Organizing and Financing Basic Research
To Increase Food Production

June 1977

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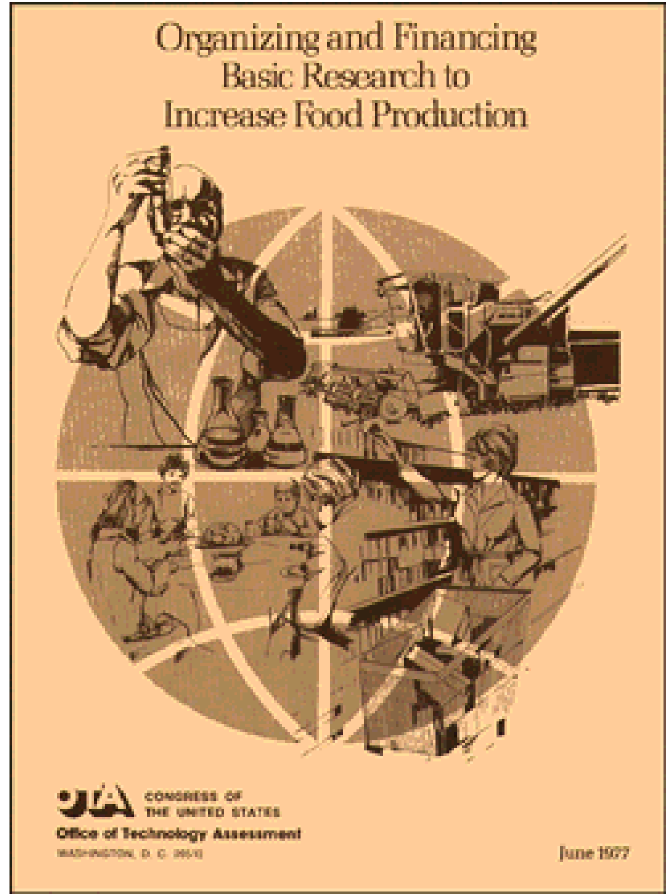

Organizing and Financing Basic Research to Increase Food Production

June 1977

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COngre$$ of the United States
OFFICE OF TECHNOLOGY ASSESSMENT
WASHINGTON, D.C. 20510

JUN 3 0 1977

The Honorable Hubert H. Humphrey
United States Senate
Washington, D. C. 20510

The Honorable Olin E. Teague
Chairman, Committee on Science
and Technology
U. S. House of Representatives
Washington, D. C. 20515

Gentlemen:

On behalf of the Board of the Office of Technology Assessment, we are forwarding to You the report Organizing and Financing Basic Research to Increase Food Production.

This assessment was performed in accordance with your request to the Office of Technology Assessment and authorized by the Technology Assessment Board on February 17, 1976.

Sincerely,

Edward M. Kennedy
Chairman

Sincerely,

Marjorie S. Holt
Vice Chairman

Congress of the United States
OFFICE OF TECHNOLOGY ASSESSMENT
WASHINGTON, D.C. 20510

[illegible]

The Honorable Edward M. Kennedy
Chairman
Technology Assessment Board
Off ice of Technology Assessment
Congress of the United States
Washington, D. C. 20510

Dear Mr. Chairman:

The enclosed report, Organizing and Financing Basic Research to Increase Food Production, analyzes alternatives for organizing and financing basic research in the biological sciences. It supplements the more general report of the National Academy of Sciences, "World Food and Nutrition Study: The Potenial Contributions of Research," which was issued in June 1977, and takes a world view of the potential contributions of research in food and nutrition, recommending expanded research in 22 fields.

The OTA report presents specific suggestions for congressional action. It describes and evaluates alternative organizations of basic research in the biological sciences; discusses alternative levels of increased funding for basic research in three areas that possess great opportunity for fundamental scientific discoveries (photosynthesis, nitrogen fixation, and genetic engineering for plants); and suggests alternative administrative structures for Federal support of basic research related to food production.

The assessment was requested by Chairman Olin E. Teague of the House Committee on Science and Technology and Senator Hubert H. Humphrey in his capacity as a member of the Technology Assessment Board. It was performed by OTA's Food Program Staff under the direction of J.B. Cordaro, assisted by the Food Advisory Committee and a panel of scientists representing agricultural and non-agricultural interests.

Sincerely,

DANIEL De SIMONE
Acting Director

Office of Technology Assessment

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Preface

This assessment is an analysis of alternatives for organizing and financing basic research to increase food production, Alternative organizations of basic research are described and evaluated. Alternative levels of increased funding for basic research in three areas which possess great opportunity for fundamental scientific discoveries-photosy nthesis, nitrogen fixation, and genetic engineering for plants-are proposed by a panel of scientists representing agricultural and nonagricultural interests, private research organizations, and industry. These areas are used as illustrations of how high-priority basic research may be organized and financed, This assessment does not endorse nor limit future basic research to these areas,

The assessment was requested by Senator Hubert H. Humphrey, member of the Technology Assessment Board, and Representative Olin E. Teague, Chairman, House Committee on Science and Technology, The report identifies the options available to Congress in placing a priority on an expansion in basic research to increase food production.

The ad hoc advisory panel on high-priority basic research provided detailed technical information and judgments with respect to ongoing basic research and research institutions. The permanent Food Advisory Committee provided advice and comment throughout the assessment, reviewed the final draft, and has recommended publication of this report.

The Technology Assessment Board, governing body of OTA, approves the release of this report, which identifies a range of viewpoints on a significant issue facing the U.S. Congress, The views expressed in this report are not necessarily those of the Board, the OTA Advisory Council, or of individual members thereof.

Contents

Executive Summary

In early 1975 the Office of Technology Assessment (OTA) received requests from Senator Hubert Humphrey and Representative Olin Teague for an independent assessment of the current status of research and development in food and agriculture. At that time a number of other agencies and committees were engaged in reviewing and evaluating food, agriculture, and nutrition research,

OTA's Food Advisory Committee reviewed the scope and preliminary findings of the studies in progress and counseled OTA to focus its food and agriculture research and development activities on two areas: (I) Implications of Increased Support of Research on Major Food Crops in Developing Countries, and (2) the area addressed in this report, Organizing and Financing Basic Research to Increase Food Production.

In the past ten years, four different scientific groups have reviewed the agricultural research conducted by the U.S. Department of Agriculture (USDA) and the State Agricultural Experiment Stations. AH recommended an expansion in research programs, and three of the groups emphasized the need to accelerate basic research in the sciences which undergird food production,

The Need for Basic Research

Basic research for increasing food production includes areas possessing exceptional opportunity for discovery of knowledge vital to the understanding of biological processes in plants and animals. Food and agriculture research is the search for new technologies within the boundaries of existing scientific knowledge. If basic research remains static, food and agriculture research is subject to diminishing returns and eventual exhaustion.

Basic research to increase food production has primarily been carried on by scientists in the Agricultural Research Service of USDA and in State Agricultural Experiment Stations (SAES) who also adapt research and development. Increases in appropriations for these scientists in the past two decades have not equaled the inflationary increases in research costs, Practical problems associated with increased food production have increased during this period rather than declined, As a consequence, the scientific talent available for this research has declined sharply.

Several recent reports issued by the National Academy of Sciences (NAS) and the National Science Foundation (NSF) listed the areas of basic research offering the greatest potential returns in the near future from accelerated programs. Three areas with outstanding potential returns are listed in all of these reports. They are photosynthesis, biological nitrogen fixation, and cell culture studies.

Achieving Return on Investment

Studies of U.S. agricultural research productivity show annual rates of return of 30 to 40 percent. On the basis of past studies and the potential payoff from accelerated basic research to increase food production, it is highly probable that an investment of $300 million to $500 million over a 10-year period would yield returns of $1 billion to $2 billion over the next 20 years.

Food and agricultural research funds are appropriated for specific USDA projects and for major functional areas at State Agricultural Experiment Stations. Funds for these stations are allocated on a formula basis. No funds are appropriated specifically for basic research in the biological sciences.

Both university and Federal agency scientists agree that the creation of new Federal agencies to conduct basic research would not be cost effective, There is also substantial agreement that the use of a formula for the allocation of funds for high-priority basic research would not be cost effective.

The most effective means of allocating additional funds for this high-priority research appears to be through a competitive grants program. These grants should be available to qualified scientists, on the basis of peer review, in USDA research agencies, State Agricultural Experiment Stations, public and private universities, and nonprofit research institutions, This approach broadens research opportunisties beyond the traditional USDA/SAES complex.

Administering Basic Research Grants

The administration of high-priority basic research to increase food production could be assigned to either USDA or NSF,

Basic research, applied research, and developmental technology are inter-related. There is merit in supporting accelerated basic research through USDA, the Federal agency which has the responsibility for both applied research and technology development,

There are several alternative means within USDA for administering a competitive grants program for high-priority basic research. It could be administered under Public Law 89-106, if amended to permit scientists in the Agricultural Research Service to participate in the grants. No other authorizing legislation would be required.

Congress, if it wished, could mandate a specific administrative structure within USDA or NSF for the administration of this high-priority basic research.

Funding Needs

The USDA's Agricultural Research Policy Advisory Committee and the State Agricultural Experiment Stations recommended expanded research on the 117 most important problems as identified at the 1975 Kansas City Conference on Research To Meet U.S. and World Food Needs, The committee did not distinguish between basic and applied research and recommended increases totaling $215 million over a 4-year period.

The NAS world Food and Nutrition Study issued in June 1977 proposes a first-year appropriation of $60 million in Federal funds for a new high-priority basic and applied research competitive grants program. The report suggests that these funds be increased 10 percent each year for a 5-year period.

An OTA advisory panel found that about $15.6 million annually is being spent on current research in the three high-priority areas of photosynthesis, biological nitrogen fixation, and cell culture studies. It estimated that in the first year of an expanded basic research program in these three areas, an additional funding of $12.25 million plus $200,000 additional administration expenses appeared cost beneficial, The panel proposed that after starting at a minimum of $12.45 million the first year the program should be increased $4 to $6 million a year for a 6-year period, as more scientists are attracted into research in these areas. The panel did not address the problem of desirable financial support for basic research in other high-priority areas, although it recognized that other areas should be included. Thus, their conclusions should not be viewed as limiting the competitive grant program to $12,45 million.

