, ecological and socioeconomic aspects must be integrated, suggests that the conceptual framework has to include macro-scale systems and, if it is agreed that the goal is development of more sustainable systems, the process that is agreed upon will probably follow a typical systems research process. Early in this process, some form of mathematical model should be developed in an attempt to identify key factors.

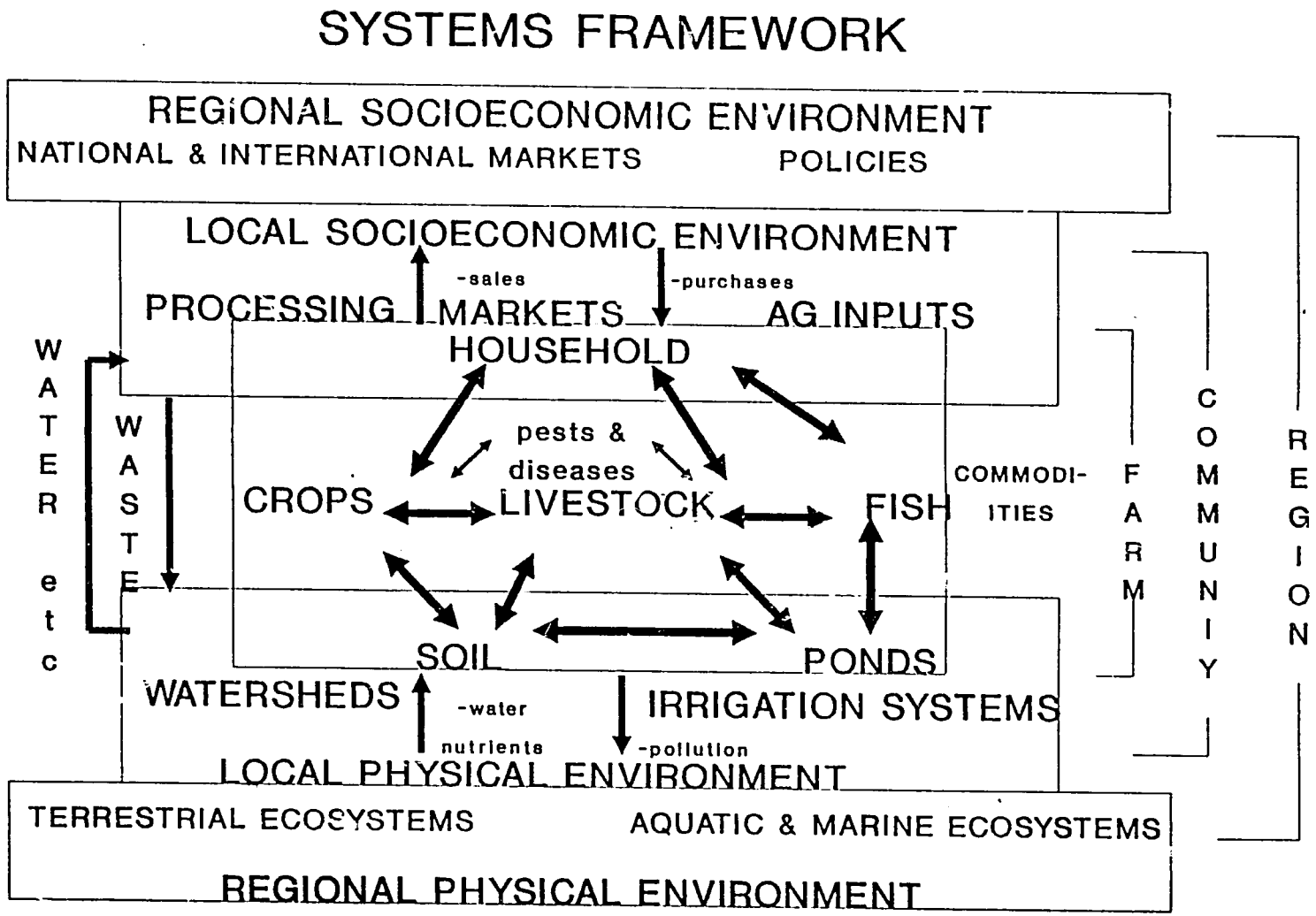
It will be immediately apparent to anyone who has been involved in Cropping Systems, Livestock Systems, or Farming Systems research that the framework and process we shall describe reflects experience with this type of multi-disciplinary systems research, except that environmental, ecological, and socioeconomic aspects, rather than only socioeconomic and short-term production aspects, have been given explicit consideration, and there is much more integration than in the earlier farming systems approach.

A general systems framework can be used by a Mission-funded A.I.D. project to develop a Sustainable Agriculture System (Hart and Sands, 1990) (Figure 1). The framework includes both ecological aspects and socioeconomic aspects. Farm households and their crop, livestock, and/or fish production systems, the key to both short-term economic survival, and long-term sustainability of agriculture, occupy the center of the framework. In such a systems framework, these farms are shown as interacting with both the local ecological,socioeconomic environment. These local systems, in turn, interact with the macro-ecological and socioeconomic environment.

If a local A.I.D. project decided to use this framework to develop a project, the first step would be to superimpose the conceptual framework over requirements of the geographic area where the project will be implemented. The committee would first define specific cropping systems, such as intercropped maize and sorghum or rice-wheat rotations; they could identify specific livestock systems such as dual-purpose goats or poultry systems; and, if they are interested in fish production they would identify suitable systems, such as *Tilapia* ponds or river fishing, that farmers are using in the region.

In addition to the local market and social institutions identified typically by most development projects as influencing the potential development opportunities of these farmers, a multi-disciplinary team implementing a sustainable agriculture project in a particularly region would also identify the characteristics and limitations of the local ecological environment--such as potential soil erosion and characteristics of the local watershed--that could effect the long-term sustainability of any alternative technology or system that is developed in the project. The framework (described in Figure 1) suggests that the committee should also consider the effect of the macro-socioeconomic environment, such as the effect of national policy on potential development alternatives and the effect of macro-ecological issues, such as potential down-stream impacts on regional productivity.

Figure 1. A general systems conceptual framework that includes local and regional socioeconomic and physical factors that influence both short-term system production and long-term resource productivity (adapted from Hart and Sands, 1990).



In the context of this general framework (Figure 1), the local multidisciplinary team that has accepted the task of developing one or more sustainable production systems for a specific region should now begin to identify its specific research needs. The needs that they are likely to identify would be of four types: (i) component or commodity research to find alternatives that can fit into farmer's present production systems; (ii) integrated production systems that account for interactions between inputs and are both more productive and more sustainable than those farmers are presently using; (iii) and a methodology composed of different component techniques that could guide them through the process of developing sustainable agricultural systems; and (iv) information management systems to help them to consider, explicitly, the resource management trade-offs related to economics vs. ecology and upstream/down-stream and inter-generational sharing of costs and benefits.

E. Production Systems Research

Although component or commodity research answers a number of critical needs, it can just as easily be a waste of resources in certain circumstances. Over the last two decades, National and International Research Centers have begun to realize that their commodity research must be linked to crop and/or livestock systems research if it is going to be cost-effective. While some international donors became disillusioned with some of the over-promised expectations of Farming Systems Research, all of the International Centers have explicitly acknowledged a need for a "farming systems perspective". On-farm research is now the norm rather than the exception for most National Research institutions.

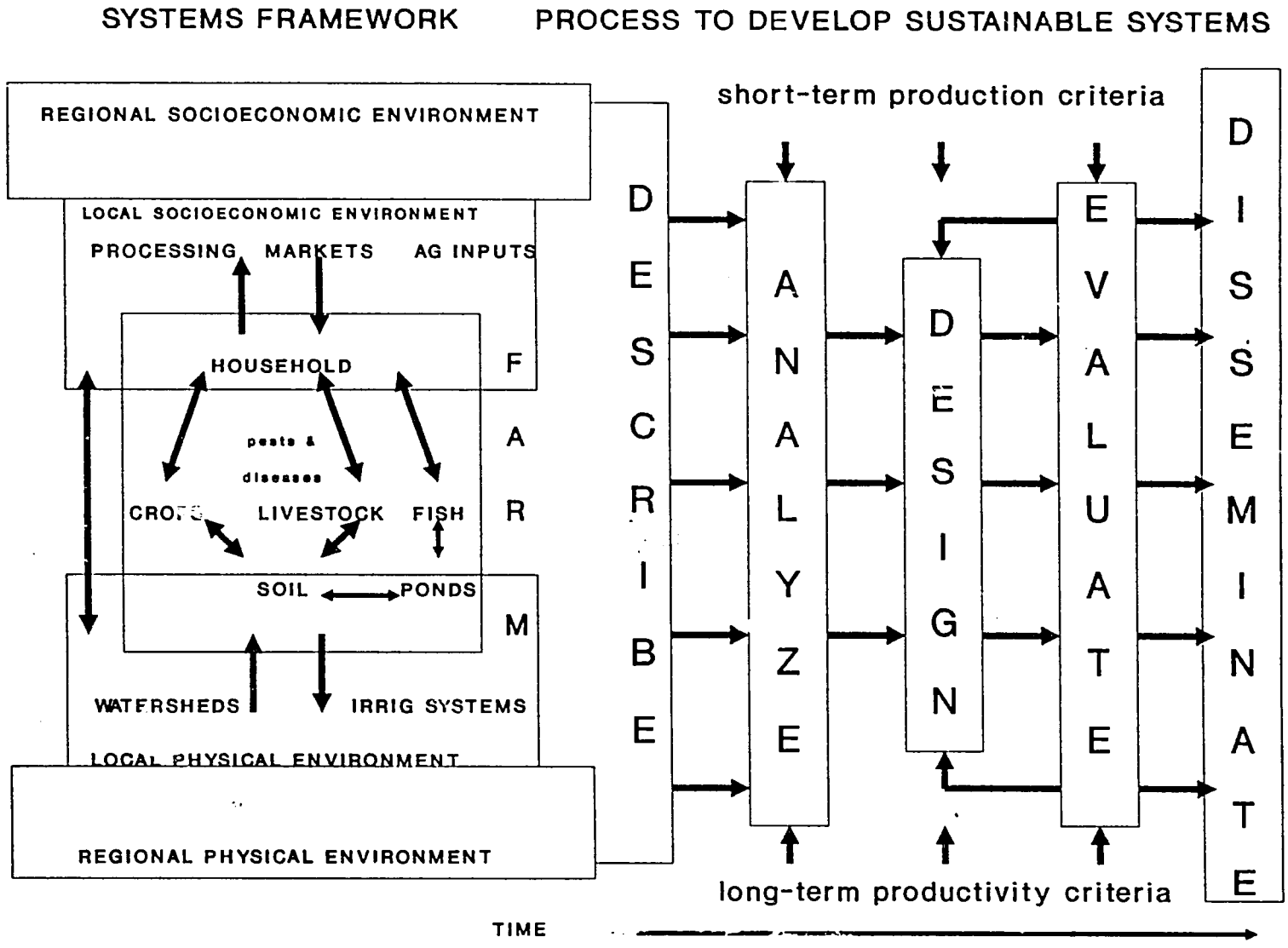
Although a few crop, livestock, and fish production systems have been studied in detail, most have not (IBSNAT, 1987). Examples of ongoing production systems research can be found at many national and international institutions. International Agriculture Research Centers such as CIAT, CATIE, and other institutions have done considerable research on intercropped maize and beans; ICRASAT and IITA have worked extensively on intercropping. IRRI and other institutions in the Asian cropping systems network have done research on rice-based rotations; ILCA and CIAT has done research on pastoral systems and other livestock production systems, and RISPAL (an IDRC-funded Latin American research network) is developing livestock production systems research.

