Chemistry and World Food Supplies: The New Frontiers

PERSPECTIVES AND RECOMMENDATIONS

Editors: Gordon Bixler and L. W. Shemilt

International Union of Pure and Applied Chemistry
and
International Rice Research Institute
Chemistry and World Food Supplies: The New Frontiers
CHEMRAWN II

PERSPECTIVES AND RECOMMENDATIONS
Chemistry and World Food Supplies: The New Frontiers
CHEMRAWN II

PERSPECTIVES AND RECOMMENDATIONS

Plenary Lectures and Recommendations from the International Conference on Chemistry and World Food Supplies, Manila, Philippines, 6-10 December 1982

Edited by
GORDON BIXLER
Office of International Activities
American Chemical Society
Washington, D.C., U.S.A.

and

L. W. SHEMILT
McMaster University
Hamilton, Ontario, Canada
The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today IRRI is one of 13 nonprofit international research and training centers supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 50 donor countries, international and regional organizations, and private foundations.

IRRI receives support, through the CGIAR, from a number of donors including:

- the Asian Development Bank
- the European Economic Community
- the Ford Foundation
- the International Development Research Centre
- the International Fund for Agricultural Development
- the OPEC Special Fund
- the Rockefeller Foundation
- the United Nations Development Programme
- the World Bank

and the international aid agencies of the following governments:

- Australia
- Belgium
- Brazil
- Canada
- Denmark
- Fed. Rep. Germany
- India
- Japan
- Mexico
- Netherlands
- New Zealand
- Philippines
- Saudi Arabia
- Spain
- Sweden
- Switzerland
- United Kingdom
- United States

The responsibility for this publication rests with the International Rice Research Institute.
CONTENTS

PREFACE
BRYANT W. ROSSITER v

FOREWORD
CYRIL PONNAMPERUMA vii

FUTURE ACTIONS COMMITTEE xi

ACKNOWLEDGEMENTS xv

RECOMMENDATIONS 1

CHEMISTRY AND WORLD FOOD SUPPLIES 5

PLENARY LECTURES
Our Greatest Challenge — Feeding a Hungry World
M. S. SWAMINATHAN 25

Economic and Social Factors Influencing the Use of Chemicals in Agriculture
W. DAVID HOPPER 47

The Future Role of Chemistry in Removing Constraints on Food Production and Utilization
LOUIS VON PLANTA 55

Biological Constraints on Food Production and on the Level and Efficient Use of Chemical Inputs
THOMAS R. ODHIAMBO 65

Physical and Chemical Constraints to Food Production in the Tropics
PEDRO A. SANCHEZ, JOHN J. NICHOLAIDES III, and WALTER COUTO 89
Basic Chemical Research and Future Food Supplies  
MELVIN CALVIN

Food and Energy — Interdependent World Needs  
GEORGE PORTER

Feeding the World During the Next Doubling of the World Population  
NORMAN BORLAUG

CONCLUDING REMARKS  
World Hunger: Problems and Opportunities  
BRYANT W. ROSSITER

APPENDIX: CHEMRAWN II Committees
From its formation immediately after World War I up to the early 1970’s, the International Union of Pure and Applied Chemistry (IUPAC) dealt primarily with international scientific administrative matters, such as publications, abstracts, and international agreements on nomenclature, atomic weights, methods, and the like. It also sponsored international meetings during which experts in the subdisciplines of chemistry presented results of chemical research.

In the early 1970’s however, several leaders in IUPAC governing bodies proposed that IUPAC move beyond its traditional activities and address international problems on which chemistry has a direct bearing. They saw that IUPAC’s international contacts put it in a unique position to tap the expertise of the world’s best chemists. They also saw, however, that no science functions in a vacuum and that the interplay with political, economic, and cultural forces must be assessed as well. Perhaps most important, they further saw that simply examining a problem is not sufficient but that a continuing effort also is essential to disseminate findings and promote adoption of solutions by persons in policy positions in government agencies, industrial companies, and research and educational institutions.

As a result of their efforts, IUPAC in 1975 embarked on what has become known as the CHEMRAWN program or, according to the formal operating designation, Chemical Research Applied to World Needs. CHEMRAWN I was held in Toronto, Canada, in July 1978. It dealt with future sources of organic raw materials, then a topic of major concern in light of oil embargoes, rapidly rising prices for petroleum, and depleting petroleum reserves. CHEMRAWN II, the conference on which this publication is based, was held in Manila, Philippines, in December 1982. It dealt with world food supplies, a topic of heightened concern in light of the continuing rapid increase in world population.
CHEMRAWN II took place within sight of the ever-darkening clouds of hunger and malnutrition. While widespread starvation has been alleviated in recent years, the growing need to feed a hungry world remains. Moreover, food-related disasters strike suddenly and with little warning. A global interdependence on food means that two straight years of bad harvests in any one of the major grain-producing nations of the world could precipitate another food crisis such as the one that occurred in 1972-74. Superimposed on that possibility are a burgeoning world population and the rapidly growing demands of a rising middle class asserting interest in more than the simplest of diets. Given the present trends, world population will expand to more than 6 billion people by the end of this century, and eight of every 10 persons will live in developing nations. Many will migrate to urban centers, where food is not grown. Nearly 1500 cities of a million or more inhabitants will have to be supplied. In the next 40 to 50 years, world food production must be increased by an amount greater than has been achieved since the dawn of agriculture 12,000 years ago if growing numbers of people and growing demands for better diets are to be met.

Within this context, the participants of CHEMRAWN II directed their attention to the following objectives:

• First, to identify and put in perspective those areas of research and development having the potential to increase food production and improve food storage and processing significantly.
• Second, to strengthen scientific research in developing nations, particularly in those fields that require professional competence and initiative without excessive capital and human resources.
• Third, to accelerate implementation of research priorities and objectives by fostering cooperation among governments, industries, and universities.

We are indebted to the many people and organizations that contributed to the success of the conference and in particular to The International Rice Research Institute. IRRI cosponsored the conference, and its work as local organizer and host in Manila proved to be invaluable. As for other persons and organizations that contributed to CHEMRAWN II, they number far beyond those we can acknowledge in the lists of affiliate sponsors, members of committees, and donors of both financial assistance and assistance in the work of their personnel at no charge to the conference. They know who they are, of course, and those of us directly responsible for the conference can only hope that their knowledge brings them the personal satisfaction that they earned so completely.

Bryant W. Rossiter
Chairman
CHEMRAWN Committee
International Union of Pure and Applied Chemistry
During the five days of December 6–10, 1982, some 600 leaders from government agencies, industrial companies, financial organizations, foundations, and universities and research institutions around the world gathered in Manila, Philippines. They were there to attend The International Conference on Chemistry and World Food Supplies: The New Frontiers. Sponsored by the International Union of Pure and Applied Chemistry and The International Rice Research Institute, the conference was the second in the CHEMRAWN series described in the preceding pages.

CHEMRAWN II’s objective was to examine the interplay among scientific, economic, political, and cultural factors affecting world food supplies and to recommend appropriate areas for priority attention by agricultural scientists and chemists and chemical engineers and their organizations if the 8 billion people expected to be living by the year 2015 are to have diets that are both adequate and varied. Organizers earlier had concurred with the view among experts that much of the knowledge now available in agriculture and food processing will soon be fully used, and the significant advances in knowledge that led to what has become known popularly as the green revolution are inadequate to meet the increasing need for food. They thus organized CHEMRAWN II as the major initial effort by the world’s chemical and agricultural communities to evaluate the problem, review options, and recommend future courses of action for chemical and agricultural scientists and engineers to pursue aggressively if severe food shortages are to be avoided.