The merits of including other research areas as high-priority basic research areas should be evaluated by the administrator of the high-priority basic research program with the advice and counsel of an advisory committee.

Options for Congress

one option for Congress would be to continue funding food and agriculture research at the current level,

A second option for Congress would be to appropriate funds specifically for basic research to be administered by the Secretary of Agriculture under Public Law 89-106, with or without minor amendments,

A third option for Congress would be to mandate administrative changes in USDA, creating an office of competitive grants and authorizing a long-term program of high-priority basic research to increase food production.

A fourth option for Congress would be to authorize and finance an NSF program for expanded basic research to increase food production.

An appendix, prepared by OTA's ad hoc advisory panel, provides supplementary technical analysis upon which the OTA report draws. Any reference to this material should cite the panel.

Organizing and Financing Basic Research To Increase Food Production

Background

In February 1975, Senator Hubert Humphrey, as a member of the Technology Assessment Board, asked the Office of Technology Assessment to assess the current status of research and development in food and agriculture, Senator Humphrey's request was followed by a similar request from Representative Olin E. Teague, Chairman of the House Committee on Science and Technology. Chairman Teague asked OTA, with the help of its Food Advisory Committee, to report its findings as a supplement to the Committee's planned oversight hearings on agricultural research and development.

At the time these requests were received, a number of agencies and committees were reviewing and evaluating food, agriculture, and nutrition research:

- The General Accounting Office was engaged in a general overview study of the organization, scope, and management of publicly supported agricultural research;
- The Congressional Research Service was preparing responses to several congressional requests on aspects of the organization, priorities, and funding for publicly financed food and agriculture research and development;
- The Agricultural Research Policy Advisory Committee of the National Association of State Universities and Land-Grant Colleges and the U.S. Department of Agriculture (USDA) were organizing a National Food and Agriculture Research Users Conference to be held July 9 to 11, 1975, in Kansas City. The purpose of the conference was to inventory the wide-ranging food and agricultural research activities underway at USDA and the universities, and to establish priorities for future research funding.
- Special oversight hearings on food and agriculture research were scheduled by two subcommittees of the House Committee on Science and Technology for the summer and fall of 1975;
- The Board on Agriculture and Renewable Resources of the National Academy of Sciences had completed a report, Enhancement of Food Production in the United States, released in late 1975.
- Responding to a 1974 request from President Ford, the National Academy of Sciences (NAS) was engaged in a 2-year World Food and Nutrition Study involving 14 committees and numerous subcommittees, (The NAS issued an interim report in November 1975.)

The requests for an OTA assessment were discussed with OTA's Food Advisory Committee against the background of these activities, Chairman* Clifton Wharton, Jr,, appointed a subcommittee to confer with OTA staff, review the scope and preliminary findings of related studies, and narrow the assessment scope.

The subcommittee and staff established the following guidelines for a response to the congressional requests. The response should:

- avoid duplication of similar reports;
- be a significant and unique undertaking;
- be manageable in size;
- lead to options for congressional action; and
- be completed in time for legislative use.

Using these guidelines, OTA focused its food and agriculture research and development activities on two areas: implications of increased support of research on major food crops in developing countries, and the area addressed in this report, organizing and financing basic research to increase food production,

"Dr. Wharton, President, Michigan State University served as Chairman until June 1976.

Bask Food Production Research Inadequately Supported

Public support for research to increase food production has declined in the last two decades for a number of reasons. In the 1950's and 1960's, Congress was concerned more with the costs of storing surplus crops and maintaining farm income support programs than with food production research. Although public support has increased modestly, in recent years increases in appropriated funds have not been large enough to offset the loss in the purchasing power of the appropriations due to inflation.

Basic research in the biological sciences related to food production has historically been an undifferentiated segment of the research programs supported both by USDA, in its own Agricultural Research Service, and in the State Agricultural Experiment Stations. Under conditions of declining funds, however, increasing demands for research to solve current production problems has forced a sharp decline in the support for basic research in the biological sciences related to food production. Scientists who testified at the hearings on agricultural research and development (before the subcommittees of the House Committee on Science and Technology, September 23 through October z, 1975,) observed that recent technological advances in crop production in the United States have exhausted the previously existing backlog of basic research available to plant and animal production scientists in a number of areas and that additional basic research is needed,

Administrators of publicly supported agricultural research institutions have been successful in obtaining modest increases in funds for agricultural research in recent years. Almost all increases have been utilized to support urgently requested pest, disease control, and adaptive research, Thus with the need to tackle immediate problems, only a small amount of the additional funds have been channeled into basic research to increase food production. The Department of Agriculture does not have established procedures for financing basic research, as distinguished from adaptive or developmental research.

The National Science Foundation (NSF) recognizes USDA as the lead agency in agricultural research, and in the past has provided only limited support for basic research in biological sciences to increase food production, Although the need for increased research in the biological sciences related to agriculture has been recognized by groups of scientists for several years, little progress has been made in developing plans for organizing and financing increased basic research to increase food production,

There is substantial agreement among agricultural scientists that three high-priority basic research areas-photosynthesis, biological nitrogen fixation, and cell culture studies-offer unusual promise of high potential payoff over a moderate to long-term time period, To illustrate its points, OTA's assessment includes:

1. A consideration of methods for organizing and financing research in these three areas, and the application of these methods to the administration of high-priority basic research to increase food production in related areas; and
2. An examination of the costs and benefits of increased research in these three areas.

To obtain the advice of a diverse group of scientists, OTA established an n-member advisory panel that represented views from the university community, both agricultural and non-agricultural, private research organizations, and industry,

The advisory panel addressed both issues: alternatives for administering basic research to increase food production, and the costs and benefits of expanded research in the three selected areas.

This report reviews the findings of scientific groups concerned with both the need for basic research in high-priority areas and the prospective returns from additional investments in basic research to increase food production, It considers alternatives for administering such research and the implications of alternative levels of financing this research, Finally, it reviews the options open to Congress in dealing with this issue. In preparing this OTA report, the OTA staff drew upon the findings and conclusions of the advisory panel, as well as supplemental materials. The panel's detailed review of the research underway in photosynthesis, biological nitrogen fixation, and cell-culture studies and suggestions for expanding this research over a 6- to lo-year period are attached to provide technical background for the report.

Findings of Scientific Groups

In the past 10 years, four scientific groups have reviewed the agricultural research conducted by USDA and the State Agricultural Experiment Stations,

In April 1965, the Senate Committee on Appropriations requested, in Senate Report No. 156,

> . . . that the Secretary of Agriculture give immediate consideration to the establishment of an appropriate research review committee comprised equally of representatives of land-grant experiment stations, Department research activities, affected producer organizations, and with appropriate industry representation, to examine fully each and every line of agricultural research conducted by the Department and by the State Experiment Stations,

A USDA-SAES task force was organized and a response to this request was issued in October 1966.[1] The task force found that USDA-SAES agricultural research activities required 10,330 scientist years in 1965, and recommended an increase to 14,250 scientist years for the year 1972, 18,170 by the year 1977.

In February 1969 Clifford M, Hardin, then Secretary of Agriculture, requested the Division of Biology and Agriculture, NAS, "To ascertain gaps in agricultural research and make such recommendations as might be appropriate ., . "

Panels were appointed by NAS to review areas of research, visit laboratories, and interview research scientists and administrators in both USDA and the universities,

An NAS committee, under the chairmanship of Dean Glenn Pound of the University of Wisconsin, issued an 80-page report of its findings and conclusions in 1972, together with a 384-page appendix consisting chiefly of the reports of the individual panels.[2] In its general summary, the committee said:

> Bold moves are called for in reshaping administrative philosophies and organizations, in establishing goals and missions, in training and management of scientists and in allocation of resources. There are too many field laboratories . . .

This underscored the report's conclusion that effective use could be made of additional funding,

With respect to level of funding, the committee recommended:

- That increases in Federal support to the SAES via formula funds be maintained at a level at least proportionately as great as for USDA in-house research.

1 Association of State Universities and Land-Grant Colleges and the U.S. Department of Agriculture, A National Program of Research for Agriculture~, Washington, D. C.: U.S. Department of Agriculture. 1966

2 Committee on Research Advisory to the U.S. Department of Agriculture, Report of the Committee on Research Advisory to the U.S. Department of Agriculture. Washington, D.C.: National Academy of Sciences, 1975.

- That the USDA seek a greatly increased level of appropriations for a competitive grants program, which should include support of basic research in the sciences-biological, physical, social—that underpin the USDA mission. These appropriations should be without commodity earmarking, although they should not exclude commodity-related research. They should be available to scientists in the USDA, in land-grant and nonland-grant public universities or colleges, and in private universities or colleges, institutes, and other research agencies.
- That this program be administered in such a way that research proposals are subjected to evaluation by peer panels of selected scientists drawn from those eligible for support, and that administration of the program be different from the administration which allocated funds for USDA in-house research.

A Committee on Agricultural Production Efficiency of the Board on Agriculture and Renewable Resources, NAS, was organized in 1971 to "evaluate the adequacy of the Nation's policies, knowledge, and technology relative to agriculture research and education efforts. " The committee issued a 199-page monograph in 1975, which reviewed new research and agricultural technology, the practical problems for getting improved technologies adopted by small, undercapitalized farms, and the ability of society to make wise choices when a technological change has the possibility of causing adverse environmental effects.[3] The committee's report included these statements:

- We see no way to avoid the problems of basic uncertainty about the future , .,
- A recent study by the Battelle Institute (1973) suggests that the average lead time in research is about 20 years and that it has not decreased appreciably over the years . . ,
- For major advances in the practices and technologies of agriculture, the Nation must continue to look to the research programs in public institutions and in private industry . . .
- The long-range breakthroughs in knowledge and technology that can boost our apparent productivity ceilings will require greater emphasis on basic research attuned to clearly perceived goals ., ,
- There is an urgent need for agricultural research to receive increasing-emphasis and much greater support. The future well-being of mankind could be at stake . . .