However, most field-level development projects find it difficult to access production systems-level research results. The traditional multi-species crop, livestock, and tree production systems, that may be important starting points for the development of more sustainable production systems, have been the subject of very little research. ICRAF has made a good beginning in developing an inventory of different systems and a practical methodology that can be used by national institutions.

F. A Process to Develop Sustainable Farming Systems

A conceptual framework involves a five-step systems research and development process that can be applied to a agricultural systems framework (Figure 2). The first

Figure 2. A general research and development process that can be applied in a specific geographic area to develop more sustainable land use systems (adapted from Hart and Sands, 1990).



step is to describe the existing systems depicted in the systems framework. This first activity often begins with a qualitative description before the collection of more quantitative data. Step Two uses the quantitative information to begin the analysis of the systems and their interactions. Step Three, the design of alternatives, is a complex process, since it requires the creation of new systems that must be analyzed to predict how well they will perform with regards to both economic viability and ecological sustainability. During Step Four in the process, these predictions are tested in the real world. Alternatives that do not pass these tests return to the design phase; those that meet both the economic and ecological criteria, move to Step Five and can be disseminated to potential users.

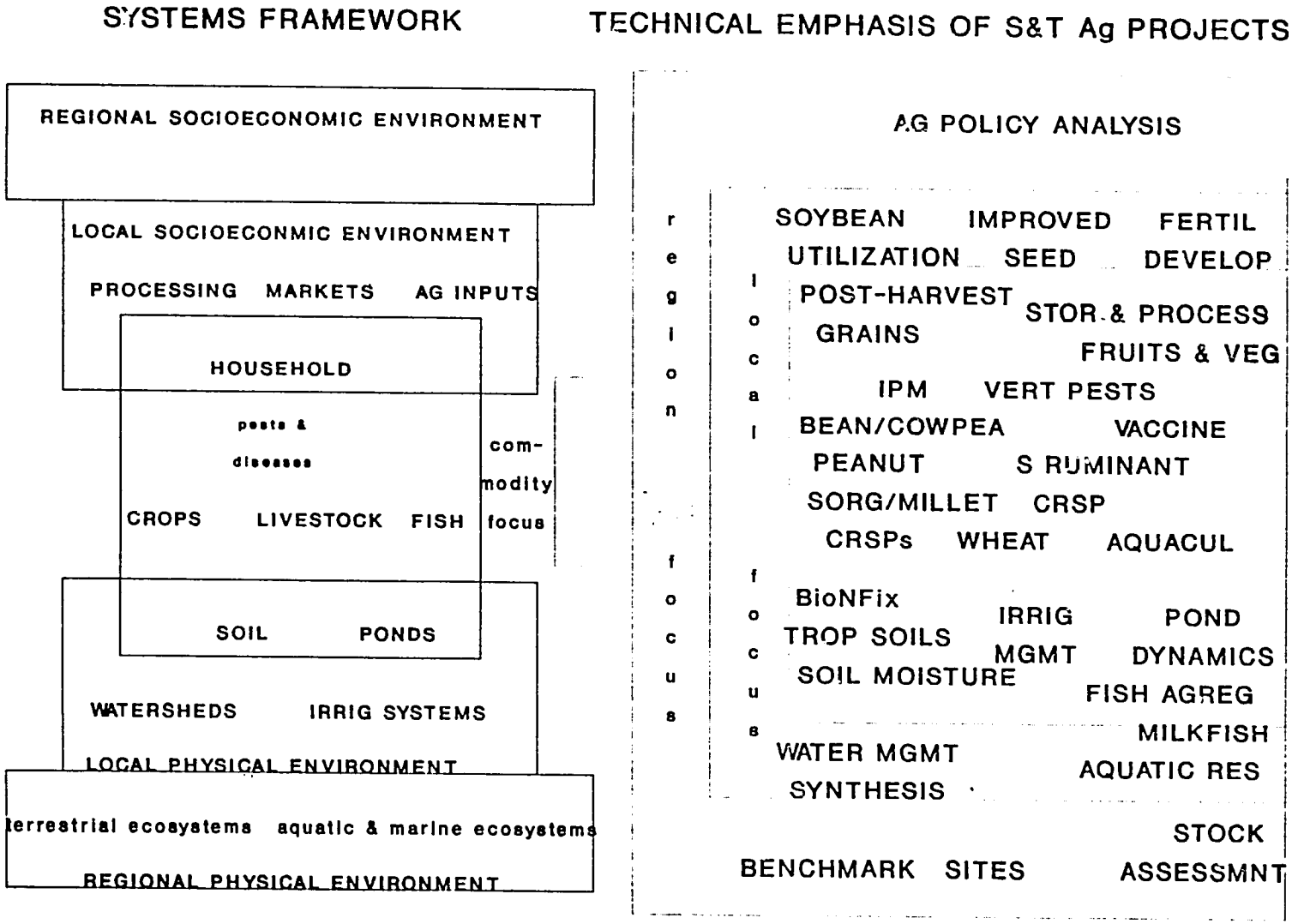
A multi-disciplinary team would probably not apply all of the steps equally to all of the systems that form the conceptual framework, The DESCRIPTION phase would probably be applied to the entire framework since qualitative information describing both farm, local, and regional systems will probably be needed. The ANALYSIS phase would probably be applied to only the farm and local socioeconomic and biophysical systems. The DESIGN phase is directed primarily at the development of alternative farming systems, although changes in the local socioeconomic system (e.g. creation of new markets or waste recycling laws) may be necessary components of some of the alternatives that will be developed. The EVALUATION phase is directed at farms and the local socioeconomic and biophysical systems that interact with the farming systems. The DISSEMINATION phase, like the preliminary description phase, is once again directed at all of the systems that form the conceptual framework.

There are several important observations that need to be made about this five-step process. The first observation is that, in the real world, few systems can be broken down into the type of simple processes and steps described above. Research and development is never as "linear" as implied in Figure 2. The reality for most projects is that alternative systems are seldom developed systematically; they are often "designed" in offices in capital cities on the basis of political expediency. But it is different to imagine how the development of Sustainable Agricultural Systems can occur without some type of systematic process similar to that described in Figure 2. Another important observation is that the process summarized in Figure 2 does not depict the roles of different people or institutions. Farmers must participate in the design phase. Extension must participate in test phase not just the dissemination phase.

G. Information Management Needs

Information management will be critical to the successful implementation of the five-step process described above. However good the technology that is developed may be, the gap between the researcher or donor and the small farmer must be bridged (Sands, 1986). The five-step, systems research and development process described above, supported by an information management system that collects and disseminate information and supports and feeds back information from the implementation process, is needed (Figure 3). A multi-disciplinary team that implements a Sustainable Agriculture Project will need some type of centralized data base, where the different types of ecological and socioeconomic information are collected, but they will also need

Figure 3. **An assessment of the technical emphasis of S&T/AGR projects that suggests that most of the components that form the systems framework depicted in Figure 1 are adequately covered by the Office's present portfolio of projects.**



to address the need for at least three types of information management processes explicitly:

* information collection, exchange, and dissemination,

* linkage between local constraints and opportunities and field station components and via integrated systems research,

* analysis of resource management trade-offs.

Information collected on site-specific projects must be analyzed and made available to the individuals and institutions in the region, that must interact in order to implement a community-level project. However, in addition to maintaining information in a user-friendly format, the information must be synthesized and analyzed so that the macro socioeconomic and biophysical systems and their impact on local production systems can be understood. This information management process should be located at or near the sites where alternative, sustainable farming systems are being developed.