Two publications are being issued based on CHEMRAWN II. This one summarizes the main points made during the conference and presents the conclusions and recommendations drawn from those points. Published by The International Rice Research Institute, it also contains the eight plenary lectures by
experts from both developed and developing countries who examined from broad perspectives the scientific, economic, political, and cultural issues affecting food production, processing, storage, and distribution worldwide.

The other publication contains the texts of the 56 scientific lectures given during the conference by experts who were invited specially by the CHEMRAWN II Program Committee because of their subject-area knowledge. Edited by Prof. L. W. Shemilt, Chemistry and World Food Supplies: The New Frontiers is being published by Pergamon Press.

STRUCTURE OF THE CONFERENCE

The conference was organized around six scientific subject areas that span the food production sequence from seeds, soil preparation, and planting through growth, harvest, storage, processing, and distribution; and it ended with a final session in which lecturers and participants evaluated the most promising lines of chemical research and development.

In broad terms, the CHEMRAWN II Organizing Committee and CHEMRAWN II Program Committee sought to focus on:

• New frontiers in food production and processing, including genetic engineering, the biochemistry of plant stress, use of growth regulators and other chemical means of modifying crop performance, the potential of cell and tissue culture, photosynthetic activity and partitioning, nitrogen fixation, pheromone chemistry, and biomass utilization.

• The role of chemistry in raising agricultural productivity in such areas as soil and crop management, integrated pest and weed control, agricultural resource and environment monitoring, animal and aquaculture systems, and control of major human and animal diseases that limit agricultural production in the tropics.

• Improving the preparation, storage, and processing of foods, including the development of new and superior food sources, use of chemical techniques to preserve food quality and prevent deterioration and losses during processing and storage, and application of chemistry in the assessment, analysis, and quality control of food supplies.

THE FUTURE ACTIONS COMMITTEE

Responsibility for summarizing the presentations and discussions and preparing the conclusions and recommendations for CHEMRAWN II was assigned to the Future Actions Committee. The 23 members of this committee (pages xi-xiv) were selected from among experts in government agencies, industrial companies, and education and research institutions. Coming from both developed and developing countries, they provided invaluable insight into the scientific, engineering, economic, social, political, and cultural dimensions of food production, processing, storage, and distribution. Moreover, they did so from national as well as international perspectives.

It has been my pleasure to serve as chairman of the Future Actions Committee.
The simple listing of their names and affiliations on the pages immediately following this Foreword constitutes far too inadequate thanks to them and to their employers for the contributions that they have made.

With summaries of the scientific sessions and texts of many of the plenary and scientific lectures in hand, the Future Actions Committee began its work some six weeks before the conference. At that time, a small representative group convened for three days in Washington, D.C., to initiate the evaluation, selection, and drafting process for CHEMRAWN II’s summary, conclusions, and recommendations. Then the committee met each morning during the conference in Manila to review presentations, refine the thinking, and prepare drafts for discussion and modification. Following the conference, the drafts on different subtopics were combined into one draft by one of the editors of this volume, Gordon Bixler. That draft has since been reviewed and revised by the committee, and it is now published.

The text begins with the recommendations’ (page 1) and then continues with a combined summary of major points presented during the conference, the conclusions drawn from those points, and the rationales for both the conclusions and the recommendations. Full rationales appear in the plenary lectures in this volume (pages 25-158) and in the scientific lectures in the companion volume. As readers will note, the text of the summary and conclusions is short and the recommendations relatively few. Otherwise, attempting to explain here the many differences and exceptions in world agriculture and then to tailor specific recommendations to account for the many diversities would lead to a totally unwieldy publication. The Future Actions Committee therefore suggests that readers use the thoughts in the following pages as guides and then consult the plenary lectures and the scientific papers for whatever details they may wish to have.

THE FUTURE

CHEMRAWN II’s value no doubt will be judged by the soundness of the conclusions and the quality and aptness of the recommendations. It will especially be judged, however, by the success that persons in policy positions and in positions to affect policies have in the months and indeed in the years ahead in promoting action in their countries. Members of the Future Actions Committee as well as members of the Organizing Committee and the Program Committee have thus outlined for themselves an ambitious program to disseminate the results as widely as possible. This publication and its companion and the efforts of everyone associated with the conference will not single-handedly solve the problem of providing the necessary greater amounts of basic foods and also the greater amounts of different foods to meet the growing demand for diets that are more varied. My colleagues and I trust, however, that the impetus that the publications and our efforts give; the discussions, workshops, and research planning sessions that must now be held; and the decisions that are made as a result of CHEMRAWN II will go far toward helping reach the critical goal of having a world population that is adequately fed.
I am most thankful to the members of the Future Actions Committee who ungrudgingly gave of their time and talent during the long period of intense discussion and preparation before, during, and after CHEMRAWN II. I owe a very special debt of gratitude to Gordon Bixler for his unstinting dedication to the task, his meticulous attention to facts and figures, and his skillful translating into a readable document the extensive deliberations and recommendations of our committee.

Cyril Ponnamperuma
Chairman
Future Actions Committee
FUTURE ACTIONS COMMITTEE

Chairman

Prof. Cyril Ponnamperuma
Director
Laboratory of Chemical Evolution
Department of Chemistry
University of Maryland
College Park, MD 20742, U.S.A.

Members

Dr. Bansi Amla
Director
Central Food Technological Research Institute
Mysore 570-013, India

Dr. Norman E. Borlaug
Director
Wheat, Barley and Triticale Research and Production Programs
International Center for Maize and Wheat Improvement
Londres 40
Mexico 6, D.F., Mexico

Dr. Nyle C. Brady
Senior Assistant Administrator
Agency for International Development
320-21st Street, N.W.
Washington, D.C. 20523, U.S.A.
Ms. Teresa Salazar de Buckle
Head
PADT-Alimentos
Acuerdo de Cartagena
Casilla de Correo: 3237
Lima, Peru

Prof. Melvin Calvin
University Professor of Chemistry
University of California, Berkeley
Berkeley, CA 94720, U.S.A.

Dr. Fujio Egami*
Director Emeritus
Mitshubishi-Kasei Institute of Life Sciences
11, Minamiooya, Michida-shi
Tokyo, Japan

Prof. Masao Fujimaki
President
Ochanomizu University
2-1-1, Otsuka, Bunkyo-ku
Tokyo 112, Japan

Dr. W. David Hopper
Vice President for South Asia
The World Bank
600-19th Street, N.W.
Washington, D.C. 20433, U.S.A.

Dr. Herwig Hulpke
Bayer, A.G.
Forschungszentrum, 512
P.O. Box 101709
Aprapher Weg
d-5600 Wuppertal 1
Federal Republic of Germany

Prof. Emil Q. Javier
Chancellor
University of the Philippines at Los Baños
College, Laguna, Philippines

The Honorable K. T. Li
Magsaysay Awardee
Academia Sinica Located in Taipei, China

*Dr. Egami was appointed to the committee at its inception. Because of declining health, however, he resigned from the committee in the spring of 1982. Everyone associated with him was most saddened when he died in July 1982, and we list him as a committee member as a mark of our respect.
Prof. Li Su  
Deputy Secretary-General  
Academia Sinica  
Beijing, China

Dr. P. Mahadevan  
Senior Officer  
Animal Production Service  
Animal Production and Health Division  
Food and Agriculture Organization  
Via delle Terme di Caracalla  
00100 Rome, Italy

Dr. John W. Mellor  
Director  
International Food Policy Research Institute  
1776 Massachusetts Ave., N.W.  
Washington, D.C. 20036, U.S.A.