The monograph closes with the following sentence:

> The breakthrough in science and technology that must precede the long-range achievement of increased agricultural production efficiency requires additional investment in promising basic research areas such as cell fusion, photosynthesis, and biological nitrogen transformations, being ever mindful of the need to seek practical field applications of major advances in knowledge . . .

The Board on Agriculture and Renewable Resources, NAS, recommended a substantial increase in support for research directed toward the production, dependability, and quality of the food supply in its 1975 report, Enhancement of Food Production in the United States[4]:

- Financial support for such research should be increased to restore at least the 1966 buying power, and the support should be broadly distributed.
- State and Federal support, now totaling about $450 million per year, for research related to agricultural productivity should be increased immediately by 40 percent.

[3]Committee on Agricultural Production Efficiency, Agricultural Production Efficiency. Washington, D. C.: National Academy of Sciences, 1975.

[4]Board on Agriculture and Renewable Resources, Enhancement of Food Production in the United States. Washington, D. C.: National Academy of Sciences, 1975.

Regarding basic or fundamental research, the report stated:

- Fundamental research undergirding food production technology has languished for two decades.
- The National Science Foundation has not focused on agriculturally related research, although it has given substantial support to botany, zoology, and plant and animal physiology and pathology.
- USDA-SAES complex has not adequately funded basic research relating to biological processes that control crop and livestock productivity and insure a greater stability of supply,

The Steering Committee, Commission on International Relations, National Research Council, repeated several of the recommendations made in the earlier report of the Board on Agriculture and Renewable Resources in its interim report, World Food and Nutrition Study, issued in November 1975. The Steering Committee stressed the potential for increasing crop productivity both through improvement in photosynthesis and nitrogen fixation and through the development and use of tissue culture techniques. The interdependence of these three research areas was emphasized as follows:

- To the extent that greater nitrogen fixation and photosynthesis can be induced by genetic changes, the prospects will be multiplied by progress in the application of cell fusion or DNA recombination techniques to genetic manipulation.[5]

Returns From Additional Investments in Basic Research to Increase Food Production

Scientific groups concerned with priorities in food and agricultural research are agreed that the returns from a long-term program of expanded basic research are likely to be great, although additional investments in a wide variety of projects are needed.

An increase in the efficiency of photosynthesis in a crop like soybeans could result in 50-percent increase in yield per acre. The annual value of increased production, reduced acreage, and/or production costs would amount to no less than $1 billion, assuming this increase of only 50 percent in the yield of soybeans in the United States.

Improvement in nitrogen fixation in legumes also would result in large gains. A 10 percent increase in soybean yield has been reported in the last few months where improved nitrogen-fixing bacteria have been utilized in producing the crop.[6] An even greater gain would be achieved with the development of symbiotic nitrogen fixation in corn, cereal grains, or any important crop other than legumes, Such a discovery could reduce the need for nitrogen fertilizer by millions of tons per year in the United States and throughout the world. A saving of half a billion dollars a year in the United States for nitrogen fertilizer is not an unrealistic expectation.

Cell-culture studies offer promise for developing new combinations of germ plasm and thus provide a means for genetic engineering which could lead to new strains of Rhizobium with much higher nitrogen-fixing capacity. They could also lead to new varieties of soybeans, cereals, potatoes, and other crops with substantially higher photosynthetic efficiency levels than occur in conventional plant-breeding methods. In addition, cell and tissue cultures have demonstrated their value both in freeing important cultivars of viruses and other pathogens and as a method for rapidly propagating new improved cultivars, especially those that are reproduced asex-

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[5]Steering Committee, NRC Study on World Food and Nutrition, *World Food and Nutrition Study, interim Report.* Washington, D. C.: National Academy of Sciences, November *1975,* p. *28.*
[6]*New York* Times, Sept. 27, **1976**.

ually. Further research with cell and tissue cultures are likely to lead to additional possibilities for plant improvement,

Scientists consulted by OTA on this project are agreed that:

- The potential for making a major breakthrough within the next 10 years in any one or all three of these high-priority areas is so great that significant expansion in research support is fully justified.
- Sustained research effort is likely to be required for the balance of the 20th century if we are to realize the gain to be made from substantially increasing and exploiting scientific knowledge.

There is a wide consensus in the scientific community that the results of additional investments in research in the areas cited above could be greater than in most other basic research areas. Groups of scientists have identified several areas in addition to photosynthesis, nitrogen fixation, and cell-culture studies which could have substantial returns from expanded research could be substantial.

Most studies of the, productivity of agricultural research indicate that investments in agricultural research in the United States since World War II have shown an annual return of 30 to 40 percent, A summary of the findings of a number of cost-benefit studies of agricultural research investments in the United States and in other countries as compiled by T.W. Arndt and V.W. Ruttan is shown below:

Summary of Direct Cost-Benefit-Type Studies of Agricultural Research Productivity*

Study	Country	Commodity	Period	Annual Rate of Return (%)
Griliches (1958)	U.S.A.	Hybrid Corn	1940-1955	35-40
Peterson (1966)	U.S.A.	Poultry	1915-1960	20-25
Ardito-Barletta (1970)	Mexico	Wheat	1943-1963	90
Ardito-Barletta (1970)	Mexico	Maize	1943-1963	35
Everson (1969)	S. Africa	Sugarcane	1945-1962	40
Ayer (1970)	Brazil	Cotton	1924-1967	77
Hertford, Ardila, Rochec, and Trujillo (1977)	Colombia	Rice	1957-1972	60-82
	Colombia	Soybean	1960-1971	79-96
	Colombia	Wheat	1953-1973	11-12
	Colombia	Cotton	1953-1972	none
Peterson and Fitzharris (1975)	U.S.A.	Aggregate	1937-1942	50
			1937-1952	51
			1957-1962	49
			1967-1972	34

*From *Allocation and Productivity in National and International Agricultural Research*, a seminar report. New York: The Agriculture Development Council, Inc., September 1975.

On the basis of these studies, it is likely that an investment of $300 to $500 million over a lo-year period in expanding basic research would yield returns over the next 20 years of $1 to $2 billion.

Institutions for Administering Basic Research for Food Production*

Basic research to increase food production is defined as those research areas 1) possessing exceptional opportunity for discovery of knowledge vital to the basic understanding of important biological processes in plants and animals, and 2) which can contribute to applied research on problems that have large impact on societal needs and urgency of implementation, They require the participation of a small group of scientists and frequently will benefit from large-scale multidisciplinary and interinstitutional cooperation.

The Federal Government might support additional basic food production research by creating new or expanding existing Federal agricultural research agencies. It could earmark funds for basic research and allocate them to the 55 State Agricultural Experiment Stations on a formula basis. Or, it could make Federal funds for basic research available through a competitive awards program administered by USDA or NSF.

Federal funds are presently appropriated for specific agricultural research projects in USDA and for major research areas such as marketing, production and rural development at the State Agricultural Experiment Stations. The stations' funds are allocated on a formula basis, taking into account population and other factors, Most efforts to increase appropriations for agricultural research in recent years have focused on increased funding for research on pressing problems, such as pest and disease control, or on increasing funds available to State Agricultural Experiment Stations on a formula basis. These increased funds in turn being used to deal with immediate problems. The net effect has been to short change basic research whose payoff is long term.

There is a widespread agreement among both university and Federal agency scientists that creating new Federal agencies to conduct basic research to increase food production would be less cost effective than providing additional funding for institutions and scientists who now have ongoing basic research programs, There is also substantial agreement that funds for high-priority basic food production research should not be allocated on a formula basis if additional basic research funds were made available to USDA and the SAES on a formula basis, There is a high probability that the funds would continue to be utilized in many cases for adapative research and the numerous pressing problems. Further, such a distribution precludes the opportunity to obtain the needed critical mass of funds and personnel to make the kind of breakthroughs expected of basic research.

There are wide variations both in the staffing of Federal, State, and private research agencies and in their ability to provide increased basic research related to food production. For this reason, the usual project and formula basis for allocating agricultural research funds would not be cost effective in allocating high-priority basic research. The greatest progress in basic research in the near future can be achieved by increased funding for those scientists and groups of scientists who now have both ongoing basic research programs to increase food production and proven competence in the field.

Competitive Awards. There is substantial concensus among scientists that the most cost-effective way of financing increased basic research to increase food production is through a competitive awards program. Competitive grants should be available to qualified scientists in USDA research agencies, the State Agricultural Experiment Stations, public and private universities, and nonprofit research

*Some scientists perceive the term "basic research" to pertain to investigations of fundamental processes and relationships without regard to how such knowledge might be applied in a production process, institutions, The key features of such a program would be:

1. Research proposals should be developed in detail by the principal investigators.
2. Research proposals should be reviewed and rated by peer review committees.
3. Funds should be distributed, usually in the form of grants for 3 to 5 years, according to the scientific merit of the proposals and an appraisal of past performance.

Disadvantages of Competitive Awards. Research grants made on a competitive awards basis tend to be awarded to scientists located at well-established research institutions, thus contributing to the rapid growth of these institutions relative to younger and smaller research institutions. The allocation of research grants on a competitive basis also requires that qualified scientists spend considerable time as members of peer review committees, reviewing research proposals.

The administration of high-priority basic research to increase food production could be assigned to USDA, NSF, another existing agency, or a new Federal agency. Historically, USDA has borne the responsibility for food and agricultural research. It has met these responsibilities within the limits of its funds. There is ample evidence of excellent basic research in the USDA-SAES complex. It appears that with adequate levels of funding and changes in allocation procedures, USDA could administer a first-rate program in basic research to increase food production,

An advantage to assigning the responsibility for basic research in the biological sciences to USDA is that the purpose of increasing the Nation's commitment to basic agricultural research is to provide new knowledge which will enable this Nation to significantly increase its production of food. Lines between basic research, applied research, and development of technology are not clear, but the three are interrelated. USDA and SAES scientists have demonstrated their ability to take new information in the biological and physical sciences and apply it to the production and protection of plants and animals through applied research and the development of improved technology, There is merit in supporting basic research through an agency that has the ability to followup with applied research and technological development, and both USDA and SAES have this ability.