A key information process is the linkage between farmers and community-level constraints and opportunities and the research designed in response to these needs. For example, if an on-farm experiment shows that yield loss due to drought is a critical concern, this information should lead to the development of research on drought-tolerant crops or better soil moisture management. When the results of this needs-driven research become available, they must be summarized and transferred to the farmers and researchers participating in the following year's on-farm research.

Another key information management process is the use of analytical tools to facilitate consideration of the trade-offs between short-term production and long-term resource productivity. Identification of economically viable alternatives for farmers is a difficult task. Moreover, when the additional criteria of ecological sustainability is factored in, the design of potential new alternatives becomes even more difficult. Local A.I.D.-funded research and development projects are likely to find the lack of analytical tools to help them analyze issues, such as up-stream benefits and down-stream costs (i.e. pesticides that economically control upper-watershed pests but negatively affects down-stream fishermen), to be a very critical problem.

CHAPTER V.

ANALYSIS OF THE CURRENT SCIENCE AND TECHNOLOGY/AGRICULTURE PORTFOLIO

A. General Comments

A thorough analysis of the current S&T/AGR portfolio, especially if those of the other Science and Technology offices are included, reveals an excellent breadth and depth in many of the individual components noted as being important to sustainable agriculture, in terms of both commodity and process research. Nevertheless, the impression the Committee received was of many worthwhile and high-quality activities running parallel, but with potential for much more cross-fertilization between them. Since sustainable agriculture is completely dependent on such cross fertilization and linkages, in an interdisciplinary integrated systems approach, the organizational and program challenge is to establish an operational pattern which can capture synergistic effects and promote linkages.

A number of developments have focussed A.I.D.'s interest in sustainable agriculture. The Agricultural Focus Statement emphasized the importance of maintaining renewable natural resources as a foundation for agricultural development. The environmental and university groups have increased pressure upon A.I.D. to make sustainable agricultural integral to its program. Within A.I.D. there is a growing concern to be responsive to these interests and pressures. The A.I.D. staff in Agriculture, Natural Resources and Rural Development have repeatedly expressed the need for a comprehensive program which will provide leadership in sustainable agriculture wherever the U.S. has the capability to make a significant contribution. BIFAD produced a report entitled "Strategies for Sustainable Agriculture" (BIFAD, 1988). The Reports of the House and Senate Appropriations Committees directed A.I.D. to consider providing no less than $10 million over three years for a new Program in Sustainable Agriculture and Natural Resource Management. It also recommends provision of an additional $5 million in FY 1990 to increase the scope of current S&T/AGR programs to address issues of sustainable agriculture such as, collaboration among developed and developing country scientists, and increased interdisciplinary interactions among the social, ecological and agricultural sciences.

To respond to these thrusts a bold new initiative and leadership is required by S&T/AGR; as part of this some form of strong new S&T/AGR program should be developed to enhance interdisciplinary collaboration, among U.S. and counterpart developing country scientists and between projects and CRSPs partially in terms of sustainable agriculture. Such collaboration will promote development of integrated sustainable farming systems and technology on both good and fragile soils that will provide food, income, and adequate livelihoods for the world's impoverished populations. These thrusts will also conserve natural resources (e.g. soil, water, and biological diversity), and facilitate functioning of ecosystem processes (e.g. recycling of nutrients, detoxification of noxious chemicals and hydrological control of watersheds), upon which lower input food production depends. Such a program has to be interdisciplinary in

nature, in order to identify and deal with the linkages among the socioeconomic, policy, and biophysical components of agricultural systems that constrain the development of sustainable systems.

Whatever form the sustainable agriculture program takes it should:

* provide capabilities to identify local, national and regional constraints in terms of productivity, equity and environmental sustainability;

* encourage collaboration among U.S. agricultural scientists, their developing country counterparts and local farmers in developing countries to enhance the capability to define constraints and to develop and apply appropriate solutions to their problems;

* promote relevant research and development on component methodologies and technologies that are the building block components of integrated systems;

* enable biological, sociological, ecological and agricultural components to be integrated through interdisciplinary research and systems analysis during design, implementation and evaluation of projects; and

* provide mechanisms for dissemination of information on such components and systems through Mission programs and professional networks.

The current portfolio of S&T/AGR Projects and CRSPs addresses many of the requirements for such a program:

* Collaboration is common <u>within</u> projects. Currently more than 500 scientists from over 40 countries are involved in S&T/AGR projects representing at least 50 Universities and Research Institutions. S&T/AGR projects collaborate with most of the International Agricultural Research Centers.

* Research and development within S&T/AGR programs encompasses many of the required agricultural components for sustainable agriculture. Programs focus on improvement of crops and animals and their cultural practices, pest management, soil and water management, fisheries and aquaculture and agricultural policy. These projects have been highly successful in increasing agricultural production, in improving U.S. and developing country capabilities in agricultural research and development, and in improving livelihoods of the poor majority in developing countries.

* Several projects have multidisciplinary components, but rarely do they span the full range of biological, ecological, social, economic sciences. An exception exists in some of the CRSPs. However, collaboration <u>between</u> projects is relatively rare. The proportion of multidisciplinary research has decreased as S&T/AGR budgets have fallen during the past several years.

There are major institutional constraints to interdisciplinary research and development within A.I.D. and the agricultural research community. Currently, S&T/AGR has two initiatives underway to enhance interdisciplinary research. There is one in Forestry, and the Soil and Water Agricultural Network Project (SWAN) is designed to develop new approaches to targeting and managing interdisciplinary research in soil and water management. However, the extent of interdisciplinary collaboration that would be needed in a new thrust in sustainable agriculture would go a long way beyond that envisaged in SWAN and be much more all-encompassing.

* The TropSoils CRSP probably has the most projects relevant to sustainable agriculture. These include low-input cropping systems for the humid tropics, legume-based pastures, and agroforestry, (Caudle, 1988). The small ruminant CRSP promotes crop and livestock systems research, including agroforestry and legume trees for feed.

* Results of S&T/AGR projects are disseminated in a number of ways. The professional collaborative nature of most projects assures the efficient dissemination of results. Several formal networks have been established in developing countries for communicating activities and results of research and development programs. Graduates of the S&T/AGR programs take with them the methodologies and knowledge that were gained within the programs and introduce it into their own country programs. Many projects contain provisions for Mission buy-ins that provide for extrapolation through mission programs.

B. The Office of Science and Technology/Agriculture Portfolio

When the various S&T/AGR projects and CRSPs are fitted against the idealized conceptual framework for an agricultural system in Figure 1, they fit well (Figure 3) and show that many of them are appropriate for a sustainable agriculture program. The current S&T/AGR portfolio is particularly strong in several areas including some selected crop component research, especially on commodities,and that of some of the long established CRSPs; and in land and to a lesser extent water research projects, especially the various soil-related projects; as well as a set of fishery-aquaculture related activities.

There are 33 projects in the current S&T/AGR portfolio (Table 8) and many of these can provide valuable inputs to a sustainable agriculture program.

The ones that are most directly relevant to sustainable agriculture, because they promote cultural and biological inputs to agricultural production include:

1. Collaborative Development of Methods to Improve Cropping Systems Through the Utilization of Soil Improving Legumes (Project 936-4109),

2. Biotechnology - Plant Tissue Cultures (Project 936-4137),

3. IPM and Environmental Protection Including Biocontrol (Project 936-4142),

4. Soil Management CRSP - (TropSoils) (Project 931-1311),

5. Technology for Soil Moisture Management (Project 936-4021),

6. Improved Biological Nitrogen Fixation Through Biotechnology (Project 936-4177),

7. Aquaculture Research and Support (Project 936-4180), and

8. Agricultural Policy Analysis (Project 936-4084)

9. Small Ruminants CRSP (Project 931-1328)

Socioeconomic analyses are handled as sub-projects within selected CRSPs and other projects and through the Agricultural Policy Analysis Project (APAP). This is a new activity within S&T/AGR and appears to be generating considerable Mission interest in the field as measured by buy-ins. The APAP project does appear, however, to be somewhat separated from the natural resources or biological science focus of the rest of S&T/AGR portfolio.

However, what appears to be missing, is overlap between projects and cross-disciplinary interaction. Just as Figure 3 is a conceptual presentation of the various portfolio elements, it may also be a rather realistic Venn diagram depiction of these activities. The overlap between any two or more elements is minimal. The projects have all evolved in response to various needs and all have valid reasons for existence. S&T/AGR is divided into Divisions that have an inherent logic but do create barriers between project offices and do not encourage interdisciplinary research. Such a research portfolio, however, falls short of a coordinated research activity on sustainable agriculture, even if all of the necessary elements are present, because they are not organized on a programmatic basis.

C. Other Science and Technology Offices

In addition to the very considerable strengths of S&T/AGR staff and their projects, the Committee was impressed by the potential for substantive collaboration between S&T/AGR and other Offices in Science and Technology in developing a sustainable agriculture program. Our meetings with staff of the Offices of Forestry, Environment and Natural Resources (FENR) and Rural Development (RD) were brief and our comments are mainly based on summary documents. Nevertheless, it seems clear that important activities exist in these Offices that could be drawn upon in developing an Agency-wide sustainable agriculture program which would be linked strongly to sustainable development. There is also a will in the various offices to find some way of increasing their interactions.

Table 8. Comparison Between S&T/AGR Formal Buy-ins and Office Budget Without IARCs, FY '84 - FY '89.