Dr. Louis G. Nickell  
Vice President — Research and Development  
Velsicol Chemical Corporation  
341 East Ohio Street  
Chicago, IL 60611, U.S.A.

Prof. Thomas R. Odhiambo  
Director  
The International Centre of Insect Physiology and Ecology  
P.O. Box 30772  
Nairobi, Kenya

Dr. Rad N. Ondarza  
General Director  
Centro de Investigaciones Ecológicas del Sureste  
Carretera Panamericana y Periférico Sur  
29290 San Cristobal de Las Casas  
Chiapas, México

Mr. Thomas W. Parton  
Ciba-Geigy AG  
CH-4002 Basel, Switzerland

Sir Charles Pereira  
Consultant in Tropical Agricultural Research and Land-Use Hydrology  
Peartrees  
Teston  
Maidstone  
Kent, ME18 5AD, England
Sir George Porter
Director and Fullerain Professor of Chemistry
The Royal Institution
21, Albemarle Street
London W1X 4BS, England

Dr. Abdus Salam
Director
International Centre for Theoretical Physics
P.O. Box 586
Miramare
34100 Trieste, Italy

Prof. Glenn T. Seaborg
Associate Director
Lawrence Berkeley Laboratory
University of California, Berkeley
Berkeley, CA 94720, U.S.A.

Prof. Dr. Khaled El-Shazly
Dean
Faculty of Agriculture
Alexandria University
3 Al-Gueish Avenue
Shatby, Alexandria
Arab Republic of Egypt

Dr. M. S. Swaminathan
Director General
The International Rice Research Institute
P.O. Box 933
Manila, Philippines
ACKNOWLEDGEMENTS

We are grateful to the following organizations and companies for their sponsorship and/or generous financial assistance.

Co-sponsors:
International Union of Pure and Applied Chemistry
The International Rice Research Institute

Affiliate Sponsors:
Chemical Society of the Philippines
International Fertilizer Development Center
International Food Policy Research Institute
International Society for Horticultural Science
International Soil Science Society
International Union of Biochemistry
International Union of Biological Sciences
International Union of Food Science and Technology
International Union of Nutritional Sciences

Financial Contributors:
Agency for International Development, USA
Ajinomoto Co., Japan
Asahi Chemical Industry Co. Ltd., Japan
Australian Development Assistance Bureau, Australia
Carnation Company, USA
Castle & Cooke, Incorporated, USA
Canadian International Development Agency, Canada
Chemical Society Located in Taipei, China
Chiyoda Chemical Engineering & Construction Co., Japan
Ciba-Geigy Ltd., Switzerland
The Coca-Cola Company, USA
The Commemorative Association for the Japan World Exposition, Japan
Department of Agriculture, USA
E. I. du Pont de Nemours & Company, USA
Eastman Kodak Company, USA
Exxon Corporation, USA
The Ford Foundation, USA
French Ministry of Research & Industry, France
Fujisawa Pharmaceutical Co. Ltd., Japan
General Foods Corporation, USA
H. J. Heinz Company Foundation, USA
Hershey Foods Corporation, USA
Hoffmann-La Roche Incorporated, USA
International Council of Scientific Unions
International Development Research Centre, Canada
International Union of Pure and Applied Chemistry
Kajima Foundation, Japan
Kikkoman Shoyu Ltd., Japan
Kyowa Hakko Kogyo KK, Japan
Dr. R. Mag Ltd., Switzerland
McCormick & Company Incorporated, USA
Meiji Seika Kaisha Ltd., Japan
The Meito Sangyo Co. Ltd., Japan
National Science Foundation, USA
Nestle S. A., Switzerland
The Quaker Oats Company, USA
Ralston Purina Company, USA
The Rockefeller Foundation, USA
Rohm & Haas Company, USA
Sandoz AG, Switzerland
Shionogi and Co. Ltd., Japan
Sumitomo Chemical Co. Ltd., Japan
Suntory Ltd., Japan
Swift & Company, USA
Takara Shuzo Co. Ltd., Japan
Takeda Chemical Industries, Japan
Teijin Ltd., Japan
Thomas J. Lipton, Incorporated, USA
Toray Industries, Inc., Japan
Toyo Jozo Co. Ltd., Japan
Treuhandstelle IM Verb. der Chemischen Industrie, FRG
UNESCO
Wm. Underwood Company, USA
United Nations Development Programme
Velsicol Chemical Corporation, USA
Xerox Corporation, Canada and USA

In addition to the sponsors and financial donors, the following contributed significantly to CHEMRAWN II and its success.

 Philippine Government
 American Association for the Advancement of Science
 American Chemical Society
 International Food Policy Research Institute
 National Academy of Sciences/National Research Council, USA
The Future Actions Committee of CHEMRAWN II — The International Conference on Chemistry and World Food Supplies: The New Frontiers notes that chemistry is at the root of all life processes. The committee projects that total world food production must be increased at least twofold and preferably three- to fourfold during the next several decades without adding appreciably to the amount of land now under cultivation. Reaching this goal will require the use of agricultural practices that are more intensive, more selective, and more cost effective. Thus, the chemical sciences and technologies must play a key and central role if the food requirements of a rapidly-expanding world population are to be met adequately.

The committee recognizes that human nutritional needs must be treated as part of the overall human system; that poverty, not the lack of food, is the primary cause of malnutrition and starvation; and that in many parts of the world the famine for jobs is as critical as the famine for food. Therefore, the committee’s concern embraces not only areas such as food production, control of postharvest losses, storage, processing, packaging, and the like, but also the social, economic, educational, environmental, and geopolitical factors involved;

With these considerations in mind, the CHEMRAWN II Future Actions Committee recommends:

• **For longer-range research at the forward edge, that:**

  1. Officials of public and private funding agencies, managers of research organizations, and agricultural scientists assign high priority to research and development programs in genetic engineering and particularly to
programs dealing with increased nitrogen fixation, improved stress resistance in plants, control of animal diseases, and enhanced efficiency in milk and meat production.

2. High priority be assigned to fundamental and interdisciplinary research in plant physiology, with particular attention to understanding the molecular basis of reproductive, growth, stress, nutritional, and preservation processes. Leaders in developing countries are especially encouraged to support research on plants that are vital to their own countries.

3. High priority also be assigned to the development of less expensive and more cost-effective nitrogen fertilizers. Among the routes to be investigated are processes for oxidative nitrogen fixation, for producing hydrogen from water using solar radiation as the source of energy, and for improved controlled-release fertilizers.

4. Institutions in developed and developing countries work together on programs designed to improve photosynthetic efficiency, direct partitioning in desired ways, and — in the very long term — achieve artificial photosynthesis.

5. Research on plant and animal growth regulators be increased significantly.

- For near-term research and development related to soils, crops, pests, and animal production systems, that:

6. Multiple, interdisciplinary field studies be conducted throughout tropical and subtropical countries to find the limiting factors between present yields and the maximum yields possible under the most favorable conditions and the results disseminated rapidly and widely in relevant rural areas through improved extension services.

7. Presently-available knowledge of pest-control systems be distributed widely and adapted as quickly as possible to conditions and practices in developing countries.

8. Internationally-accepted standards of safety for people in different environments be established and international agreements be reached on registration, licensing, and patent procedures for pest control chemicals and methods.

9. High priority be given to the development of new chemical and biological methods to control pests in developed and developing countries.

10. Integrated control programs for animals be devised that emphasize (a) new genetic types of animals bred for disease resistance, (b) continuous disease monitoring and diagnostic systems for appraisal of livestock diseases, (c) improved chemotherapeutic and prophylactic measures appropriate for large and small animal husbandry enterprises, and (d) production of medicinals to control infectious diseases and cancers in animals.
• For near-term research and development on food processing systems, that:

11. New and inexpensive packaging materials be developed that allow easy food sterilization, are impermeable to moisture and oxygen, and provide adequate protection under tropical conditions.