The National Science Foundation has established an excellent record for supporting basic research, including work in the biological sciences important to agriculture. It has devised effective procedures for soliciting research proposals in the basic sciences, reviewing the proposals, and making awards to the most productive and promising scientists. The National Science Foundation is capable of handling basic agricultural research but does not have the responsibility, nor is it as well-equipped to support or to integrate the necessary applied research and the development of new technology.

While increased funding for basic research to increase food production could be administered by NSF, it appears that a more efficient and less costly way to proceed would be to assign the responsibility to USDA.

Administering Agencies within USDA. A number of agencies within USDA could administer basic research. Any agency selected would require an experienced administrative officer with high standards of performance in research. The person in charge of administration should be a recognized authority in an important area of basic agricultural research.

If a new office for awarding grants for basic research to increase food production were established, it would not need a large staff. The staff should be sufficient to solicit and acknowledge receipt of research proposals, organize and assist peer-review panels, allocate and administer grants, organize and sponsor special symposia, and prepare annual reports and budgets. In addition to his or her other responsibilities, the person in charge of the administration of grants for basic research to increase food production should have liaison with other agencies supporting or conducting agricultural research and be a member of the interagency Federal Coordinating Council for Science, Engineering, and Technology, and other such relevant groups as may be established.

An advisory board of 12 to 15 rotating members, appointed by the Secretary of Agriculture and representing a variety of disciplines, regions of the county, and Federal, State, and private organizations, may be needed to oversee the program, If such a board were established, it could assist the administrator in the development of proposals and in the selection of areas of research which should be given priority.

The board could also periodically or annually review the areas of basic research to increase food production which should be given priority. It would be the board's responsibility to recommend to the administrator of the program, as conditions change, and to the Secretary of Agriculture the designation of additional basic research areas to be given priority funding,

In establishing operating and review procedures, the administrator and the advisory board should be guided by current practices in the National Institutes of Health (NIH) and by the recommendations in National Science Foundation Peer Review, Volume I, January 1976.

USDA **Has Competitive Grants Authority.** Under Public Law 89-106, the Secretary of Agriculture now has authority to make research grants on a competitive basis for a period not to exceed 5 years for any one grant. Scientists in Federal agencies, however, are not eligible for grants under Public Law 89-106. This authority has been delegated to the Administrator of the Cooperative State Research Service. Congress appropriated funds for FY 1977 for research grants totaling $4.5 million to be awarded on a competitive basis in 11 specified areas.

Administration of grants for basic research to increase food production could be assigned to the Administrator of the Cooperative State Research Service (CSRS). He or she would be responsible for administering all research grants.

There would be a number of advantages in making such an arrangement, as CSRS has experience in administering grants awarded on a competitive basis. Congressional concern could be minimized, overhead costs reduced, and continuity provided. There are also disadvantages to such an arrangement, since CSRS is primarily concerned with activities of the State Agricultural Experiment Stations. Current CSRS programs require increasing amounts of funds and might prevent programs in basic research from receiving the attention and funds they need. The Secretary of Agriculture would have to see to it that participation in the program is open to all qualified scientists, whether they are at State Agricultural Experiment Stations, publicly or privately endowed universities, or at nonprofit research agencies.

An alternative would be to establish an Office of Basic Research Grants as a separate USDA agency, This would provide a high visibility within USDA, assure program integrity, and it would not disrupt operations. It would prevent domination of research grants by a single agency and prevent confusion with other competitive grants. The major disadvantage of this arrangement is that a separate agency would require a separate accounting staff and other administrative services; such services are available in other research agencies in USDA, Since it would be a leading office, its future budget might be restricted despite its small size.

Alternative number 3 is a variation on number 2, It would establish an Office of Basic Research Grants as a separate USDA agency, However, it would have a pass-through provision for funding other agencies which support or conduct basic research to increase food production, such as NSF. This arrangement would recognize USDA as the leading Government agency for food and nutrition research, but would assure the entire scientific community access to funds supporting basic research, Coordination of research funding activities in USDA, NSF, and other agencies concerned with funding basic research would be improved, The scientific community might have greater confidence in the new funding program under such an administrative arrangement.

The significant disadvantage is that it reduces the leadership role of USDA as the agency to promote basic research to increase food production, and increases the costs of administering the grant funds.

Alternative Levels of Financing High-Priority Bask Research To increase Food Production

A comprehensive statement concerning the additional research needed on the more important problems relating to food was prepared by an ad hoc work group of the Agricultural Research Policy Advisory Committee,[7] This group reviewed the adequacy of current research for each of 134 of the most important problem areas identified at the 1975 Kansas City Conference on Research to Meet U.S. and World Food Needs and, in its 1975 report, by the NAS Board on Agriculture and Renewable Resources.

The ad hoc working group of the committee concluded that research should be increased on 117 of the problems. The increases recommended for all 117 problems would require 2,031 scientist years and cost $215 million over a period of 4 years.

The amount of labor expressed in scientist years and the recommended increases over a 4-year period in each of three broad subject areas is shown below:

	Current Scientist Years	Recommended Increase in Scientist Years	Percent
Human Needs for Food, Including Nutrient Requirement, Food Technology, and Food Safety.	622	305	49
Organization of Resources to provide Public Policy,, Finance, and international Development.	582	191	33
Management of Resources to Provide Food, Including Land Water, Crop, and Livestock Production	4702	1535-	33
Total	5906	2031	35

No comparable analysis has been made for the number of scientist years and necessary increases in basic research to increase food production.

The OTA advisory panel was asked to direct its attention to the more limited subject of needed increase in basic research in photosynthesis, nitrogen fixation, and cell-culture studies, Their analysis indicates that current research funding through all public and private sources amounts to about $15,6 million annually for the three areas. About 290 USDA-SAES scientists are engaged in the three areas of research. In addition, approximately 75 scientists are at other universities, nonprofit organizations, and in private industry. (Table 1.)

[7] Report of Ad Hoc Work Group on Most Important Problems, U.S. Food Research. Washington, D. C.: U.S. Department of Agriculture, May 1976 (duplicated).

The advisory panel estimated that in the first year of an expanded basic research program in the three areas of photosynthesis, biological nitrogen fixation, and cell-culture studies, research funding requests of merit would total $12.25 million. Additional funds would be needed for administering the program of grants to be awarded on a competitive basis.

The advisory panel emphasized the close relationship among the three areas of research and urged maximum flexibility in allocating them any increased funding. The panel's technical analysis and discussion is included in their attached "Supplementary Technical Analysis."

The first objective of an expanded basic research program should be the provision of more adequate support for scientists now doing high-quality research in these areas. After their needs have been met, the panel recommends annual increases in funds for a 6-year period in order to increase the number of scientists working in these high-priority areas by 40 to 50 percent,

The minimum expansion program for the three research areas would start at $12.45

Table 1. **Estimated** Annual Expenditures and Scientist Yews for Research on Photosynthesis, Nitrogen Fixation and Cell Studies

(Expenditures in $1000)

	Current Research Information System[1]							NSF[4]
	CSRS Admin./ USDA Approp.	Other Federal	Non-Federal[a]	Total	No. Res. Projects	Number of Scientists		
						Scientists	Years[3]	
Photosynthesis	$2,497	$633	$2,849	$5,979	140	182	77	$3,723
Nitrogen Fixation	867	415	920	2,202	54	71	30	1,285
Cell Studies	451	58	601	1,110	28	37	16	612
Totals	$3,815	$1,106	$4,370	$9,291	222	290	123	$5,620

[1]Analysis of Juno 1976 CRIS data by W. K. Kennedy.

[2]Agricultural Research and Development Special Oversight Hearings, Part II, before Subcommittee on Science, Research, and Technology and the Subcommittee on Domestic and International Scientific Planning and Analysis of the Committee on Science and Technology, U.S. House of Representatives, No. 51, U.S. Government Printing Office, 1976, Pages 1126 and 1127.

[3]*Note:* Scientist years indicates the number of full-time scientist equivalents. A somewhat greater number of scientists are engaged in the designated areas of research, since those at the universities hove teaching os well os research responsibilities.

[4]*Note:* At least o portion of the support provided by NSF for research on photosynthesis and nitrogen fixation may be included in the other federal funds listed under CRIS. Hence the total for photosynthesis may be about $9.2 million and for nitrogen fixation about $3.1 million. The total level of annual research support for these three high. priority areas moy be about $13.4 million through USDA, NSF, and SAES.

million the first year, increasing to about $50 million in the tenth year. The advisory panel believed that such an expansion program should be considered a minimum effort. The provision of funds for an even greater expansion was recommended, permitting a 60 to 70 percent increase in the number of scientists engaged in basic research in photosynthesis, biological nitrogen fixation, and cell-culture studies over a lo-year period.

A complete review of basic research in the three areas and a proposed lo-year expansion program is developed in detail in the advisory panel's attached "Supplementary Technical Analysis, "

Bask Research in Other Areas

Expansion programs for basic research to increase food production in other areas, such as management and breeding of plants to minimize environmental stress, plant growth regulators, or more effective and less dangerous pesticides, would merit perhaps roughly comparable funding.

The NAS World Food and Nutrition Study issued in June 1977 proposes a first-year increase in Federal funds for food and nutrition research of $l20 million to be divided equally between (1) USDA in-house research and Hatch formula allocations, and (z) a new grants award program. The study proposes that after the first-year research funds be increased 10 percent per year for a 5-year period. Such a program of increases would raise USDA research support from $522 million to nearly $1 billion annually.[8] Although the scientists in this study emphasize the need for increased basic research to increase food production, they do not indicate how the funds for competitive grant programs should be allocated between basic and applied research. It is probable that fully half to two-thirds of the funds made available in the next 5 to 10 years for expanded food and nutrition research under a competitive grants program should be allocated for basic research.