Fiscal Year	S&T/ Agriculture Total Budget $M	Budget Index (1984=100) %	S&T/ Agriculture Without IARCs $M	W/O IARCs Index (1984=100) %	Total Buy-ins	Buy-ins Index (1984=100) %
1984	83.7	100	36.0	100	3.3	100
1985	37.9	45	36.1	100	3.2	97
1986	37.0	44	33.8	94	2.3	70
1987	32.1	38	28.6	79	3.0	91
1988	30.6	37	29.1	81	1.0	30
1989	32.0	38	30.4	84	4.1	124
1990	32.7	39	31.1	86	6.5	197

Source: S&T/AGR Office Records

The Office of Forestry, Environment and Natural Resources (FENR) has a somewhat different style of operation to that of Agriculture, being more Mission-oriented. However, its range of projects deal with a number of topics important to sustainable agriculture. For example, agroforestry and forestry are both important components of some sustainable agriculture systems. The F/FRED project (Forestry/Fuelwood Research and Development) has obvious links in many locations, just as the Coastal Resources Management project could play a role in development of sustainable marine or aquatic systems in its target countries (Ecuador, Sri Lanka, Thailand). The Conservation of Biological Diversity project and the Forest Resources Management project also have potential for making substantive contributions to sustainable agriculture activities.

In a similar manner, the Office of Rural and Institutional Development (S&T/RD) has links through the F/FRED project (joint with FENR) and various marketing activities such as the AMIS (Agricultural Marketing Improvement Strategies) project. The RD Office also has a number of broad-based policy analysis projects that could be potentially useful. These would appear to include several in the Regional and Resource Development Division such as ACCES (Research on Access to Land, Water and Natural Resources), DESFIL (Development Strategies for Fragile Lands), and FSA (Food Security in Africa).

We are aware of the difficulties in establishing meaningful links between projects within the Office of Agriculture and also of the even greater difficulties involved in linking across Offices which are common to many similar organizations. However, it seems clear to the Committee that the considerable expertise and resources in the other Science and Technology Offices could make a valuable contribution to any sustainable agriculture activity. Even if the conceptual logic exists, the barriers may not easily be overcome unless there is a united will between the Directorates.

D. Hypothetical Case Study

A key premise of this Report is that national institutions in developing countries and the United States Congress have begun to recognize that long-term productivity based on maintenance of natural resources is as important as short-term production needs. As a result of both local interest and international pressures, local A.I.D. Missions will increasingly begin to ask S&T/AGR for assistance in designing, implementing, and evaluating Sustainable Agriculture Projects.

We have identified the types of research needs these Missions are likely to request. We have compared S&T/AGR's portfolio of projects with these research needs and concluded that S&T/AGR is strong in component and process research, but weaker in the areas of systems research, and most deficient in its current capability to provide methodologies for designing, evaluating, and disseminating more information on sustainable farming systems. In Chapter VI we will outline options that S&T/AGR could consider that will strengthen its capabilities to respond to the needs of local Missions in promoting sustainable agriculture. We recommended that a CRSP or Program Center

approach be adopted. It might be appropriate to consider how such a Program would work.

One way to illustrate how S&T/AGR Sustainable Agriculture Program could function is to invent a case study in Country X and describe how the new Program could respond. For purely illustrative purposes, let us assume that the Minister of Agriculture in Country X meets with an Agricultural Development Officer (ADO) of the local A.I.D. Mission, tells him/her that he/she has just attended a workshop at a university in the U.S., and that everyone is talking about Sustainable Agriculture. The ADO has heard that the U.S. Congress has earmarked money for Sustainable Agriculture so he/she writes up a Project Identification Document (PID) and sends it off to her Regional Bureau and asks for help in writing up the Project Paper (PP). The Regional Bureau now calls S&T/AGR and asks if a Technical Advice (TA) committee could be sent to Country X to prepare a Sustainable Agriculture project paper.

The question is "how would the leader of S&T Agriculture's new Sustainable Agriculture Program (SAP) respond?" First of all, he/she would find out if any of the current S&T/AGR projects have field activities in Country X, and if the geographic area where the Mission wants to implement the project is ecologically similar to either the semi-arid African site, the humid tropics Latin American site, or the wet-dry Asian site where the sustainable agriculture program has field projects. Let us assume, for hypothetical purposes, that the Bean/Cowpea CRSP has field activities in Country X, and that the area where the Mission wants to implement the project is a humid tropical region, but not in the same country where the sustainable agriculture program has its humid tropics field site.

The Coordinator would begin by sending a technical assistance committee to Country X that includes someone from the Bean/Cowpea CRSP and someone from the humid tropics site team. The TA team would meet with the Mission ADO and his/her staff, and with the Ministry of Agriculture staff and they would agree upon the goals, purpose, and possible outputs (the logical framework) of the project. They would spend enough time in the project site to talk to farmers, representatives of local institutions, local extension and research staff, etc. to be able to understand both local short-term production needs and long-term resource productivity issues. The explicit consideration of both these issues at the same time would be one of the key differences between the project paper this committee would prepare, as opposed to past project papers. It is likely that the Mission has had experience designing and implementing both agricultural production projects and natural resource projects; it is unlikely that they would have experience implementing projects that integrated these concerns.

Again, for illustrative purposes, suppose we assume that the project paper identified the project's goal as improving the livelihood of small farmers in the upper White River Watershed and decreasing sedimentation behind the lower White River dam. The purpose of the project is to identify and disseminate land use systems that will increase farmers' incomes and reduce soil erosion. The projects outputs will be at least five alternative land use systems that have at least a 25 percent greater economic return

and cause 50 percent less soil erosion than the current cassava and cowpea production system that predominates in the region.

Following the usual A.I.D. process, the A.I.D. Mission would next issue a Request for Proposals (RFP) seeking U.S. institutions that would be interested in providing technical assistance for the White River Watershed (WRW) Project. However, if S&T/AGR's Sustainable Agriculture Program is functioning well, the Regional Bureau might want to ask it to analyze the technical assistance needs of the WRW Project to determine what kind of technical support functions could be handled by current S&T/AGR projects and which functions would actually require an RFP to obtain another contractor.

Let's assume that the Sustainable Agriculture Program (SAP) analyzes the WRW Project Paper and suggests that the Bean/Cowpea CRSP, TropSoils, and the Water Management Synthesis Projects have expertise that would be very useful to the WRW Project. It might also suggest that the CIAT Cassava program could make a major contribution and that the SAP humid tropics field site team is developing different methodologies that could be relevant to the WRW Project. SAP could now write an RFP that requests a contractor that has the capability of integrating the different technical disciplines that are needed and the capability of analyzing up-stream/down-stream tradeoffs and short-term economic vs. long-term erosion tradeoffs.

The technical assistance team would arrive in Country X and work with the Ministry of Agriculture research and extension scientists to implement the process described in Figure 2 of this report. The project team would describe the present farming systems and the local socioeconomic and biophysical environment. They would analyze the interactions in these systems (e.g. soil/crop/livestock interactions) and, using both short-term production criteria and long-term resource productivity criteria, they would design alternative land use systems. The local field team could draw upon the expertise and experience of the Bean/Cowpea CRSP, TropSoils, Water Management Synthesis, the CIAT Cassava program, the humid tropics SAP field team, and any other technical expertise that they would need. The WRW field team would evaluate the alternatives that came out of the design process and would disseminate the new technology that was found to be both more economically viable and more ecologically sustainable.

The final stage in all A.I.D. projects is evaluation. One of the most difficult questions that is likely to arise is "how to evaluate a sustainable agriculture systems project." As this stage nears, the ADO in the A.I.D. Mission in Country X would ask SAP to send an evaluation team. It is unlikely that the original ADO that promoted the WRW Project would still be in Country X and there would be a need for clear evidence that the alternative systems are more sustainable. An evaluation team usually begins with the logical framework in the original project paper. A key question is "are the alternative systems developed by the project both economically and ecologically better than those farmers were using before the project started?" Economic viability is not simple to evaluate, but ecological sustainability will be even harder to measure making this question difficult to answer.

After five years it is unlikely that farmers would have begun to adopt any new technologies developed by the project to the extent that down-stream sedimentation rates would have decreased. Clearly, sustainable agriculture projects will need to have life-spans of a minimum of 10 years, and 20 year projects would be preferable. An important challenge is to develop methodologies for measuring sustainability in environmental, ecological, economic, and social terms.

CHAPTER VI.

RECOMMENDATIONS ON THE ROLE OF SCIENCE AND TECHNOLOGY/AGRICULTURE IN MEETING FUTURE SUSTAINABLE AGRICULTURE RESEARCH CHALLENGES

The overall role of S&T/AGR in promoting sustainable agriculture is linked inextricably with the overall organization of the Agency, as well as that of the Directorates. This Report is aimed mainly at addressing the portfolio of S&T/AGR but it must also comment on interactions between the various units.

A. Organizational Recommendations

a) Inter-Directorate

The Bureau for Science and Technology is organized into five Directorates, three of which are relevant to sustainable agriculture: Food and Agriculture, Energy and National Resources and Human Resources (Figure 4). Within these Directorates there are three relevant Offices: Office of Agriculture, Office of Forestry, Environment, and Natural Resources and Office of Rural Development, all in different Directorates and all of which have projects directly linked to Sustainable Agriculture. For instance, deforestation and soil and water management affect all the Directorates. If agricultural sustainability is to be adopted by the Science and Technology Bureau some mechanism for cross-linking the activities of these Offices is essential, if for no other reason than to eliminate redundancy, to maximize synergy, and to minimize disciplinary bias.

b) Inter-Division

The three Divisions in S&T/AGR: Agricultural Production, Renewable Resources Management and Economic Policy and Sector Analysis (Figure 5), all have excellent projects that would be major components of any sustainable agriculture endeavor developed by S&T/AGR. Some of these projects are related, but others are not, and it seems that the coherence of the portfolio would be improved if projects were cross-linked together. For instance, projects could be linked into "technology elements" such as cereals and legume research, crop protection, post-harvest crops, biotechnology and animal production, soil fertility promotion, soil management, water management, and agricultural policy.