12. Increased emphasis be given to programs to improve preservation methods, especially those that can be operated at the home or small-community level without large infusions of capital but that produce foods having good nutrition and good acceptability in light of local customs and preferences.

13. Specialists in genetics and genetic engineering rank postharvest storage and processing characteristics on a par with yield, nutrition, and aesthetic properties in planning experiments and in evaluating experimental results.

14. About the present level be maintained on such recognized methods for enhancing food supplies as producing intermediate moisture foods; supplementation with amino acids and vitamins; and preparation of food analogs, regenerated protein foods resembling meat, and carbohydrates and fats derived from simpler chemicals.

• In the field of education, that:

15. Developing countries formulate long-term programs to attract to agricultural- and food-related scientific disciplines those students and workers who are better and more qualified by improving their educational programs at the primary, secondary, and technician levels; by providing scholarships and awards to qualified citizens to complete their educations at the highest level possible in domestic and foreign institutions; and by increasing the prestige and public understanding of food-related sciences and technologies through educational and public communication channels.

16. Major efforts be made in all countries to educate persons in policy positions, members of special interest groups, and citizens in general to the benefits as well as the risks of chemical inputs to agriculture and food processing.

17. The International Union of Pure and Applied Chemistry continue the CHEMRAWN II initiative and convene conferences in the future on a regular basis to assess progress, needs, and priorities.
Early in the year 2015, 8 billion people will be living in the world. In the very short span of 40 years, if the estimate proves to be correct, population will have doubled from 1975’s population of 4 billion. Not only will there be twice as many people to feed in 2015 as there are now, but the demand for diets that are more nutritious and varied will be much greater than it is today as a result of the higher standard of living that many more people will have at that time. The implication is formidable:

Farmers, livestock keepers, and food processors and distributors will not only have to produce, process, and distribute twice as much food as they do now. They also will have to change the mix among cereals, meats, and vegetables as well as increase production and distribution by perhaps as much as another 100% to satisfy the greatly expanded demand in developing countries for other than the simplest of diets based primarily on the major cereals.

Increasing world food production in some 40 years three-to fourfold is a global problem; but the problem’s nature, its size, the potential solutions, and the prospects for success differ markedly from major region to major region, from country to country, and indeed from area to area within countries. In fact, no human endeavor devoted to a single broad objective operates within the extremes or faces the diversities that farming and animal husbandry face worldwide. To be sure, the number of internationally-important crops on which attention must focus for the greatest impact is not large, totaling fewer than two dozen.* Major crops (10 million metric tons or more annually) in descending order are wheat, maize, barley, cassava, rice, sweet potatoes, bananas, sorghum, pulses (as a group but excluding soybeans and groundnuts), soybeans, citrus, millet, grapes, coconuts, tomatoes, yams and related root crops, groundnuts, dry beans, dry peas, mangos, and watermelons.

*Major crops (10 million metric tons or more annually) in descending order are wheat, maize, barley, cassava, rice, sweet potatoes, bananas, sorghum, pulses (as a group but excluding soybeans and groundnuts), soybeans, citrus, millet, grapes, coconuts, tomatoes, yams and related root crops, groundnuts, dry beans, dry peas, mangos, and watermelons.
animal types are even less numerous,** and so are major climate/crop zone categories.*** However, when these relatively few variables are multiplied by ranges in farm size, soil type, number of individual crop varieties, length of growing season, changes in local climates at particular times, type and population of pests, degree of mechanization, cultivation practices, and farmer/husbandman level of education, the permutations become exceedingly great.

Despite the resulting complexities, certain generalizations are possible. The developed countries should easily increase food production to satisfy populations that are growing relatively slowly and at the same time continue to provide diverse foods for diets that are nutritionally balanced and aesthetically pleasing. Developing countries, meantime, face a much less optimistic future. Many depend heavily on imports to meet their needs for food. Although trade among them offsets food deficits in some cases, their overall deficits are met by surpluses exported by the developed countries. The limit will soon be reached at which the relatively few developed countries can produce more food to make up the deficits in the much more numerous developing countries. Therefore, developing countries will have to become much more nearly self-sufficient as a group if they are to meet their increasing demands for both basic nutrition and also for diets that are more varied.****

As it happens, the gap between actual production and potential production in developing countries is high in both agriculture and aquaculture.

**Much of the increase in food production needed the balance of this decade and into the early 1990’s can be achieved by a combination of technology transfer and technology adaptation.**

Based on this assessment, the conclusions and recommendations for the near term stemming from the CHEMRAWN II conference deal with what must be done for the most part in the developing countries. Some of the research and development that we recommend will be properly conducted in the developed countries, and some will be properly conducted in the developing countries. Scientists and organizations in both types of countries must cooperate closely, however, if advances are to be made sufficiently rapidly and put to effective use sufficiently rapidly to achieve the needed increase in the time available.

The gains in production that can be reasonably expected from research and development on agriculture and aquaculture in developing countries should meet much of the need for more food in the near term. There is no assurance, however,
that these efforts will permit a 100% increase in world food production by 2015 or whenever population does reach 8 billion, much less provide a three- to fourfold increase if rising expectations also are to be met.

We consider it vitally important that several research projects of a very fundamental nature be assigned high priority for support. If they are, then perhaps findings will be available within the next decade that will lead to increases in food production not in inadequate successive steps of several percentage points each but adequate increases in steps of 50%, 100%, and more.

Success can by no means be promised. However, the world risks truly severe shortfalls in food production to meet both growing populations and growing expectations unless such basic programs are supported adequately in the years ahead.

THE FORWARD EDGE

The best opportunities for providing production gains of 50%, 100%, and possibly more lie in the fields of genetics and plant physiology.

Hybridization has been the traditional technique for improving plants to get higher yields, good nutritional balance in edible products, and resistance to pests and hostile environments. The traditional approach of crossing strains with desirable characteristics and introducing the most successful crosses will continue, and it will continue to provide incremental gains as it has in the past. In very recent times, however, biochemists have developed the new technique of genetic engineering. Highly refined analytical and manipulative techniques now permit them to isolate genetic material, identify portions of the genetic molecule responsible for specific characteristics, and then splice this portion onto the genetic molecule from another strain.

The technique that was originally successful only in transplanting genetic information from one microorganism to another now holds promise for plants and animals as well. When this technique becomes broadly applicable to plants, it should be possible for chemists not only to shorten dramatically the time needed to develop new strains of crops, but they may be able to provide advances that enhance characteristics by factors of two, three, and possibly more compared to traditional cross-breeding's incremental gains.

The many research projects classified under the broad rubric of genetic engineering in laboratories of all types worldwide have implications for world food supplies that are more profound than any other category of research.

Scientists conducting such research likely will record near-term successes in making important products, such as amino acids and vitamins to supplement
Population experts now estimate world population 2000 years ago to have been about 250 million, and they calculate it had doubled four times following the advent of agriculture some 10,000 years earlier. The next doubling (to 500 million) appears to have occurred by about the year 1650. Within only another 200 years, however, or by about 1850, population doubled to 1 billion. Then only a short span of 80 years passed (to 1930) to reach 2 billion, and an even shorter span of 45 years passed (to 1975) to reach 4 billion.