[8] Steering Committee, NRC Study on World Food and Nutrition, *World Food and Nutrition Study*, final report, Washington, D.C., National Academy of Sciences, June 1977, p. 19.

Summary

Available studies and discussions with informed agricultural scientists point to an urgent need for additional basic research directed toward increasing food production. The three highest priority areas, from the standpoint of prospective payoff, appear to be those discussed in this report—photosynthesis, biological nitrogen fixation, and cell-culture studies. A minimum expansion program in these three areas should start at $12.45 million and increase several million dollars a year for a 6-year period, An even larger program would be needed to fully use the potential opportunities for an accelerated program of basic research in five or six important basic research areas.

Congressional Options

The past 10 years have been years of rapidly growing research programs in health, space explorations, energy, environmental protection, and related fields, but years of declining research programs for the enhancement of food production. Scientists have been drawn from basic food and nutrition research into these other fields. The sharp inflationary price increases in the past 5 years have not been matched by comparable increases in Federal funds for food and agriculture research. Federal appropriations for research in USDA and the State Agricultural Experiment Stations totaled $522,284,000 for FY 1977. However, appropriations of $570,584,000 would have been required to provide the same level of research support as in 1966. Federal appropriations for USDA-SAES research for FY 1977 lack $48.3 million of equal purchasing power of the 1966 appropriations for research.

The issue for Congress is what priority to place on an expansion in basic research to enhance food production. If Congress desires more public funds invested in such basic research, it appears that funds will have to be earmarked for this purpose. Otherwise, as research funds are now administered both in USDA and in the State Agricultural Experiment Stations, there is no assurance that additional funds will be utilized for these specific purposes. Thus option number one for Congress is to continue the status quo. However, if changes are desired, option number two would be to earmark funds allocated under a competitive grants program utilizing a peer review system. This appears to be the most satisfactory means of assuring that such funds will be utilized effectively in expanding high-priority basic research. Additional legislation is not required for the administration of such funds. Without additional directives the Secretary of Agriculture would have discretion, as provided in Public Law 89-106, to delegate the administration of such funds to any member of his administrative staff, Legislation may be required, however, to authorize the Agricultural Research Service to participate in competitive grants programs,

The third option for Congress would be to pass legislation setting up a USDA Office of Basic Research Grants, with or without a pass-through provision. The legislation could provide for a 5- to lo-year or longer term program at either minimum or higher funding levels,

A fourth option for Congress would be to authorize and fund an NSF program of expanded basic research to increase food production.

Appendix

Supplementary Technical Analysis

Prepared by an ad hoc Advisory Panel
for the Office of Technology Assessment,
Congress of the United States
W. K. Kennedy, Chairman
September 1976

The views expressed in supplementary material are not necessarily those of the OTA Board, or its individual members. Any reference to this material should clearly identify the source as the Advisory Panel.

Rationale for selecting photosynthesis, nitrogen-fixation, and tissue culture as high-priority areas

The need for basic research in the plant sciences, and the potential for increasing crop productivity both through improvements in the efficiency of photosynthesis and nitrogen fixation and through the development and use of tissue culture techniques, have been outlined in the November 1975 Interim Report of the Steering Committee of the NRC Study on World Food and Nutrition and the Board on Agriculture and Renewable Resources report, "Enhancement of Food Production for the United States;" in the report prepared by a panel of eight scientists in February 1976 for the National Science Foundation, "Researchable Areas which have Potential for Increasing Crop Production;" and in the report of the International Conference in October 1975, sponsored by Michigan State University and the Charles F. Kettering Foundation, "Crop Productivity—Research Imperatives, " Reports of the Agricultural Research Policy Advisory Committee (ARPAC) of the U.S. Department of Agriculture (USDA) and the National Association of State Universities and Land-Grant Colleges, and internal documents of the Agricultural Research Service, also recognize the need for expanded research on photosynthesis, nitrogen use and fixation, and cell cultures, The above-cited reports properly emphasize the tremendous opportunity for enhancing food production through expanded research in the three areas, but additional benefits that should be noted are the resulting technologies would be nonpolluting, would produce no noise, would add to the resources of the earth, and are nonpolitical, All mankind would benefit from significant advances in any one or all three areas.

Excellent review articles on the current state of knowledge and the opportunities and need for expanded research in each of the three areas appeared in Science, Volume 188, May 9, 1975, "Improving the Efficiency of Photo synthesis," by Israel Zelitch, pp. 626-633; "Nitrogen Fixation Research: A Key to World Food?, " by R.W.F. Hardy and U.S. Hevelka, pp. 633-643; and "Plant Cell Cultures: Genetic Aspects of Crop Improvement," by Peter S. Carlson and Joseph C. Polacco, pp. 622-625.

While promising research in the three areas is being carried out in a limited number of laboratories throughout the United States, the advisory panel is distressed that world leadership for research in the three areas currently does not rest with the United States, and available data indicate that there will be a further decline in the relative position of U.S. mission-oriented basic research to enhance food production unless there is a major change in U.S. agricultural research policies and levels of support.

The importance of photosynthesis is obvious because the ultimate yield of crop and animal products is dependent upon the net accumulation of photosynthate and the partitioning of accumulated photosynthate between the usable portions of the plant and those that are not usable by humans or animals. The integration of photosynthate accumulation and its partitioning among the usable and nonusable portions of the plant gives realized yield, The maximum daily efficiency of converting light energy into photosynthate only approaches 3 percent in a highly efficient crop such as corn, and most plants have even lower light-energy conversions. Utilizing 1 percent more of the sunlight falling on a plant during the growing season for production of photosynthate could lead to realized yield increased from 50 percent to well over 100 percent, if the ratio of usable and nonusable portions remained the same.

Achievement of high crop yield under a given set of soil and climatic variables requires exact integration and precise balance among the numerous gene-directed and enzyme-implemented biochemical actions and physiological processes. High-yielding crop cultivars often differ extensively, indicating not one or only a few genetic-biochemical-physiological pathways, but rather numerous combinations with potential for giving high yield. Unfortunately, low- and moderate-yielding combinations occur far more frequently than high-yielding combinations, making the breeding of higher-yielding cultivars a slow and difficult process,

Currently, limited understanding of the physiological genetics of yield leaves genetic improvement of plants almost totally dependent upon chance recombination of favorable genes and of the accompanying enzyme-implemented biochemical and physiological processes. Efficiency of breeding higher-yielding cultivars would be increased if the roles, interactions, and modes of integration of the many physiological components of yield expression were better understood.

Experience accumulated over the past 40 years indicates that improvement in efficiency of breeding higher-yielding cultivars requires consideration of more than one or a few of the physiological component processes leading to yield, Benefits from crosses using genetic variation in one or a few components have been disappointing. Major improvement in the efficiency of breeding high-yielding cultivars will require broad and coherent research, including integration of the efforts of different scientific disciplines directed toward the common goal of enhancing crop productivity.

While realized yield is dependent upon the net accumulation of photosynthate in usable organs of the plant, the availability of adequate supplies of nitrogen also is essential for high crop yields. Increased input of fertilizer nitrogen during the past quarter century has been an important factor for the 3-percent average annual increase in world cereal production. Increasing yields in both less-developed countries and more-developed countries parallel increasing use rates of fertilizer nitrogen during this period. In 1974, world consumption of fertilizer nitrogen was 40 x 10^6 tons compared with 3.5 x 10^6 in 1950.

The additional nitrogen inputs required for increasing world crop production during the next quarter century could be provided by the construction and operation of about 500 additional large-scale ammonia synthesis plants to produce a total of 160 x 10^6 tons annually. There are many reasons, including energy and economic costs, that support the desirability of developing and applying improved or alternate technologies for nitrogen input rather than relying solely on fertilizer nitrogen. Exploratory leads available in both chemistry and biology suggest that the opportunities for development of such technologies for nitrogen input in the short- and long-term appear to be favorable.

Recent advances in the culture of plant cells and tissues in vitro have provided the basis of a novel technology that permits the application of microbiological methods to higher plants. By employing populations of haploid or diploid cells as experimental material, it is possible to utilize the genetic, physiological, and biochemical procedures developed with microorganisms to induce and recover potentially desirable mutations, to make possible the rapid screening of natural-occurring variability and to extend the range of plant hybridization beyond the bounds of sexual compatibility, Since, in some species, plants can be regenerated from cultured cells, modifications induced in culture can be examined and utilized in the whole plant. The development of cell-culture technology is of importance for practical applications in agriculture and for continued long-term advances in crop improvement,

It should be noted that there is an interrelationship among the three selected high-priority research areas. Realized yield is dependent upon the accumulation and partitioning of photosynthate. Realized yield also is dependent upon the availability of adequate supplies of nitrogen for vigorous growth of leaves (where most of the photosynthesis occurs) and for the protein portions of the photosynthate accumulation in usable plant organs such as the seeds of cereals, corn, and soybeans, Much of the nitrogen taken up by plants is in the nitrate form, and energy derived through photosynthesis is required to reduce the nitrate in order that it can be utilized by the plant to synthesize protein. If the nitrogen is obtained through the symbiotic fixation of nitrogen, there is an energy requirement for the growth and development of the nodule as well as the support of the Rhizobium nitrogen-fixing bacteria, In fact, available photosynthate is a limiting factor in biological nitrogen fixation by Rhizobium. Thus, the level of nitrogen utilization in all plants and of nitrogen fixation in legumes is governed by the efficiency of photosynthesis.

Improving crops through the recombination of currently available genetic material is felt by many to have great potential for future advances in photosynthetic efficiency and nitrogen fixation. Both depend upon the integration or recombination of new types of genetic material, and such advances will require the combined efforts and close cooperation of biochemists, plant physiologists, microbiologists, plant breeders, agronomists, and horticultural scientists. The perfection of cell-culture techniques will provide these scientists with more rapid ways of screening potential new sources of biochemical pathways and/or new ways of inducing more efficient mechanisms for accumulating and partitioning photosynthate and in utilizing applied nitrogen fertilizer or in enhancing biological nitrogen fixation,

A more detailed listing of research opportunities in each of the three areas was developed at the International Conference on Crop Productivity-Research Imperatives held at Harbor Springs, Mich., October 20-24, 1975. More than zoo participants-most of them active scientist+ examined how plant scientists with input from other disciplines could best contribute to enhancing crop productivity and dependability on a global scale, The focus of the conference was on the fundamental biological processes that control productivity of economically important food crops, with appropriate concern for husbanding nonrenewable resources. The conference included six discussion groups of 30 to 40 scientists, each group addressing itself to key areas affecting crop productivity, The conclusions and recommendations of each discussion group represented the consensus of the participating scientists as summarized by the selected reporters. Portions of the reports of three discussion groups—photosynthesis, nitrogen fixation, and genetic engineering of plants follow.