The project areas that should be linked in the sustainable agriculture thrust are shown in broken lines in Figure 5. To make these cross-links effective, there is a need for some organizational structure, preferably with funding available, to encourage the functioning of the links.

c) Need for Programs as well as Projects

The whole portfolio of S&T/AGR is based currently upon individual projects and CRSPs rather than programs. The review committee considers that if these projects were

Figure 4. Organization of the Bureau for Science and Technology.

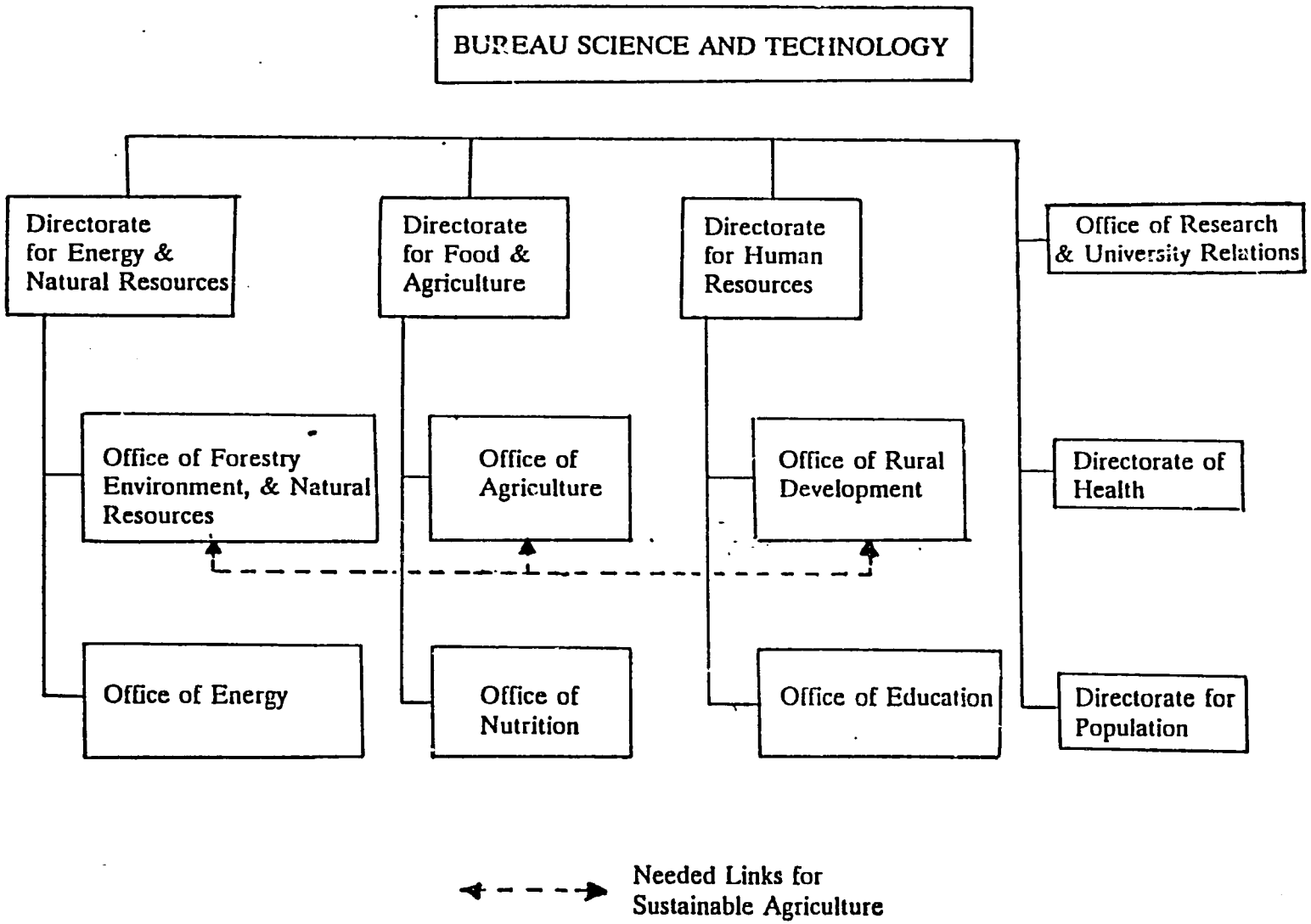
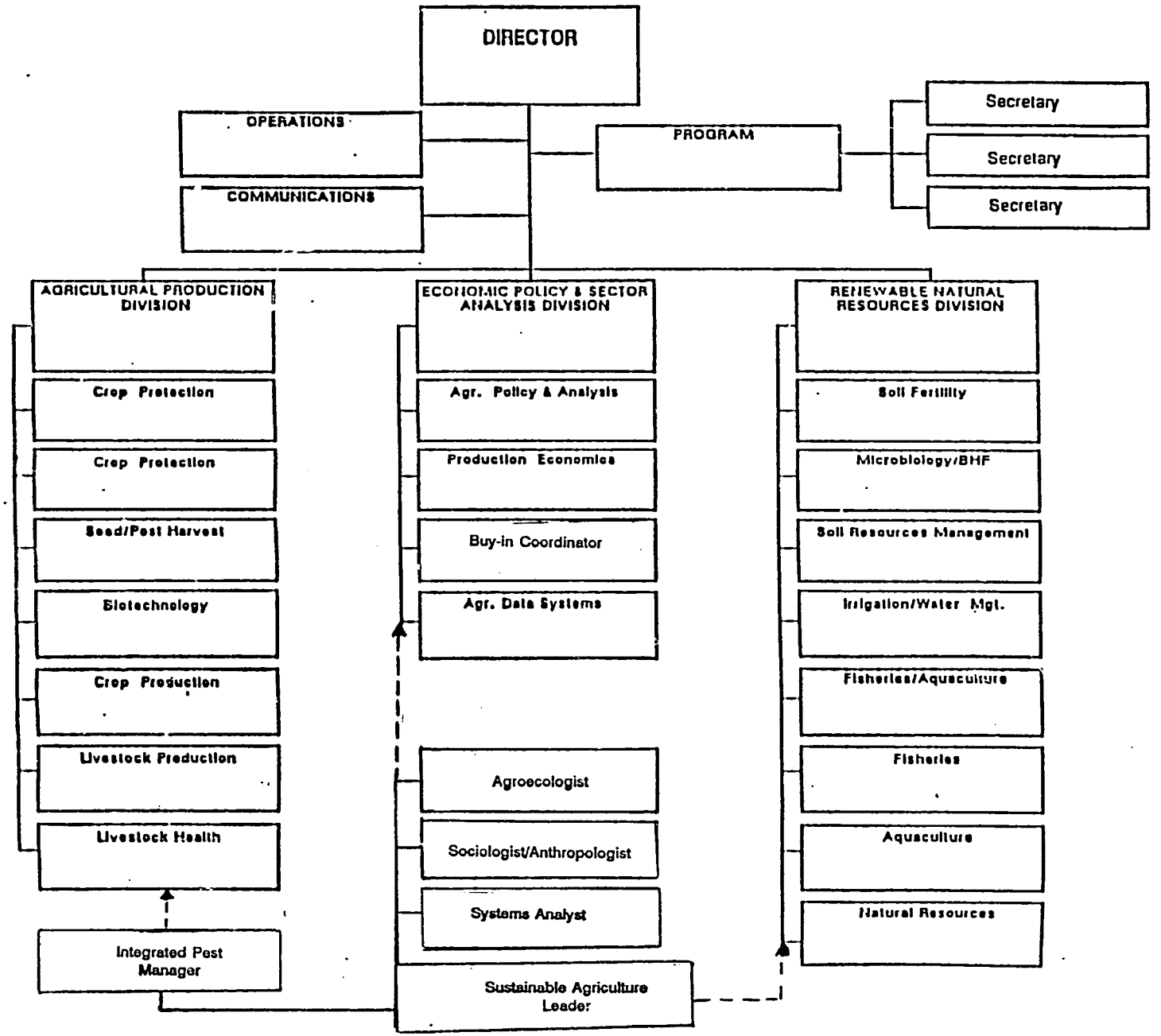


Figure 5. Suggested Reorganization of S&T/AGR for Sustainable Agriculture.



linked into programs involving several projects such as those suggested as "technology elements" there would be much more potential for cross-fertilization and more integrated goals in the overall portfolio.

There are strong resemblances between the organizational structure of S&T/AGR and that common to universities with a strong disciplinary emphasis. For the portfolio to address agricultural sustainability, there must be emphasis on interdisciplinary and cross-linked activities and a more systems-orientated approach. For instance, there is an urgent need to cross-link excellent projects such as biological nitrogen fixation, soil and water management and fertilizers with the various commodity projects and commodity CRSPs. There is a need for designing integrated systems that take account of interactions between inputs into cropping systems whether they are chemical, biological, or cultural.