How accurate the projection for 8 billion by 2015 proves to be will depend on how rapidly death rates actually decline as health care becomes more widespread and how well birth rates are controlled. Death rates will decline inexorably, of course, pushed as they are by strong worldwide demand for better health care. The need to reduce birth rates, meantime, does not benefit from the same strong support worldwide. Nonetheless, some progress is being made. The Chinese, for example, must maintain the most people within a finite area. They therefore are taking draconian steps not only to slow to a zero increase in population but actually to reduce population in the next several decades. Bangladesh, another country with population at the limit that its land will support, is accelerating attempts to stabilize its population by similarly stringent means. Many other countries, however, including some very populous ones, are succeeding much less well in slowing their birth rates, much less in aiming for reductions in population. These lacks of success are especially apparent in countries of sub-Sahara Africa. Unfortunately, these countries are also in many cases among the ones foods and feeds and in making agriculturally-important health products such as vaccines to control or cure animal diseases. However, successes in the long term offer prospects for a second revolution in agriculture rivaling that of the recent revolution sparked by high-yielding strain of wheat and rice.

Since genetic processes control all characteristics of plants, gaining an understanding of different genetic processes should in time allow scientists to tailor food and feed crops for maximum yields at higher efficiencies and for maximum resistance to pests and environmental conditions. In order to provide advances much greater than traditional incremental gains, however, scientists must emphasize research that increases fundamental knowledge of plant biology and biochemistry if they are to realize the potential of genetic engineering.

A major barrier to progress lies in the difficulty in transmitting genetic material into plant systems except through the sexual cycle. The development of gene-transfer methods, or gene vectors such as the Ti plasmid, represents a major advance. Because this system is limited to dicotyledonous plants, however, scientists must now focus on the development of gene vectors for cereals and other monocotyledonous crops. Meantime, other constraints include the difficulty of...
with the severest deficits in food now and among the ones that face the most difficulty in increasing production in the future to provide enough food.

Chemists can help devise population planning methods that are effective, safe, and easy to use in the many different cultures worldwide. Chemists also can help provide alternatives to children as sources of labor by developing ways to reduce the need for labor. For example, farmers who can be shown how to produce, say, a ton of rice with half the labor by using new methods provided by chemistry will have an alternative to large families and may more readily participate in population stabilization programs.

World population will be stabilized as a result of individual decisions or of national political decisions or both. These are not decisions that we as chemists may make either for individuals or for countries. As chemists, however, we can point out very clearly that:

The world’s land is finite and so are world resources. Neither chemistry nor any other science or combination of sciences related to agriculture and food processing offers infinite prospects for increasing the world’s supply of food.

The measures advocated as a result of the CHEMRAWN II conference can provide time for solving the population growth problem. The time that they will provide is not limitless, however, and world leaders, persons in policy positions, and people everywhere must take steps to limit population growth.

identifying genetic characteristics at the biochemical level and the inability to regulate gene expression (that is, in effect to turn genes on and off).

A second major way in which chemical research can lead to large gains in yields and other desirable characteristics lies in plant physiology studies.

Thanks to analytical instruments and techniques introduced in the past one to two decades, chemists and other scientists have isolated a number of chemicals present in very minute amounts during different growth stages of a number of crops. They have then been able to determine the molecular structures of these plant growth regulators and to trace the reactions that they undergo or induce. This knowledge in turn has permitted chemists to develop methods for applying them and related chemicals to enhance or modify important plant characteristics, including yields, resistance to lodging, growth rate, time of flowering and harvest drop, defoliation, and storage life.

Research along these lines will continue. In time, findings no doubt will lead to gains not only in the foregoing characteristics but also in such other characteristics
as growth under less than ideal conditions; nutritional and aesthetic qualities of the edible products; the distribution of plant material between edible portion and stalks, stems, and leaves; and ease of cooking.

Most important, research on plant growth regulators offers the very real prospect of modifying in a major way the photosynthetic rate per unit of solar energy absorbed, the ability to fix nitrogen, and transpiration.

Because of the complexity of plant physiology processes and the present lack of fundamental knowledge, understanding will not be achieved rapidly. Intensive research will be needed before numerous practical applications will occur. The potential is so great, however, that laying the base must receive greater support now, so that major gains in yields and other important plant characteristics indeed become possible in the long term.

Meantime, in addition to the foregoing direct benefits, there are likely to be spin-off benefits as well. These most probably will occur in the area of plant resistance to pests. As chemists learn how plants respond to attack and isolate the chemicals responsible for resistance, they will have the opportunity either to produce these chemicals for use as pesticides or to make related chemicals that function as well or better. Not only may control be improved as a result, but possible damage to the environment could be less, since the chemicals will mimic nature itself. To the extent that these spin-off benefits are realized, concern for the environment and especially for such unwanted effects as harmful residues on foods and feeds should be lessened materially.

THE INTERIM MANAGEMENT OF CRISES

Before turning to other conclusions and their rationales based on the CHEMRAWN II conference, a few words about crises posed by starvation and malnutrition. If events in 1983 match those of recent years, about one half of one percent of the people in the world will starve to death. In almost any endeavor, a loss of only one half of one percent would cause barely a ripple of concern. One half of one percent of the world’s present population, however, is 20 million. Some 15 million will be children, and the balance for the most part will be elderly adults. Together, they comprise a group comparable to the population of, say, Canada (24 million), of Scandanavia (22 million in Denmark, Finland, Norway, and Sweden), or of America’s agricultural/industrial heartland of Illinois, Michigan, Ohio, and Wisconsin (17 million).

In addition to those who starve to death, another 500 million and possibly more will range from being somewhat undernourished to severely malnourished. Depending on the degree, they will at best contribute little to their own betterment and at worst heavily drain health and welfare services.

Ironically, nearly everyone who starves or does not have enough to eat today does so not because there is not enough food worldwide. Rather, people starve or
go hungry today almost entirely because they cannot afford to buy the food that is available or because badly inadequate distribution systems allow shortages to occur in one region while surpluses accumulate in another.

Improving food distribution systems and raising incomes are not matters to be solved by agricultural research and development.* We make no recommendations concerning them or other strictly economic or political matters. It is appropriate for us to note, however:

**Major delays will occur if government agencies and private institutions neglect the long-term need to increase food production for everyone while they attempt to cope with short-term needs posed by today’s starvation and malnutrition. Welfare and relief to prevent suffering are extremely important, to be sure, but they must not be allowed to undercut long-term efforts.**

**SOIL AND CROP MANAGEMENT**

As noted earlier, most of the increase needed to feed double today’s population will have to come from the developing countries. Moreover, virtually all of the increase will have to come from the land,** since 98% of the world’s food needs are met by land crops and animals. Fortunately, the potential is great for increasing food production on the land of the developing countries. Unfortunately, however, the difficulties are great, too. In discussing chemistry’s role in soil and crop

* Agricultural research and development can lead to better distribution, of course, but the impact usually will be indirect rather than direct. Better preservation methods, for example, can help improve distribution by retarding spoilage and allowing added time for foods to reach consumers. The truly significant ways to improve distribution, however, call for large investments in roads and railroads; warehousing, distribution, and retailing systems; and the formation of numerous enterprises to conduct such activities. These activities do not require scientific research in order to be instituted, but we mention them here so that national leaders do not overlook their critical importance in eliminating starvation and hunger.

** Since the oceans and inland waters meet only about 2% of world food needs, improving the harvest of seafoods was not given major attention during the CHEMRAWN II conference. Even a worldwide increase of 10% in seafood would add only about 7 million metric tons annually to world food supplies. An increase of 10% in the harvests of wheat, rice, and maize, however, would add about 150 million metric tons annually. Concentrating on increasing yields of major crops, therefore, offers the best prospect for more than doubling world food supplies by 2015.