Photosynthesis

During the past 15 months several papers have been prepared by scientists engaged in photosynthesis research in which current knowledge was summarized and the opportunities for increasing photosynthetic efficiency were discussed. The paper by Bukovac, Moss, and Zelitch in Crop Productivity—Research Imperatives summarizes the analysis of a work group of 37 scientists at the International Conference at Harbor Springs, Mich. on the research needs and opportunities in the following areas of photosynthesis:

"I, Identify the aspects of photosynthesis which limit CO_2 input in natural environments.

"a. Interception *and* Utilization of Light: Crop photosynthetic productivity is strongly influenced by growth rate of leaves, leaf angle. leaf lifetime, and photosynthetic capacity. Research is needed to determine how these factors interact and the degree to which they can be exploited to increase photosynthetic productivity per unit field area.

"b, CO_2 Absorption: The opportunities must be explored to increase the rate of CO_2 fixation in plants by altering leaf stomatal characteristics, cell size and shape, and components of the system of plants.

"c. Biochemical Processes of Carbon Metabolism: Emphasis should he placed on characterizing the properties of the enzymes of CO_2 fixation and subsequent metabolism. How are these enzymes controlled, and what are the limits within which they can be altered? The limitations imposed by electron transport processes should be determined. The role of photorespiration and its relation to photosynthesis and plant growth must be evaluated. The range of enzyme variation of natural ecosystems should be determined with particular emphasis on the different biochemical systems for photosynthesis in the C_3-, C_4-, CAM-type plants. The roles of respiratory processes in carbon input in plant productivity should be examined. The environmental responses of rate-limiting steps i n carbon metabolism should be studied. Genetic basis of these processes and chemicals to modify them need to be identified.

"II. Relationship of plant development to photosynthesis: We need to know how photosynthesis influences plant growth and which developmental stages of crop plants are limited by the availability of products of photosynthesis.

"a, Translocation and Partitioning: Studies are needed on the transport processes in crop plants and on the partitioning of photosynthetic products among the sites of utilization such as fruits or other storage organs or sites of nitrogen-fixation. We need to know the mechanisms and controls that determine whether photosynthate remains in the leaf cell or moves into the phloem and on to sites of storage or utilization,

"b. Hormonal and Chemical Regulation in Crop Plants: Both basic and applied research on plant growth regulators is needed. What plant hormone systems are involved? What are the signals between cells and plant organs? Which signals control plant productivity and how can the signals be altered? Synthetic growth regulators and genetic means should be developed to modify beneficially the production, internal partitioning, and storage of carbon compounds in plants.

"III. Provide plant breeders with new screening procedures: Research is needed to provide plant breeders with rapid screening procedures which would aid in identifying and incorporating yield-enhancing carbon input characteristics into crops. " Tissue culture (in vitro) techniques offer considerable potential in providing these new screening procedures.

Nitrogen Fixation

The opportunity for increasing plant yields through greater biological fixation of nitrogen and more effective use of available nitrogen by plants has been outlined in several recent papers, The chapter, "Nitrogen Input," by Hardy, Filner, and Hagemen in Crop Productivity y—Research Imperatives, summarizes the judgments of 32 scientists regarding research imperatives in the chemical and biological fixation of nitrogen and its availability and efficient use by plants, The authors point out the advantages of developing improved technology that would "minimize the energy and capital costs of nitrogen fertilizers. "

Recommended areas of research include:

1. Development of "catalysts that work at lower temperatures and pressures" for the production of synthetic nitrogen fetilizer,
2. Increased understanding of the role of molybdenum and iron in N_2 reduction in nitrogen-fixing bacteria.
3. Decrease the need for nitrogen fertilizer through improved procedures for rotational-, inter-, and relay-cropping of legumes and cereals, by the development of better recycling processes for recovering nitrogen from urban and agricultural wastes, and by maximizing "the efficiency of use of soil nitrogen and fertilizer nitrogen" through:
   "a) improved utilization of nitrogen by plants through chemical, cultural and genetic means:

"b) modulating the rate of soil nitrogen transformations by chemical and cultural means (such as denitrification): and

"c) improved rate data for each of the steps of the global nitrogen cycle, "

4. "Develop nitrogen self-sufficiency in crops" by:
   a) ' ' Developing optimal plant-microorganismal combinations' increasing nitrogen fixation of legume-rhizobial associations by optimization of host-strain combinations, quality contro1 of rhizobia1 innoculum, development of effective inoculation technology and overcoming inhibition of nitrogen fixation by fixed nitrogen.
   b) "Increasing the transfer of photosynthetic energy from the plant to N, -fixing microorganisms associated with the plant. " Major attention should be given to improved nitrogen fixation of legume-rhizobial associations by increasing photosynthate available to nodules through genetic or chemical means, but the photosynthetic requirements of N_2-fixing associations in cerea1s and grasses such as the Spirillum-grass association should not be ignored.
   c) "Seeking, evaluating, and developing N_2-fixing microorganisms for use in supplying nitrogen to cereals and grasses.

The panel of eight scientists who prepared a report for the National Science Foundation in February 1976 entitled, "Researchable Areas Which Have Potential for Increasing Crop Production, " recommended two additional areas of research that are long-term projects (perhaps 25 or more years):

1. "Extend rhizobial-based nitrogen fixation to non-legume crops. "
2. "Transfer genetic information for N_2 fixation and necessary associated reactions to higher crop plants. "

There is little hope of attaining either of these goals until cell culture techniques have been improved. Furthermore, they will involve recombinant DNA research that in turn will require special containment facilities.

Genetic Engineering of Plants

Increasing our knowledge and understanding of photosynthesis and nitrogen fixation and utilization will enable plant breeders to make more rapid progress in crop improvement through the use of conventional but time-consuming plant-breeding methods. Considerable potential exists for increasing the rate of plant improvement through the use of in vitro (tissue culture) techniques. The paper by Adams, Carlson, Grafius, and Wallace in *Crop* Productivity—Research Imperatives, outlines the conclusions of 33 scientists about needed research in plant cell and tissue culture. These authors list the following short-term research imperatives:

"1, Determine how to regenerate whole plants of the major crop species.

"2, Adapt and apply the techniques of somatic cell genetics to the goals of understanding genetic modification, organization and regulation in higher plants.

"3. Perform mass selective screening for traits of agronomic value, as well as for processes involved in the agronomic expression of components,

"4. Cell and tissue cultures might be used for preservation of germ plasm of vegetatively propagated species.

"5. Two currently applicable techniques of in vitro culture in plant improvement are: (a) recovery of pathogen-free plants and (h) rapid vegetative increase of new clones and cultivars. The first is especially important in vegetatively reproduced crops such as potato and sugar cane, and it is predicted that the second will become very important in forest crops and in certain orchard crops, The techniques now available should be applied to a wide range of crop species, "

The authors outline long-term research imperatives while recognizing that the current absence of proper techniques limit progress, Perfection of cell- and tissue-culture techniques for the major food plants such as cereals, corn, and soybeans will permit new approaches to the improvement of these crops.

· 1. Severe limitation of cell culture technology stems from limited knowledge of plant physiological and biochemical processes. The recognition and recovery of genetic variation in vitro is dependent upon distinct cellular phenomena. Further research will provide insight into the molecular and cellular mechanisms underlying agronomically important traits. The biochemical and physiological components of whole plant characters must then be duplicated in vitro. Selection schemes which recover variants for processes unique to higher plants must be developed. There are also certainly limits as to the types of variants which can be recovered in vitro. Selective systems designed to recover mutuants in basic metabolism have a high probability of success, Mutant systems attempting to modify tissue specific characters or characters unique to certain differentiated states would have a lower probability of success. If a character is not expressed by cells in culture, then it is impossible to select for variants of that character in vitro. At the present time, in vitro methods are inadequate for attempting to modify complex developmental characteristics. This area requires further research.

"Z. An area which holds promise for increased productivity is increased genetic diversity. Fusion of protoplasts from different species is one approach to increasing genetic disparity, In many instances, the goal of increasing genetic diversity is not limited by hybrid production but by the integration of evolutionary divergent genomes. Sterility and lack of recombination between the genomes do not permit the potentially novel germplasm to be utilized. In vitro techniques often reveal ways to circumvent this problem. Research which focuses on inducing, recognizing, and recovering chromosornal changes in somatic cells should be encouraged. These techniques should particularly attempt to develop methods to induce chromosome loss. There is also a need for techniques to induce and recover genetic recombinant from somatic cells. In this fashion, in vitro culture can be used in conjunction with sexually and somatically produced hybrids where incompatibilities present barriers to growth and development, Tissue from the hybrids might be cultured in vitro, subject to the treatments which caused genetic alterations and then regenerated into plants, Fertile individuals which display the derived combinations of characteristics could then be recovered from the population of regenerated plants.

"3. Cell-culture techniques offer the possibility of exploring the importance of genetically different organelles and cytoplasm to plant improvement. In normal sexual reproduction, the male gamete contributes little to no cytoplasm to the zygote. Somatic hybridization allows the production of cells which are hybrid for the cytoplasmic components. Genetic utilization and manipulation of these cytoplasmic hybrid should permit a more refined analysis of the importance of these components in plant improvement,

"4 Long-term approaches to genetic engineering should be encouraged. Such speculative goals as accomplishing genetic transformation, transduction and plasmid transfer may provide a future source of genetic variability as well as an analytical technique to define the genetic organization in crop plant species,",

A special case for cell studies (less long term) is that of the legumes, The bacteroid is the repositor of some important genetic traits (particularly nitrogen fixation). The technology for genetic engineering (gene transfer) between microorganisms is known and has been well developed. Therefore it should be possible to increase the gene dosage for nitrogen fixation in Rhizobium and evaluate the consequences of that enrichment, and this should be possible for all legumes, Similar transfers to the grasses should take much longer because:

(a) they do not associate with bacteria (which is the 'mutated' agent);
(b) they have not the characteristic structure (nodules, leghemaglobin, etc.) to protect the nitrogenase enzyme.