B. Office Support Suggestions

During the Committee's discussions with the staff a number of comments were made on organizational matters that a number of the staff considered detracted from their overall efficiency in achieving the targets of S&T/AGR. We raise these issues only for the information of the administration; they may or may not be factual. However, we consider that although we do not plan to critique these issues the administration should review them. These included:

* Funding for travel allowed regular service staff to make on-site visits to their projects only every 2-3 years. This does seem to be a serious shortcoming because it seems to the Committee that for the efficient administration of a project on-site inspections and discussions which familiarize the staff member with local problems are essential.

* The complex nature of the Agency and projects based on a need for planning two years ahead tends to restrict the ability to respond quickly to new opportunities, pressures or needs.

* The variability in types and tenure of staff appointments make maintenance of long-term programs and continuity difficult to achieve. Comments were made that only seven percent of the A.I.D. staff are agriculturalists and that it is virtually impossible to rise through the ranks of A.I.D. via a technical route.

* There were various comments on communication problems such as obtaining approval for cables to mission being time consuming, and the lack of an electronic mail system.

* It was indicated that a relatively low availability of secretarial and program assistant support often resulted in senior staff becoming over-involved in clerical matters.

* The need for an organized directory of world contacts was mentioned several times.

* Several staff members commented on the shortage of conference rooms in S&T/AGR.

* It was suggested that the overall Bureau, Directorate and Office information system could be improved to enable the results of S&T/AGR projects to reach Missions and Regional Bureaus, more quickly and efficiently.

* In our discussions it was clear that current funding for S&T/AGR has been falling significantly in real terms in recent years. The new funding of $15 M earmarked for sustainable agriculture would go a long way towards reversing this trend. We consider that funding will continue to fall unless S&T/AGR addresses issues associated with loss and deterioration of natural resources. Even if new funding does not materialize, there must be some redirection of resources toward a sustainable agriculture program.

C. Staff Recruitment Recommendations

To implement a major thrust in sustainable agriculture we perceive that there may be a need for up to five new permanent staff positions. We realize the constraints on such appointments at a time of declining funding, but perhaps reallocation, as well as the additional funding proposed by Congress and Senate Committees, may be used. The positions in order of priority are (Figure 5):

a) Sustainable Agriculturalist - Program Leader

The first and greatest need would be for a leader for the Sustainable Agriculture Program whatever form it might take. He/she would coordinate the overall program and facilitate the interactions between Directorates, Divisions, CRSPs and projects. This position will become necessary whichever of the options described for implementing a sustainable agriculture program is adopted and whatever form of organizational structure is used. This position will be critical in any modification in the S&T/AGR portfolio. It needs a person with a broad background and interest in sustainable agriculture. He/she could be trained in agronomy, systems analysis, agroecology, sociology, or integrated pest management.

b) Agroecologist

Agroecology involves applying sound ecological and biological principles as a basis for agricultural productivity. It is the whole base for sustainable agriculture. Currently, these duties are being performed by Dr. Thurman Grove but he is seconded from Cornell University on a two-year appointment. The very considerable value of his position and activities is clear from the way he has spear-headed the issues of sustainability and interdisciplinarity in the office. There is a clear need for a permanent

input by an agroecologist into the S&T/AGR portfolio. This should be made a permanent staff appointment.

c) **Systems Analyst**

The main difference between sustainable agriculture and current agricultural practices is in the use of a systems approach which takes full account of all the inputs into agriculture, considers the interactions between the inputs, and defines the main factors which influence the system. It will be obvious from this Report that the Committee considers that any Sustainable Agriculture Program implemented by S&T/AGR must be systems-orientated. In any case, there is an urgent need for the expertise of a systems analyst in S&T/AGR, not only for his/her inputs into a sustainable agriculture program but also in injecting a systems approach to interactions between existing projects and CRSPs and interactions between the various Offices and Divisions. Such inputs by a systems analyst would also make it easier to prioritize needs and structure new projects and CRSPs. In crop production systems, he/she could define interactions between inputs and their relative importance.

d) **Sociologist/Anthropologist**

Agriculture has strong impacts in the social area and is emphasized even more in the promotion of sustainable agriculture because of the implicit links with regional social issues. There is a need for all projects to be reviewed in social terms, since their results will never be implemented successfully if this aspect is neglected. Such activities are essential to any major sustainable agriculture thrusts. In order for them to get adequate attention a new staff member with these responsibilities is necessary.

e) **Integrated Pest Manager**

Although the Division of Agricultural Production has a Pest Management Project, this is linked mainly to the environmental aspects of pesticide use. Integrated pest management is an absolutely essential component of sustainable agriculture and requires much more attention that is currently possible with the present staffing structure. The same concept of interactions between inputs used in integrated pest management are at the heart of integrated sustainable agricultural systems. Integrated pest management is a successful example of the interdisciplinary systems approach.

Although six new positions are suggested, only four are probably needed, since the Program Manager would have one of the four main areas of expertise. The new staff positions could be in any of the existing Divisions, but would probably be best situated in an interdisciplinary group which could function independently if required.

f) **Natural Resource Economist**

The success of a Sustainable Agriculture Program will depend upon sufficient consideration of the economics of sustainable agriculture, particularly in relation to maintenance of natural resources. Such expertise is essential, but it is possible that this

could be provided by existing staff in S&T/Agr in the Economic Policy and Section Analysis Division. If nobody is available, serious consideration should be given to adding a Natural Resource Economist to the staff.

D. Component Research

There are a number of interdisciplinary research areas which could make a major contribution to sustainable agricultural systems in developing countries. S&T/AGR should seriously consider these as important areas to consider for new projects. We realize that it may be difficult to implement so many new projects, even at a time when some of the existing ones are close to termination. However, our recommendations stand and should be reviewed for priority and implementation when the new program in sustainable agriculture is set up. We suggest a number of new projects critical to a sustainable agriculture program. They are all needed, and if they cannot be implemented in the near future, their incorporation into existing projects should be considered. They are ranked more or less in priority and include:

a) Conservation Tillage

This is probably a key issue for the conservation of tropical soils. There is a large body of evidence (Lal, 1987) that many forms of conservation tillage or no till provide dramatic improvements in soil erosion, particularly on the more fragile soils, because it leaves a covering of plant residues on the soil surface. This is a major component of sustainable agricultural systems.

b) Biological Inputs to Soil Fertility

The provision of nutrients through breakdown of organic matter, nitrogen fixation and enhancement of phosphorus uptake by vesicular arbuscular mycorrhizae are all processes of considerable importance in increasing crop productivity without use of inorganic supplements. A better understanding of these processes would enable their enhancement and improvement to occur. There is an existing project which is beginning to address some of these issues, which could be expanded.

c) Agroforestry

In general terms, agroforestry involves the combination of land use systems where trees are combined spatially or temporally with agricultural crops and/or animals (Farrell, 1987). As a result of the improved growing conditions for crops and more efficient use of natural resources productivity is usually improved. This is particularly true when the tree component consists of tree legumes, which provide nitrogen. These techniques could be of key importance in improving traditional low-input farming systems and minimizing soil erosion and would certainly justify a new project.

d) Alley Cropping and Strip Cropping

Such intercropping systems involve growing crops in strips wide enough to permit independent cultivation but narrow enough for the crops to react agronomically and ecologically. Such cropping practices have beneficial effects on soil erosion, nutrient availability, and pest, disease, and weed problems. As an important component of sustainable agricultural systems they merit further study and would justify a new project, which would have to operate on a regional basis.

e) Weed Control

Weeds are one of the most important factors contributing to loss of productivity. In the U.S. 80 percent of all pesticides used are herbicides. In many developing countries, a principal means of weed control is manual cultivation. There are many cultural weed control practices that minimize the need for mechanical cultivation. These include allelopathy through growing antagonistic crops, use of live and dead mulches, use of mycoherbicides, and use of special cropping patterns. At present, the problems of weed management are not a consideration in any project, CRSP or by any IARC at the level of effort that their importance warrants. Weed control is one of the most important components of sustainable agricultural systems and may be a major contribution to loss of productivity, if herbicides are not available at reasonable cost, as in many developing countries.

f) Integrated Pest Management

Losses to pests and diseases are of major importance in tropical developing countries and are extremely difficult to control. There is a need for systems of integrated pest management that combine chemical control with biological and cultural control techniques effectively using as tools: resistant varieties, rotations, cropping patterns, controlled weed growth, tillage and manipulation of planting time. Such systems are at the heart of integrated sustainable agricultural systems.

Although there is a current consortium for International Crop Protection that addresses pest management it is orientated more towards environmental protection than pest and disease control. There is an urgent need to expand this activity and a project would be the best option.

g) Socioeconomic Aspects of Sustainable Agriculture

Sustainable agriculture is very dependent upon social and economic inputs, and a project in this area could be linked with many existing projects and CRSPs.

h) Crop Breeding through Genetic Engineering

Although the IARCs are becoming increasingly involved in tissue culture and genetic engineering, crop breeding is also important to sustainable agriculture through designing more productive crop varieties that can resist pests and diseases and/or are

tolerant of drought. Similarly, animal breeding for productivity and resistance to disease could be accelerated through genetic engineering. A project(s) on these topics should be considered seriously by S&T/AGR.

i) Post-harvest Technology

There are considerable post harvest losses to crops in many tropical countries. These losses increase the production systems requirement of the cropping and have a negative impact on sustainability. These are so important that they would merit a project on this subject.

j) Horticultural Crops

Sustainable agriculture is associated with cropping diversity; high-value horticultural crops grown as far as possible with low-input techniques could play an important role in a sustainable agriculture program. Hence, a project in this area would be important as a component of various sustainable systems.