Not too many years ago, the sea was popularly viewed as potentially the source of considerably more food than was then being harvested, and optimistic predictions pointed to overcoming much starvation and malnutrition with such increases. Seafoods figure importantly in the diets of people in some countries, and exports of seafoods do help balance-of-payments positions for these and other countries. However, these countries generally tend to be the ones that are neither more populous nor have the greatest food deficits. More importantly, however, not only have recent efforts to increase food from the sea not been too effective, but concern in fact is now rising that some species face an uncertain future because of possible overharvesting.

While efforts to increase seafoods may thus not be a method to emphasize in a world facing the need to more than double food production in half a century or less, the conclusion should not be construed as denying the importance of producing fish and other aquatic forms of food in integrated farms operated by individual farmers in developing countries. Fish grown simultaneously in rice fields or fish production systems themselves, for example, can be important elements in the overall yields of food from farms where such opportunities exist and where close attention is paid to recovering and recycling what might otherwise be wastes but which can be used as sources of nutrients elsewhere in the cycle.
management, therefore, we shall focus on the developing countries of the tropics, where problems are the greatest but where the gains can also be the greatest.

Although most tropical developing countries have some farms that produce yields comparable to those in developed countries, yields on the average are very low. Rice yields, for example, average 2 metric tons per hectare, and wheat and maize yields average 1.5 metric tons. On farms in high-latitude countries, and indeed on better-managed farms in some tropical developing countries, the averages range around 6 metric tons per hectare. Yields at both levels, however, are far less than the maximum under optimum laboratory environments, where yields of wheat and rice approach 14 metric tons per hectare and those of maize approach 22 metric tons.

Developing countries continuously lose croplands because the fertility is exhausted, erosion depletes them, salination makes them unsuitable for cultivation, and they are diverted to other uses. In addition, subsistence cultivators and herdsmen increasingly invade marginal lands that have inadequate rain or that have thin soils on steep slopes. As a result, increasingly greater zones of destroyed forests and steep watersheds erode under subsistence agriculture and overgrazing. Irrigation systems face increasing hazards from flooding and salination, and serious shortages of wood for fuel occur. As farmers and herdsmen turn more and more to dung for fuel, they hamper further their ability to maintain soil fertility.

Finally, what is known as the Inter-Tropical Convergence Zone dominates tropical agriculture. This climate condition results from an unstable trough between northeast and southeast trade winds that causes a variable and unstable pattern of intense radiation and heavy rainfall. Droughts and floods are endemic.

Inadequate supply and balance of plant nutrients and adverse soil conditions can be major constraints for crop yields. Good practice therefore calls for proper tillage, planting on contours, controlling runoff, and constructing irrigation and drainage systems where necessary to provide good environments for root growth. Individual farmers in tropical developing countries can take some of these steps, but a more important need is for resources to be organized on the scales of river basins and subwatersheds.

Regional efforts at watershed management are beyond the capabilities of groups of farmers. Governments of developing countries in the tropics must therefore give priority to controlling watersheds to provide the physical conditions under which farmers can benefit from agricultural products and processes developed by chemistry.

Given good land use patterns and watershed control, the best short-term solution for tropical developing countries to increase food production will be to adapt as quickly as possible the intensive farming practices that have been so successful in the agriculturally-advanced countries.

If it were possible to transfer the intense and advanced farming practices directly and completely to developing countries, concern for world food supplies
could be sharply reduced. Some of the knowledge about fertilizing and use of pesticides and plant growth regulators has been transferred directly or readily adapted to some farms in developing countries and more no doubt can be. In most instances, however, differences in soils, climates, pests and diseases, cultivation practices, and growth characteristics of different crop varieties can make developed-country information of little direct use. Most often, one or more key gaps exist in understanding the interplay among the many different growth and yield parameters. As a result, no “package” of crop enhancement technology can be transferred directly to thousands of farms without modifications for particular crops and particular local conditions.

This complexity has often been underestimated by chemists and other agricultural scientists. They have conducted many thousands of trials, particularly for the major plant nutrients, but they have accumulated conflicting results because other vital deterrents to yields have not been controlled adequately and sometimes not even observed and recorded. Included are sowing date, rooting depth, duration of available soil moisture, supply of major and minor nutrients, the effects of salinity and other toxic soil conditions, severity of weed competition, and damage by pests and diseases.

Transfer and adaptation of knowledge from developed countries to tropical developing countries also suffers from a general drawback: the knowledge generally reaches only the centers of learning and research in or near the larger cities. Effective increases in per-capita food production in tropical developing countries will therefore depend strongly on the extent to which agricultural scientists and engineers are deployed into rural areas. There they must study on a very local level the problems and diagnose the constraints in all aspects of soil and water management, nutrient supply, and crop protection. They must also devise and demonstrate solutions locally. The social problems associated with placing well-trained professionals in rural areas are acute, but they can be solved to some extent by providing improved housing and financial rewards and by speeding advancement by giving extra credit for rural service.

FERTILIZER DESIGN

Of all the agricultural technologies based on chemistry that can be used to increase food production rapidly in all countries in the short term, the single most effective is increased use of fertilizers and increasing the efficiency of the fertilizers that are used.

While incremental gains in yields can still be made in developed countries by improved fertilizers and improved fertilizing practices, much greater gains can be made in developing countries if fertilizers are used to the same extent as in developed countries. In developing countries, however, cost is a major deterrent to use. So are levels of education, lack of availability, and insufficient knowledge about the best fertilizing techniques for many crops on widely different soils and under highly diverse climates.
Education level is an issue addressed elsewhere in this discussion (see page 21). Lack of availability, meantime, stems from lack of manufacturing capacity; inadequate or nonexistent transportation, warehousing, distribution, and retailing systems; and lack of credit. These shortcomings are essentially political and economic issues, and they are therefore ones on which chemical research and development can have no impact. Cost, however, can be changed by chemical research and development, and we shall thus deal with that issue here.

Leaching of soluble nutrients out of the root range of crops is a major concern in tropical farming under heavy rainfall and high temperature conditions. As much as two thirds of applied nitrogen may thus be lost. Chemists have designed slow-release fertilizers for use under tropical conditions, but they are costly to make and are not yet in general use. With respect to phosphorus, meantime, many tropical countries have phosphatic rock deposits of low quality. New methods of on-site treatment could offer major savings in transport, but they require high investments that are not readily available locally. In addition, some phosphatic rocks in tropical countries can be ground and used without further treatment, since they are sufficiently soluble under the acid conditions of tropical soils. However, storage, handling, and distribution pose critical problems.

The greatest challenge to chemical research in the field of plant nutrition is to improve the processes for fixing nitrogen into a form that plants can use.

The bulk of the nitrogen fertilizers used today is based on ammonia, and most ammonia in turn is produced by what is known as the Haber process. A reduction process, it may well be one of the half dozen most important industrial chemical processes ever developed. However, although the hydrogen-nitrogen reaction itself in the Haber process absorbs no energy, the overall process requires a great amount of energy. Moreover, the hydrogen used in the process is derived from natural gas or petroleum, and use of the Haber process is thus restricted to sites near these hydrocarbon sources. Finally, the amount of energy needed requires the use of relatively large plants, where economies of scale can spread the cost of the energy over large tonnages.

Reducing the cost of making hydrogen from natural gas or petroleum would reduce the cost of nitrogen fertilizers to some extent, but reductions are likely to be some few percentage points at best, given the considerable research and development to which such processes have been subjected. Nor can distribution costs be lowered by building ammonia plants near centers of use rather than at sites close to hydrocarbon resources, for the cost of transporting fertilizers would only be replaced by the likely higher costs for transporting hydrocarbon raw materials.