Current and Proposed Levels of Funding for Research on Photosynthesis, Nitrogen Fixation, and Cell Cultures

The ad hoc Work Group established by ARPAC to study the 134 most important research problems submitted its report in May 1976. The report summarizes current levels of support in USDA's Agricultural Research Service (ARS) and the State Agricultural Experiment Stations (SAES) for different areas of agricultural and related research. The Work Group estimates 68 scientist years are devoted to research on photosynthesis mechanisms and improvements and recommends an increase of 31 scientist years over the next 4 years, The current average expenditure for a scientist year is approximately $73,000, which is an inadequate level of support for most highly productive scientists. Present expenditures by ARS and SAES for photosynthesis research amount to approximately $4,960,000 annually and the ad hoc Work Group suggests an increase of $2,250,000 annually by the fourth year.

The ad hoc Work Group estimates 38 scientist years are allocated to nitrogen fixation by ARS and the SAES, and it recommends an increase of 30 scientist years for research on nitrogen fixation by legumes and nonlegumes, Present annual expenditures are estimated at $2,524,000 and the Work Group proposes an increase in annual research support of about $2,000,000 within the next 4 years,

The ad hoc Work Group estimates 14 scientist years devoted to cell studies and recommends an increase of 8 scientist years for research on basic cell and tissue-culture techniques and "16 scientist years to develop cell and tissue-culture approaches for (1) studying biochemical pathways of protein synthesis, (2) tracing pathways and identifying desirable metabolic products and defining regulators of many growth processes, and (3) determining and quantifying plant metabolic disruptions caused by diseases and other host-specific pests. " Current levels of expenditures total $1,163,000 annually, and the recommended increase would amount to $2 million annually within 3 years.

The annual research expenditures estimated by BARR in "Enhancement of Food Production for the United States, " include research support provided by NSF, NIH, AEC-ERDA and SAES (ARS was not listed but was included). BARR indicates annual expenditures for photosynthesis research are $10 million, and recommends a two-fold increase in level of funding,

BARR reports current funding level for nitrogen fixation at less than $5 million for all sources. It states, "Research funding should be increased to $25 million beginning in FY 1977, with a 25 percent increment of the base for the next 5 years, " The same group reports that less than $500,000 is currently invested in cell studies and proposes a five-fold increase beginning with a doubling in FY 1977.

A recent analysis of the research work included in the USDA Current Research Information System (CRIS) by the OTA panel chairman indicates that current levels of support in the USDA-SAES complex are approximately $6 million, 182 scientists, and 77 scientist years for photosynthesis, $2.2 million, 71 scientists and 30 scientist years for nitrogen fixation, and $1.1 million, 37 scientists and 16 scientist years for cell and tissue studies (table 1). Research support through NSF for these three areas amounts to about $5.6 million annually, but a portion of the NSF funding probably is included in the support for CRIS research projects. Research in all three areas is being carried out by scientists not receiving support through USDA, SAES, and/or NSF. Total research funding through all public and private sources for photosynthesis, nitrogen fixation, and cell and tissue studies probably amounts to about $15.5 million (approximately the same level, but with a slightly different distribution as estimated in the BARR report). The total number of scientists engaged in these areas of research is about 290 in the USDA-SAES complex, with perhaps at least

75 scientists at other universities, nonprofit organizations, and private industry, for a total of approximately 365 scientists,

The November 1975 Interim Report of the NRC Steering Committee supports increased funding for agricultural research with the statement, "We believe that an overall food and nutrition research budget increase, compared to FY 1974 of at least 50 percent in real terms over the next 2 or 3 years is needed to make a strong start on the new priorities, and that a steadily rising real expenditure trend is essential over the next decade and beyond to do justice to the purpose of reducing world hunger and malnutrition. "

The close interrelationship of these three high-priority areas of research should be emphasized. Maximum flexibility in allocating any increased funding among the three areas is urged, Some exciting advances are currently being made in our knowledge of the basic processes governing biological fixation of nitrogen, including the discovery that some strains of Rhizobium are capable of fixing

Table 1. Estimated Annual Expenditures and Scientist Years for Research on Photosynthesis, Nitrogen Fixation, and Cell Studies

(Expenditures in $1,000)

	Current Research Information System[1]							NSF[4]
	CSRS Admin./ USDA Approp.	Other Federal	Non-Federal[2]	Total	No. Res. Projects	Number of Scientists: Scientists	Number of Scientists: Years[3]	
Photosynthesis	$2,497	$633	$2,849	$5,979	140	182	77	$3,723
Nitrogen Fixation	867	415	920	2,202	54	71	30	1,285
Cell Studies	451	,58	601	1,110	28	37	16	612
Totals	$3,815	$1,706	$4370	$9,291	~	~	123	$5,620

[1]Analysis of June 1976 CRiS data by W. K. Kennedy.

[2]Agricultural Research and Development Special Oversight Hearings, Part II, before Subcommittee on Science, Research, and Technology and the Subcommittee on Domestic and International Scientific Planning and Analysis of the Committee on Science and Technology, U.S. House of Representatives, No. 51, U.S. Government Printing Office, 1976, Pages 1126 and 1127.

[3]*Note:* Scientist years indicates the number of full-time scientist equivalents. A somewhat greater number of scientists are engaged in the designated areas of research, since those at the universities have teaching as well as research responsibilities.

[4]*Note:* At least a portion of the support provided by NSF for research on photosynthesis and nitrogen fixation may be included in the other Federal funds listed under CRIS. Hence the total for photosynthesis may be about $9.2 million and for nitrogen fixation about $3.1 million, The total level of annual research support for these three high-priority areas may be about $13.4 million through USDA, NSF, and SAES.

nitrogen in the free-living form, Hence, it can be argued that so to 60 percent of the additional funds should be allocated to nitrogen research. Yet, one of the limiting. factors in symbiotic nitrogen fixation is available photosynthate to support the nodule and Rhizobiurn, Thus, a counterargument can be made for major emphasis on photosynthesis research. Cell and tissue studies may provide the key for making major advances in understanding and improving either or both photosynthesis and nitrogen fixation, and perhaps this research should receive the most favorable consideration.

The panel recommends the use of competitive grants for the allocation of increased funding for high-priority basic research to enhance food production. It urges that decisions about relative level of funding in the three areas be based upon the quality of the submitted proposals and the assessment at the time of the awards by the peer review committees, the program administrator, and the proposed advisory board as to which of these areas, if any, should receive the most favorable consideration.

The first priority in increased funding is to provide adequate support and equipment for the scientists currently doing high-quality research in the three areas, Discussions with a number of recognized scientists engaged in these areas of research reveal that on the average most of them could utilize, effectively approximately $70,000 of additional direct support annually, Indirect costs (overhead) would be in addition to the direct support of the scientists and would amount to about 40 percent of the direct costs, Some scientists need funds for additional supporting personnel such as post-doctorates, graduate assistants, technicians, field, and greenhouse help, Others need substantially more funds for chemicals and special supplies; all scientists need continuing funds for new replacement laboratory equipment, The specific needs of some scientists are substantially greater than an additional $70,000 annually, while an additional $50,000 or less would be adequate for a few of the better-supported scientists currently engaged in these three areas of research.

If it is estimated that high-quality research proposals would be submitted by at least 125 established scientists currently doing research in the three areas, as individual research workers or as members of research teams, the increased funds to meet these existing needs would be $12.25 million for direct and indirect costs (overhead) in FY 1978. Using a 7-percent annual inflation rate, the annual level of increased funding for 125 existing scientists would be $13.10 million in FY 1979, $14,03 million in FY 1980, $19,67 million in FY 1985, $27.58 million in FY 1990, and $54.25 million in FY 2000, (Table 2.) Additional funds would be required for operating the office administering the competitive grants.

Specialized containment facilities will be required for cell studies directed towards recombinant DNA research in nitrogen fixing microorganisms and, desirably, four in number, The estimated cost for a single containment facility is approximately $600,000 (1976 prices). It is proposed that funds be provided for two containment facilities in FY 1979 and for two additional facilities in FY 1981, A 7-percent annual inflation rate was used to estimate a unit cost of approximately $690,()()0 in FY 1979, and $790,000 in FY 1981.