E. Organization of an Overall Science and Technology/Agriculture Program on Sustainable Agriculture

a) Institutional Structure and Staffing

To take the best advantage of the current portfolio of good projects in the context of an overall sustainable agriculture program and assume a leadership role, S&T/AGR needs to create an institutional structure that is seen as responsive to the Congressional directive to integrate long-term environmental concerns with short-term production needs, and is administratively linked to Mission field-level projects where sustainable agriculture projects will be implemented. To implement project(s) in sustainable agriculture new staff would be needed as described previously. These would include an overall supervisor, with experience in sustainable agriculture, an agroecologist, a systems analyst, a sociologist/anthropologist and an integrated pest manager.

b) Operating Procedures and Organization

Incorporation of sustainable agriculture into the S&T/AGR portfolio will require considerable changes in operating procedures and organization of S&T/AGR. Project design must include provisions for gathering information, often through field studies, on local socioeconomic and biophysical environmental factors as key inputs to design of suitable sustainable systems. Economic analyses will need modification to reflect the true economic values of natural resources. Environmental assessments need to be used as active planning tools during project design. The design, implementation, and evaluation of projects will have to set sustainability as a major goal. The development of sustainable management for natural resources requires interdisciplinarity across all sectors. Time horizons need modification because programs of ten to twenty years or more duration are required to develop sustainable natural resource management systems. New programming modes are required to accommodate "bottom-up" approaches which

progress slowly and require extensive efforts. Designs must be flexible because sustainable development is a reiterative process in which learning and programmatic readjustment are constantly reinforcing each other.

The most immediate organizational question that arises is to what extent new projects can be added to S & T/Agriculture's current portfolio, and whether a program can be developed that integrates existing projects and links this set of integrated projects to A.I.D. Missions. Adding new projects is administratively easier. The primary disadvantages to this approach is that it is more expensive to create new projects than to integrate existing projects, since all new projects would duplicate some components of some existing projects. In all events some form of integrated sustainable agriculture management program will be necessary.

Integrating existing projects is less expensive than starting new projects and is intuitively very attractive since it builds upon the existing strengths of S&T/AGR. However, a key disadvantage to this approach is that integration often occurs on paper but not in reality. Integrated projects are basically more difficult to administer and often the institutional interest in forcing these linkages to occur (such as by pooling part of various project's budgets and putting this money under the control of a central office) is often lacking. Past experience with projects such as the Farming Systems Support Project (FSSP) suggested that research and development process-oriented (as opposed to technology development) projects, that ideally should be directly linked to other projects and should "naturally" develop cooperative relationships, often never develop these operational linkages unless there is an appropriate funded administrative structure.

Another key question is whether any proposed new organizational structure should be only within S&T/AGR or whether it should also link the Forestry, Environment and Natural Resources (FENR) and Rural and Institutional Development (RD) Offices. There are obvious advantages from linking projects like F/FRED and DESFIL to S&T/AGR. Throughout this analysis we have argued that sustainable agriculture can not be separated from the larger natural resource and rural development issues. A disadvantage is that considerable time would pass before an inter-Office program could be installed and made operational. Experience with SWAN has demonstrated that there are tradeoffs between what is administratively feasible and what is conceptually ideal.

c) Options for Development of a Sustainable Agriculture Program in S&T/AGR

There are a number of organizational options that can be considered. Five basic options that S&T/AGR can consider:

* OPTION 1. **Create a Sustainable Agriculture Secretariat within S&T/AGR**

Such a Secretariat would have to be able to fund ongoing projects that are wide enough in focus to include both production and natural resource productivity concerns. It would insure that ongoing S&T/AGR projects are linked with these wider-focused

projects, commission small projects to fill in gaps, synthesize lessons learned, and identify methodological needs.

An Information Secretariat would have the advantage that it would build on and not compete with ongoing projects. It would be relatively inexpensive to fund, leaving more money to be funneled to biological and social science research projects.

A major disadvantage to creating a Secretariat to link ongoing projects is that it would not be seen by Congress as very responsive to its directive to put more emphasis on sustainable agriculture. While information management is important, sustainable agricultural research must begin with real environmental concerns and production needs. Although this option would be cheap it probably would not be able to integrate projects to the extent necessary to the extent to support Mission-level Sustainable Agriculture Projects.

* OPTION 2. **Create a Secretariat outside S&T/AGR that would report to a Committee named by the three Science and Technology Offices.**

This option would have the advantages of Option 2 and, in addition, the Secretariat could access projects in all three Science and Technology Offices. The Missions could ask for backstopping within the wide range of expertise within the Science and Technology Bureau. Its potential for success would depend upon its status within the Bureau.

A major disadvantage of a Bureau-level Secretariat is that it would report to three Offices. It could be abandoned by any one or all three Offices since no one would feel ownership of the Secretariat. In short it would be difficult to organize and would be dependent on goodwill between S&T/AGR's.

* OPTION 3. **Create a Sustainable Agriculture Program within S&T/AGR that explicitly links ongoing projects**

The Program Office would act as a Secretariat as in Option 2, but it would also implement site-specific projects and it would use the lessons from those projects to actively try to influence the research priorities of other ongoing Science and Technology projects.

Such an integrative program would be a high-profile response to the Congressional earmark and would demonstrate to Congress that S&T/AGR is serious about its commitment to sustainable agriculture. Linking and building on existing projects while implementing site-specific projects would be the most efficient way of quickly developing the resource management trade-off analysis methodology that is needed.

If this option were implemented it would be important not to give the impression that S&T/AGR is responding to Congress by stating "we are already doing sustainable agriculture." To make all of S&T/AGR's current projects suddenly part of a Sustainable

Agriculture Program could be seen as suddenly getting on the "sustainable" bandwagon. Without making any substantiate changes, it would be expensive, administratively complicated, and would probably take at least two years to become operational.

* OPTION 4. **Create a Sustainable Agriculture CRSP within S&T/AGR.**

This CRSP would operate similarly to one of the present CRSPs, i.e. it would have a management entity, administer sub-projects in different disciplines, and manage a few regional pilot sites where methodologies, such as tools to analyze the implications of different natural resource tradeoffs, are developed. It would have to include a mechanism to link existing CRSPs and appropriate projects.

The creation of a Sustainable Agriculture CRSP would be a high-profile activity with high visibility and would be seen as a clear response to Congressional earmarking of funds for sustainable agriculture. It would be easy to administer since S&T/AGR has considerable experience setting up and managing CRSPs. There is a consensus in S&T/AGR, other Directorates, and Regional Bureaus that CRSPs are all extremely cost-effective. This option would minimize the need to appoint new S&T/AGR staff, since it would coincide with increasing activity in sustainable agriculture in Title XII institutions. At least five land grant universities have programs in sustainable agriculture relevant to developed countries, and others have activities related to sustainable agriculture in developing countries.

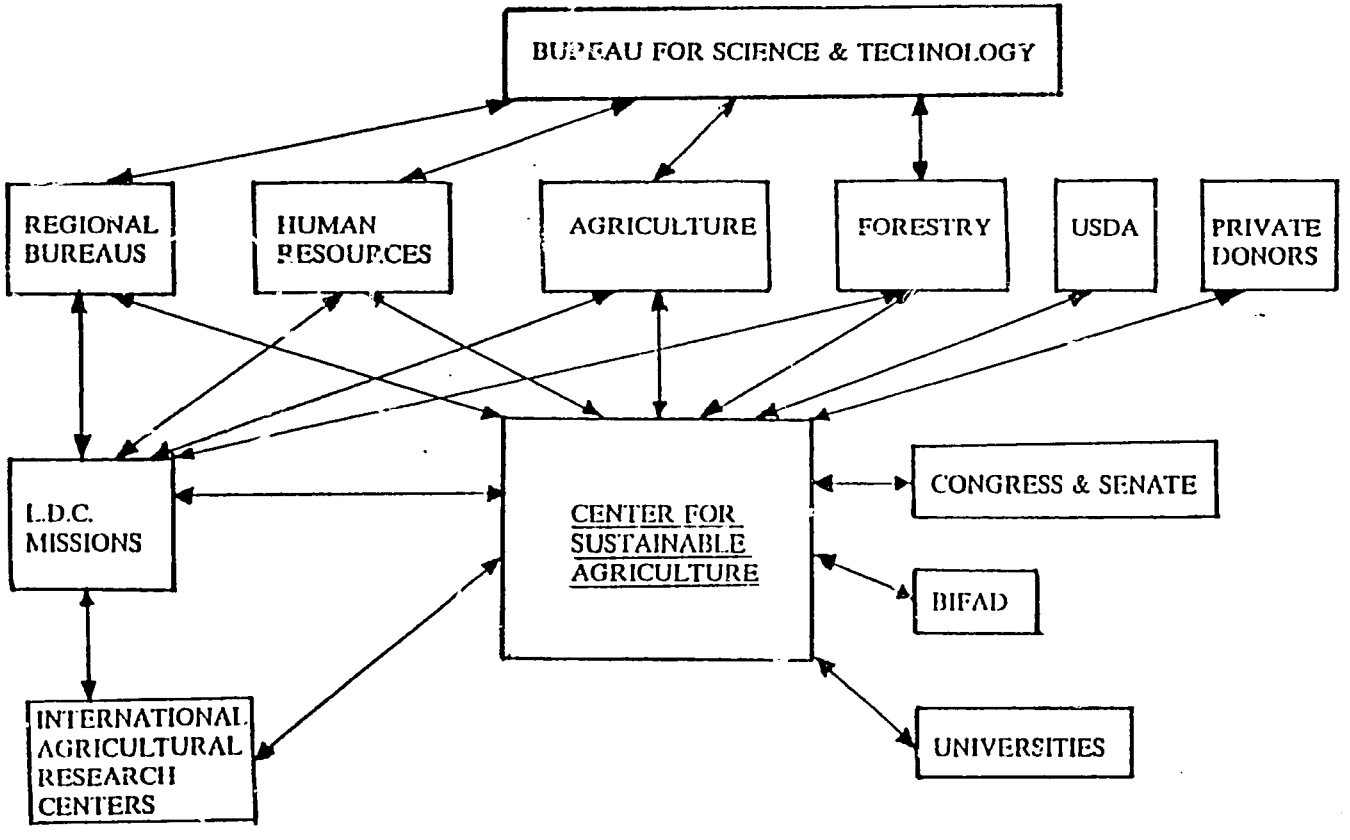
A disadvantage with this option is that the current CRSPs have often had difficulty in developing effective cooperative relationships with each other. It could be that a Sustainable Agriculture-CRSP would have difficulties in developing strong cooperative relationships with other S&T/AGR projects. A CRSP that includes a wide range of technical areas from soil, water, crops, livestock, pests, post-harvest, and policy might involve a number of institutions and could be a complicated multi-institutional structure that would be complex to manage. A CRSP within S&T/AGR would have difficulties developing linkages with other S&T Offices since it would be seen as only "one more project" in the overall S&T/AGR portfolio.