One solution offering great potential for reducing the cost of nitrogen fertilizers is to make hydrogen at a significantly lower cost from a feedstock readily available at dispersed locations.

Water meets these criteria, but hydrogen can be produced from it today only by using expensive electricity to split it into hydrogen and oxygen. If the sun could be
substituted as the source of energy necessary to split water, however, the process could be based on both a readily available raw material and a limitless source of energy. Photolytic, photochemical, and photoelectrochemical processes all exist for making hydrogen from water, but their efficiencies are far too low at present for economical production. Strong support for research and development projects to increase reaction efficiency and to reduce costs is therefore a matter of priority importance.

A second very promising way to reduce the cost of nitrogen fertilizers in a major way would be to develop a satisfactory process to oxidize nitrogen directly without first reducing it to make ammonia. Much chemical research on catalytic oxidation processes will be required before a commercial method is developed, however.

SOIL TOXICITY AND POLLUTION

Chemical research and development will be essential to bring into production some millions of hectares of land suffering from toxic soil conditions. These soils include the acid aluminum-toxic soils of the cerrados (the closed areas) of Brazil and Colombia, the salted soils of the Indus Basin, the potentially fertile marsh soils deficient in zinc or copper, the acid sulfate soils of tidal areas, and soils needing very small quantities of different trace elements to become productive. Great progress has been made in the Indus Basin, where saline soils are being reclaimed by applying minimum amounts of gypsum and by leaching with pumped groundwater. Successful methods have also been developed to permit the leached aluminum-toxic soils of the South American savanna to be used for crops and pasture. Finally, large returns from the application of small quantities of zinc are illustrated by the restoration of peat soils to rice culture. Textbook knowledge on these and other methods is available worldwide, but diagnosing the problems and devising solutions demand chemical research on the spot.

PEST MANAGEMENT

Any field planted with a given crop will produce less food than its full potential under totally ideal conditions even if the soil is not deficient. Seeds germinate imperfectly and microorganisms destroy some of them. Once the crop begins growing, insects and microorganisms as well as polluted air, water, and soils reduce yields. Weeds rob it of nutrients, water, and possibly sunlight, and severe weather may destroy all or part of it before harvest. Mechanical losses then occur during harvest, edible portions are damaged physically during transportation to processing and consumption points, and attacks by pests and spoilage during postharvest periods reduce amounts reaching consumers even more.

Many estimates have been made for losses that are due to these different causes. The estimates are extrapolations from data derived from samples that are limited in both area and time, and they likely are not as reliable as the precision they are stated with implies. Nonetheless, losses do occur, many of them substantial, and reductions will do much to increase world food supplies.
Of all the causes of losses, those that are due to attacks by fungi, microorganisms, and insects are the most serious. While the loss estimates of 35 to 50% that are frequently cited are too high for world averages, they clearly indicate the magnitude of the problem that farmers face. For much of agricultural history as a result, farmers relied on natural selection to single out crop strains that resist attack and grow best under adverse conditions. In more recent times as scientists have become more knowledgeable about genetics, active breeding has become a significant tool to find strains that resist attack. Even more recently, the advent of organic pesticides has given farmers many added tools.

As a result of all of these efforts, yield reductions in the developed countries are much less of a problem than they would be without them. Even with the contributions of both genetics and chemistry, however, yield reductions caused by pests in the developed countries have not been reduced to the achievable minimum. In developing countries, meantime, use of both chemical and biological control methods lags far behind the use in developed countries. Moreover, as agriculture in the developing countries becomes more intense, the need for pest control will become even greater, since the better the crop the better the environment for pests.

The best approach to control pests is an integrated one in which agricultural, biological, chemical, and mechanical measures complement each other and in which careful attention is paid to the value of the benefits compared to the cost to achieve them.

Such integrated pest management practices are becoming more established in developed countries, but much has yet to be learned about pest management in developing countries before great progress can be made in them.

Needs range from very numerous field trials throughout developing countries on application amounts and times to more fundamental studies on host-pathogen-environment relationships that point the way to effective control methods having the least deleterious effects on people and the environment.

Meantime, instances of pollution of air, soils, and water by toxic chemicals used in agriculture have led developed countries to introduce and enforce systems of legislation, licensing, and monitoring. In developing countries, where rural areas are characterized by lack of education, poor communications, and lack of technical supervision, use of such agricultural chemicals is minimal. In these countries, serious problems from pollution result mostly from soil washed from unprotected hills, from untreated sewage, and occasionally from industrial effluents.

For the near term, it is important that governments of developing countries focus attention on controlling pollution from erosion, sewage, and industrial effluents rather than divert scarce personnel to pursue what are
presently minor problems associated with agricultural chemicals.

Although the need for close control of agricultural chemicals is not great now in developing countries, it is time to begin developing cadres of analytical chemical experts. By doing so, developing countries will have experienced personnel when agricultural practices require legislation, licensing, and monitoring that is more complex. Also, there should be more attention to devising simpler techniques for residue analysis. The highly expensive analyses in advanced chemical laboratories attain accuracies needed for research but not for routine monitoring.

ANIMAL PRODUCTION SYSTEMS

Vast areas of the world exist on which only grazing animals can convert the natural resource base into foods suitable for human consumption and into unique products such as leather, fibers, and feathers. In addition, bodies of water suitable for aquaculture are sufficiently extensive to suggest that their contribution to the world’s food supply could exceed that presently contributed by marine fishing. Nevertheless, increases in food supplies in developing countries based on livestock and aquatic species have been disappointingly low. In fact, except for poultry, increases in livestock production for consumer use have barely kept pace with population growth, while aquatic species have proved to be only marginal sources. As a result, resources in grazing land and inland waters are far from full exploitation as sources of food.

Many reasons exist for this state of affairs. Important among them, however, are the difficulties in devising and introducing rapid improvements in the genetic quality of animals and forages; in the proper use of fertilizers, pesticides, and irrigation; and the new techniques of management. The technology of good husbandry has therefore yet to reach and be used by livestock owners and sedentary small holders in whose hands the bulk of the ruminants are to be found in developing countries.

Perhaps the most important single reason for the lag in animal production in developing countries, however, is the relatively poor reputation that animals have in the minds of some as sources of food in a world facing shortages. With some 20 million people starving to death every year and another 500 million or more suffering from malnutrition, many leaders in developed and developing countries alike do not rank animals among the best ways to improve food supplies immediately. Animals admittedly are notoriously inefficient converters of cereals into animal products except when cereals are fed in catalytic amounts to supplement predominantly forage diets. Up to 90% of the calories and 90% of the protein can be lost, for example, when a predominantly cereal diet is converted into meat by some species. Opponents of immediate, large-scale investment in animal husbandry systems in times of starvation and malnutrition therefore do not favor large-scale diversions of cereals to animals when those cereals might better be made available to people.

As in much of agriculture, however, a simplistic view can be misleading. For example, much of the feedstuff for livestock is not satisfactory for or acceptable to
people. Thus, the value of animals as food storers and food processors should not be overlooked. Nonetheless, for animals to contribute effectively to the food supply in developing countries now, there is no need for these countries to adopt immediately the capital-intensive animal production systems of the developed countries. In fact, they will do themselves a disservice by doing so. Capital-intensive animal production systems involving extensive grazing areas, numerous feed lots, and high consumption of grains may be established in time in parallel with overall economic growth.

**The focus in developing countries should be largely on integrating animals and crop agriculture, so that they share complementary roles.**

In this way, animals not only can provide food as well as draft power for crop cultivation, but they will also be essential parts of a recycling system, consuming organic matter that people cannot or will not eat and contributing wastes that are inputs to other parts of the food cycle on small farms.