Research progress would be enhanced substantially if additional scientists were encouraged to shift their research efforts to these three high-priority areas, The added scientific capability would include young scientists who are just launching their research careers, and established scientists who have demonstrated excellent research capability in related disciplines or areas of research and who would bring a new set of skills into these high-priority areas of research, Such scientists would be outstanding members of multidisciplinary teams that are prepared to direct their efforts to a comprehensive

Table 2. Alternative Levels of Increased Funding by Years for

Increasing Levels of Annual Support		FY 78	FY 79	FY 80
		(in millions of dollars)		
1. Increased Support for 125 Established Scientists	Direct Costs	8.75	9.36	10.02
	Overhead	3.50	3.74	4.01
2. Support for Compute- [illegible]		0.20	0.30	0.40
3. Two Special Contain- ment Facilities plus Annual Operating Costs			1.38	0.20
4. Support for 25 Addi- tional Scientist Years	Direct Costs		2.75	2.94
	Overhead		1.10	1.18
5. Support for 20 Addi- tional Scientist Years	Direct Costs			2.35
	Overhead			0.94
6. Two Additional Special Containment Facilities plus Annual Operating Costs				
7. Support for 20 Addi- tional Scientist Years Years	Direct Costs			
	Overhead			
8. Support for 20 Additional Scientist Years	Direct Costs			
	Overhead			
9. Support for 20 Additional Scientist Years	Direct Costs			
	Overhead			
10. Support for 20 Additional Scientist Years	Direct Costs			
	Overhead			
11. 5 Percent Growth in Operating Funds for FY85 and Beyond				
Annual Operating Costs		12.45	17.25	22.04
Special Construction Costs		—	1.38	—
Total Annual Appropriations		12.45	18.63	22.04

Research on Photosynthesis, Nitrogen Fixation and Cell Studies*

FY 81	FY 82	FY 83	FY 84	FY 85	FY 90	FY 2000
		(in millions of dollars)				
10.72	11.47	12.27	13.13	14*05	19.70	38.75
4.29	4.59	4.91	5.25	5.62%	7.88	15.50
0.50	0.54	0.58	0.64	0.68	0.95	1.88
0.21	0.23	0.24	0.26	0.28	0.42	0.83
3.15	3.37	3.60	3.86	4.13	5.79	11.39
1.26	1.35	1.44	1.54	1.65	2.32	4.56
2.52	2.70	2.89	3.09	3.30	4.63	9.11
1.01	1.08	1.16	1.24	1.32	1.85	3.64
1.58	0.23	0.24	0.26	0,28	0.42	0.83
2.52	2.70	2.89	3.09	3.30	4.63	9.11
1.01	1.08	1.16	1.24	1.32	1.85	3.64
	2.70	2.89	3.09	3.30	4.63	9.11
	1.08	1.16	1.24	1.32	1.85	3.&l
		2.89	3.09	3.30	4.63	9.11
		1.16	1.24	1.32	1.85	3.64
			3.09	3.30	4.63	9.11
			1.24	1.32	1.85	3.64
				2.49	3.49	6.87
27.19	33.12	39.48	46.59	52.28	73.37	144.36
1.58	—	—	—	—	—	—
28.77	33.12	39.48	46.59	52.28	73.37	144.36

that institution; currently it is 60 to 70 percent of salaries and wages for most institutions.

research program on the interrelationships of photosynthesis and nitrogen fixation, including the full use of cell- and tissue-culture techniques.

Establishing new scientists in these areas of high-priority research will require an average annual funding of at least $110,000 per scientist in FY 1979, Young scientists can be funded adequately at $85,000 to $110,000 per year. Scientists shifting their research efforts from other fields probably have some level of basic support, but they will frequently need substantial sums to remodel and equip laboratories as well as meet increased annual operating funds. The ad hoc Work Group of ARPAC recommended an increase over the next 3 to 4 years of 31 scientist years for photosynthesis, 30 for nitrogen fixation, and 24 for cell studies. The BARR report recommended substantially larger increases in terms of total funding, but did not specify the number of additional scientists,

The panel suggests that an expansion in scientific capability be phased over a 6-year period beginning with an increase of 25 scientist years in FY 1979 at a cost of $110,000 indirect costs and $44,000 for overhead (1978 dollars) per scientist, or a total of $3.85 million above the funds for the increased support to established scientists.

Further increases in support would be for 20 additional scientists in each of the subsequent fiscal years of 1-980, 1981, 1982, 1983, and 1984, It is proposed that a 5-percent increase in operating funds (above the 7-percent inflationary rate) be provided for 1985 and subsequent fiscal years.

Sequential levels of funding are outlined in table 2. As stated earlier, the first priority for increased funding is to provide qualified scientists currently working in the three areas with realistic levels of support by means of competitive research grants. Funds will be required for establishing and operating the competitive grant program office, including funds to support peer-review panels, special symposia, and other program needs. At least two special containment facilities should be constructed for recombinant DNA research with plant cell and related microorganism cultures. This would appear to be the bare minimum for increased funding, It would provide existing scientists with much needed support and would accelerate their individual and collective programs. This level of funding would not provide the support required to bring new talent and skills into the research arena and, thus, the tremendous need and opportunity for establishing multidisciplinary teams of scientists would be largely lost.

Much would be gained by moving to a level of funding that would permit the establishment of four containment chambers and the addition of at least 45 scientist years (through item 6 in table 2). The level of funding would provide adequate support for the present scientists and would attract a modest amount of new talent into these areas of research. It would provide the resources necessary for the development of all important new and expanded multidisciplinary teams for research in these three high-priority areas to enhance U.S. and world food production.

The benefits from modest improvements in photosynthesis efficiency and/or in nitrogen fixation and utilization would be so great that the panel urges full funding of the entire program presented in table 2, Research work could be expanded substantially and in an orderly manner. Full funding would permit considered judgments through FY 1984 as to where new breakthroughs have or are likely to occur, with additional resources to support the most promising research. Beyond FY 1984 the projected levels of additional funding are extremely modest (only 5 percent increase per year above a projected rate of inflation of 7 percent), but the panel recognizes that reallocation of resources should also occur as new knowledge opens up new avenues of research in these three high-priority areas. Hence, funds beyond those proposed for 5 percent annual growth would be available for new or expanded research.

Finally, as stated near the beginning of this section, the panel urges that a fixed percentage of available funds not be assigned to each of the three areas. Rather it urges that all three areas receive increased attention by the quality of the proposals and the judgment of the program administrator, the advisory board, and the peer-review committees.

Most Promising Areas of Research in Photosynthesis, Nitrogen Fixation, and Cell Studies.

As pointed out in the panel's report, maximum flexibility should be maintained in the selection and funding of proposals. The most promising research proposals as judged by peers are the ones that should be funded even though some may fall outside of the areas listed below:

Photosynthesis:

1. Role of photorespiration in C_3 plants, with the aim of reducing the large losses of CO_2 shortly after carbon fixation occurs. Some plants (such as soybeans) lose, through photorespiration, up to 50 percent of the carbon dioxide fixed by photosynthesis. At the present time, this enormous loss through photorespiration serves no known useful purpose, It is important to discover if it indeed does serve a useful function and, if not, how it can be reduced, Increased research on photorespiration should yield extremely useful information about photosynthetic efficiency.

2. Understanding the factors governing leaf and whole-plant senescence. Currently, leaf senescence and, in some cases, whole-plant senescence, occurs in many food plants before they reach maturity. Many of the leaves are dead or dying at the time when seed (grain) development is occurring, and the demand for photosynthate is high. Developing cultivars that would retain active photosynthetic activity for a greater portion of the growing season would increase the yield potential of many food plants by 20 percent or more,

3. Research on translocation and partitioning of photosynthate.What are the factors that determine the amount of photosynthate translocated to usable portions of the plants, such as the seeds (grain) or to other important sites, such as the nodules of legumes, as a source of energy for the nitrogen fixing Rhizobium? Differences exist among cultivars in the ratio of weight of usable portions of the plant to weight of nonusable portions, but the basic processes causing these differences are not understood, and thus selection of plants with higher yield of usable parts continues to be by trial and error.

Nitrogen Fixation

1. Three relatively recent and important observations in biological nitrogen fixation merit substantial increases in research funding.
   a) There are reports from several laboratories that some strains of Rhizobium are capable of nitrogen fixation in the freeliving form (Bergerson in Australia, Keister in the United States, Child in Saskatoon, Scowcroft in New Zealand). This observation permits the selection of efficient nitrogen-fixers without having to infect plants. It also permits genetic engineering experiments in which the complement of nitrogen fixation genes is increased, It allows mapping of the Rhizobium chromosome, with special emphasis on the structural and regulatory genes for nitrogen fixation.
   b) Valentine of California and Brill of Wisconsin have observed that certain double mutants of Klebsiella and Azotobacter are capable of excreting ammonia. These results suggest the possibility of ammonia product ion through fermentation.

c) The very recent observation of Evans of Oregon that hydrogen evolution is a major factor affecting the efficiency of nitrogen fixation in nodulated symbionts. This observation suggests that legumes should be screened for H_2 evolution capability.

2. Loss of fertilizer nitrogen due to denitrification is a major problem, especially in Southeast Asia. More effort needs to be devoted to studying the denitrification process—the organisms involved, the nature of the enzyme catalysis process, and chemical inhibitors of the denitrification process.

3. Crop legumes should be screened for varieties that can utilize fertilizer nitrogen without, at the same time, impairing nitrogen fixing ability. Some available information suggests that strains of legumes have variability in sensitivity to nitrogen fixation in the presence of nitrogen fertilizer (especially ammonia).

Cell Studies and Genetic Engineering of Plants

1. Determine how to regenerate whole plants from the cells of major food plants. The use of cell cultures as a means of improving food plants is of limited value until we know how to regenerate from cells such important crops as rice, corn, wheat, soybeans, etc. Research with carrots and tobacco indicate that such regeneration of whole plants is possible, but intensive research with other plants, especially those in the grass family—cereals and corn—is required to develop the required techniques.

2. Learn how to use cell cultures effectively in selecting improved sources of germ plasm in important food crops, The use of cell cultures offers a way of hastening the development of improved cultivars by plant breeders, but current knowledge is insufficient to permit effective use of this potentially invaluable technique.

3. Increase the gene dosage for nitrogen fixation in Rhizobium. The techniques are available for transferring or bringing about recombinations of DNA in microorganisms and other cellular material. The likelihood, of being able to develop a highly efficient nitrogen fixing strain of Rhizobium is extremely high if specialized facilities for recombinant DNA research are constructed at selected sites.

Team Research in All Three High-Priority Areas

This material has stressed the interrelationships of photosynthesis and nitrogen fixation and how cell studies can contribute to the improvement of the efficiency of photosynthesis in food plants and/or to the development of more effective strains of nitrogen-fixing organisms,

The panel urges that special consideration be given to funding teams of scientists who can demonstrate, through the quality of their proposals and peer assessment of past performance, the ability and desire to undertake fully integrated research programs for the improvement of the efficiency of photosynthesis and biological fixation of nitrogen in important food crops. It would appear that cell cultures and genetic engineering of plants would be an important component of such a research effort in addition to the other contributions of biochemists, plant physiologists, microbiologists, and other plant scientists,

OTA Advisory Panel
W.K. Kennedy, Chairman

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