OPTION 5. **Create a Sustainable Agriculture Center within S&T/AGR that explicitly links ongoing projects in Agriculture, Forestry, Environment and Natural Resources (FENR) and Rural and Institutional Development (RD) (Figure 6).**

The primary advantage is that this would combine activities in the Offices of Natural Resources, Rural Development, and Agriculture. It would have to provide a separate funding line for Sustainable Agriculture, using funds allocated by the three Offices. It could link directly to the Missions and Regional Bureaus and it could interact easily with S&T/AGR projects, CRSPs, CGIARs, and Universities (Figure 6).

The main disadvantages to this Option are that it would be administratively complicated to set up. It would also add another layer of administration to those existing

Figure 6. Mode of Operation of a Center for Sustainable Agriculture.



already. As a result it could take up to two to three years for this type of Center to become fully operational.

F. Conclusions

It is never easy to change patterns of activity that have developed over many years and seem very productive. The current S&T portfolio has developed over a long period (in some cases decades) in response to outside pressures, requests from Missions, and other factors. Each project has its own unique history as to what its aims are and how it was conceived and developed.

However, it does appear to the Committee that S&T/AGR may have a unique opportunity to make major programmatic change to its portfolio in the next year or so, and to reallocate some funds to support the maintenance of natural resources and sustainable agriculture activities as well as acquire additional funding. In reviewing the February 1989 Program Guide to the Office of Agriculture we note that at least 15 projects have termination dates for their current project agreements in 1990 or 1991. Although a number of these projects would normally be extended, this opportunity to either reprogram funds or redirect activities in existing projects is fortuitous. The total 1989 funding of these projects is more than $8 million (Table 9).

Although we realize that it is unrealistic to expect to change the overall portfolio of S&T projects as drastically as recommended here, there remains an opportunity to make major programmatic changes over a two-year period even if additional funds are not forthcoming. Since the current S&T/AGR portfolio already contains almost all of the elements needed for an integrated systems approach to sustainable agriculture, the problem may be more of how one thinks about a problem and approaches research rather than which components one chooses to address.

If additional funds are forthcoming from termination of projects or reallocations in response to Congressional recommendations the process of change will be made easier. The Committee suggests that whether or not additional resources are provided for sustainable agriculture, it is probably necessary for S&T/AGR to consolidate some of its activities into programs, carry fewer projects, encourage interactions between projects and Divisions and fund those projects that it does have at higher levels. With the changes in funding for S&T/AGR over the past decade, and with inflation and general cost increases, many projects are currently underfunded, resulting in pressure on researchers and project officers. On the positive side, the mix and programmatic depth of the S&T/AGR portfolio will probably mean that no major research sectors need to be dropped; rather, some consolidation within sectors (e.g. crop production, water resources, soil, fisheries) should improve the overall cost-effectiveness of S&T/AGR sponsored research.

The Committee presented five options for a sustainable agriculture initiative. It is the opinion of the Committee that the preferred option is either of a new Sustainable Agriculture CRSP or a Center (or Program). A Sustainable Agriculture Secretariat, either within or outside S&T/AGR, although intellectually and administratively appealing,

would probably not be effective in creating the types of activities and changes needed to promote sustainable agriculture. Secretariats tend to be ignored and, since they have little financial or administrative power, frequently end up on the sidelines when faced with strategic day-to-day decisions.

Table 9. Funding for S&T/AGR Projects (FY '89).

Project Categories	Proportion of Total Funding (%)
Fisheries and Aquaculture	11.2
Crops (primarily production)	25.2
Animals (primarily production)	8.7
Social Science	2.6
Plant Protection	2.3
Animal Disease	3.0
Post-harvest	4.2
Inputs	31.5
Soils	14.5
Biological Nitrogen Fixation/*Rhizobium*	4.0
Seeds	1.0
Fertilizer	10.8
Water	1.2
Other	11.3
Total	**100.0**

A Sustainable Agriculture CRSP (or Program) has the advantages that all of the present CRSPs have demonstrated: a long-term commitment to research, active collaborators in the U.S. and abroad, the potential for high-quality work and a very efficient use of funds. However, as pointed out in the Options section, since sustainable agriculture must be a multidisciplinary process and must embody a systems approach, the traditional scale CRSP would be over-stretched to handle all of the components adequately. One possible solution is the creation of a super-CRSP that would have a considerably enhanced level of annual funding (perhaps several million dollars per year as Congress suggested). In some ways this becomes a de-facto Center, our other preferred option.

Considerable expertise is available in sustainable agriculture in U.S. Universities to contribute to a super CRSP. Five Universities--the University of California, The Ohio State University, Iowa State University, the University of Minnesota, and the University

of Wisconsin--have formal programs in sustainable agriculture (Edwards, 1989), and others have projects relevant to sustainable agriculture.

A Sustainable Agriculture Center would have money and administrative authority allocated to it that would allow it to overcome the inherent weakness of a Secretariat. As a Center, it could provide funding to existing projects and establish new ones, thereby creating an identifiable program in this area. It could operate on both Congressional earmarks and funds made available through S&T/AGR program consolidation.

A Center would add another layer of administration but this may be the price of having the power to actually affect change. If it was thought of as a kind of super CRSP, a Center could be modeled on the CRSP pattern but with larger numbers of project officers and, hopefully, staff and financial input from the other S&T Offices (especially FENR and RD). One drawback might be that whereas the mechanism for development of CRSPs is well known, setting up a Center is a newer experience and it might take two to three years to become fully operational.

As we said at the beginning of this Chapter, change is not easy, and creation of a Center or Super CRSP will require major changes. It could, however, build on the excellent existing resources, both in terms of staff and projects, in S&T/AGR and also draw in the other S&T/AGR Offices (and maybe even Regional Bureaus). Since sustainable agriculture requires an integrated process, systems-orientated approach, A.I.D.'s respond will also require an innovative attempt to meet this challenge.

Thus, the overall recommendation is to create a CRSP, Center, or Program on Sustainable Agriculture that should be independent of the present Divisions (Figure 5) in order to facilitate inter-Divisional cooperation. Since setting up such a Program may take as long as two to three years, it might be preferable to adopt a step-wise procedure and set up initially a Secretariat or SWAN-like interdisciplinary activity. This could serve as a planning mechanism to assemble the diversity of expertise that will be necessary to ensure that the Program functions in a truly interdisciplinary manner. Both the interim Secretariat and eventual Program would report directly to the Director of S&T/AGR and have a separate funding line.

The Committee also recommends the establishment of several interdisciplinary collaborative research sites. A primary constraint to the accomplishment of interdisciplinary programs is the lack of common research sites among projects. Each site should be representative of a major agroecological zone and staffed by an interdisciplinary team of scientists to include at least one social scientist, one ecologist, and one agronomic scientist. It should have equipment and personnel for normal field and laboratory operations. Three sites are suggested initially: one in humid tropical forests, one in semi-arid lands, and one in an intensive rice producing area. These are critical zones which require immediate attention as their natural resources and productivity are declining. Sites are representative of major agroecological zones so as to allow extrapolation of results to larger areas. Additional sites could be added in the future as resources become available.

The Program should reserve significant financial resources to co-sponsor collaborative projects at the interdisciplinary research sites with other S&T/AGR projects and contractors. This reserve could be distributed under the guidance of a peer review mechanism to assure that projects funded are most relevant to the purpose of developing integrated management systems and technology. The on-site staff should devote a portion of its time to facilitating such projects.

The Program should also develop a technical assistance capability to assist missions and host countries in planning, developing, and executing integrated systems. This capability will be linked strongly to the research program.

In the final analysis, S&T/AGR or the three Offices in the S&T Bureau must adopt one of these options, if they wish to be seen to respond to the various recommendations and directives they have received from Congress, BIFAD, and other sources. Any administrative upheaval caused will be balanced by the attraction of additional funding at a time of declining budgets. Our final recommendation is that the S&T Bureau and S&T/AGR adopt one of the suggestions that we have made and ensure that adequate funding is made available to develop a significant move in the overall Portfolio toward a sustainable agriculture. This is an extremely urgent issue, since the environment and productive potential in developing countries is degrading rapidly. Clearly, S&T/AGR, and the capacity that it has built into its current Portfolio, are an excellent foundation for a rapid response to this urgent problem if it is willing to review this Portfolio urgently and take steps to implement some form of sustainable agriculture program.

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