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
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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 40×10^6 tons compared with 3.5×10^6 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 160×10^6 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 control of rhizobial inoculum, 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 cereals 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 tech-

niques 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 Stat ions (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	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 CRS. 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 forthese three high-priority areas may be about $13.4 million through USDA, NSF, ond 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 100 Scientist Years	Direct Costs	8.25	9.90	10.62
	Overhead	3.20	3.75	4.01
2. Support for One Special Containment Facility	Direct Costs	0.20	0.20	0.40
3. Two Special Containment Facilities plus Annual Operating Costs			1.38	0.20
4. Support for 25 Additional Scientist Years	Direct Costs		2.75	2.95
	Overhead		1.10	1.18
5. Support for 20 Additional Scientist Years	Direct Costs			2.38
	Overhead			0.94
6. Two Additional Special Containment Facilities plus Annual Operating Costs				
7. Support for 20 Additional Scientist 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 . 8 8	15.50
0.50	0.54	0.58	0.64	0 . 6 8	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.&I
		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_2evolution 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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