For example, cows fed on crop residues that are either digestible or processed to enhance digestibility and protein content can produce both milk for the family and dung for a biogas plant to fuel the family’s cook stoves and provide evening lighting. In addition, the slurry waste from the biogas generator can be used as a fertilizer on the family’s fields. The milk, meantime, is both directly available and can also be preserved as cheese at the individual household level. In addition, surplus young stock and livestock products can generate ready cash to buy fertilizers, better seeds, and crop protection measures to further increase productivity.

Though it is well recognized that the developing countries should not adopt the capital-intensive production systems of the developed countries, it should also be recognized that modern technology can be applied to less intensive systems. Agricultural scientists have successfully introduced improved varieties of cereal grains, achieved acceptability of plant densities, and devised fertilizer and pest control programs. The principles that they used can be applied to animal production systems, so that in time these systems will benefit from the same depth of findings.

Animal populations must be in balance with the available feed supplies, or animal maintenance systems rather than animal production systems exist. Too frequently, two animals are placed where sufficient feed is available only for one. The result is very poor feed utilization, whether it be for work, for milk, or for meat. In addition, little or no attention often is paid to the nutrient balance in the diets the animals have. For example, a cow can have all the forages she can eat, but if that forage is deficient in a single mineral element, she may not be able to maintain her weight, let alone have the strength to pull a plow or the nutrient combination needed to convert protein and energy in the forage to milk or meat.

It will be unfortunate if developing countries themselves do not recognize the role that animals can have. During the past two decades, for example, production of poultry meat and eggs has grown faster than any other major food item in developing countries. This growth, however, has been achieved largely by
importing substantial tonnages of cereals. Officials and others in developing countries might be tempted to conclude that meat production can be assured and indeed increased by importing grain. Not only is there a limit to the amount of grain that will be available to meet increased demand in the future, but continued reliance on imports will postpone development of indigenous sources of animal feeds. When the import limit is reached, no alternatives will be available.

Governments in developing countries in the short term may follow policies that encourage production of poultry and swine based on imported grain. If they do, however, they should at the same time also emphasize development of feed technologies that can use locally-available crops and crop by-products.

Feeding systems for ruminants must be organized to take full advantage of their capability to use cellulosic products and nonprotein nitrogen. Proper supplements, particularly minerals and nitrogen sources, need to be developed to balance the poor quality of roughage diets and thus increase conversion in the rumen and uptake of derived metabolites. Inexpensive and simple methods also are needed to treat lignocellulosic waste materials to make them more digestible by ruminants. Finally, alternative sources of feeds for monogastric animals must be developed to minimize the competition with food for people.

It appears that worldwide emphasis on increasing the production of cereal grains has led to a reduction in the total biomass available to meet other needs. This emphasis is especially deleterious when cereal grains are produced in ecological zones that may be more suited to other crops (both food and nonfood) and to livestock. The high biomass potential of tropical crops such as sugarcane should not be overlooked. Such crops possess an unparalleled potential for providing both food for people and feed for animals and at the same time by-products that can serve as fuel.

For animals to achieve their full potential in developing countries, major improvements are needed in reproductive stock.

Attention must also be given to the appropriate use of essential amino acids, minerals, trace elements, vitamins, and growth promoters. In order to improve their production, keepers must also be educated in the need to monitor and record performances, including survival rates, growth, and feed conversion efficiencies.

Continued efforts by chemists and medical and veterinary scientists to determine host-pathogen relations and to develop cures or preventive measures deserve the strongest encouragement.

Otherwise, the prevalence of diseases and pests to which animals fall victim or for which they are important vectors will remain a major impediment to animal production. As much as 1 billion hectares in Africa, for example, cannot be used for grazing because of the prevalence of trypanosomiasis carried by tsetse flies.
River blindness, malaria, and shistosomiasis also make large areas of the tropics uninhabitable or habitable only at great cost in human suffering.

**Officials of public and private funding agencies and scientists can exploit the tremendous opportunities for advancing animal production by direct or indirect use of genetic engineering and biotechnology.**

The most immediate gains should occur in controlling diseases, as exemplified by the recent production and introduction of a safe and effective vaccine for hoof and mouth disease. Moreover, microbial syntheses of essential nutrients such as vitamins and amino acids can be extremely beneficial for animal production as well as for balancing diets of people, while microbial syntheses of polypeptide hormones offer great possibilities for regulating the growth and the lactation processes in animals.

Drawbacks hampering the development of aquaculture include a shortage of fish seed, the high cost of feeds, and limitations in culture techniques. Further research on nonconventional feeds, and in particular on wastes, and on species best able to use them is essential for intensive culture systems. Equally important is research on breeding by induced spawning of culture fish, the use of chemicals and diluents, and the ways in which cryoprotectants can preserve fish gametes and embryos. Similar needs exist for understanding the role of hormones and other chemicals controlling reproduction and development, such as in producing monosex and sterile fish.

**FOOD PROCESSING**

In a world facing the need to more than double food supplies in less than half a century, most of the effort will have to be on increasing harvests.

*World food supplies can be supplemented substantially, however, by improving the ways in which foods are stored, preserved, and processed following harvesting.*

*World food supplies also can be supplemented by manufacturing food analogs from raw materials that people or animals cannot eat directly or that do not have the desired characteristics of texture, palatability, and nutrition in their natural states.*

The trend to urbanization and industrialization in the developed countries has led to sharp declines in farm populations. The largely urban populations are served by complex and extensive food processing industries that freeze, dehydrate, can, and otherwise convert foods to forms that are largely processed and that require minimum preparation in homes. This trend is under way in developing countries as well, but quite some time will pass before processing industries in these countries are nearly as extensive as those in developed countries. For the near term, therefore, and perhaps even up to the time that world population doubles, food in developing countries will be consumed mostly in many small- and
medium-sized localities. In addition, much of the preparation will be done on an individual family basis.

The large-scale food processing technologies available in developed countries cannot yet generally be transferred readily to developing countries. Until such time as the economies and demographics of these countries more nearly match those of developed countries, therefore, the emphasis in food processing should be to improve small- and medium-sized preservation techniques and home cooking methods.

Large-scale processing installations can then supplant home processing in a gradual way as economic growth justifies them. Since great differences exist in food resources, food habits, and food availability from country to country and from region to region within countries, the research and development projects for small- and medium-scale processing and for home cooking will have to be conducted in ways that take these differences into account.

Much information exists on food handling and processing that has not been applied to problems encountered in developing countries. Particularly helpful in promoting the rapid and efficient use of such information would be formation of a worldwide food technology network that links food science and technology research and development centers.

Such a network’s main task at the outset would be to identify inefficiencies in food production and consumption systems in tropical countries and then to propose the proper methods to correct the problems. Such a network could also be effective in coordinating multinational efforts to use excess industrial capacity wherever it might occur in developing countries, so that surpluses and shortages would be balanced and locally-grown foods processed properly rather than wasted.

EDUCATION

A separate session on education was not part of the CHEMRAWN II conference, but the need for improving education was a point that was addressed in paper after paper.

It is clear that for developing countries to become self-sufficient food producers, or nearly self-sufficient food producers, each will need some minimum number of scientists and engineers who are well trained in agriculturally-related disciplines.

Otherwise, they will not be able to assist in adopting or adapting presently-available agricultural and food processing technologies. More importantly,
however, the most significant incremental advances in production and processing will be put to use most rapidly in developing countries if their scientists and engineers are among primary contributors to agricultural and food processing knowledge. In addition, developing countries depend on many crops that are not significant internationally. These crops are not likely to be targets that are economically attractive for research and development in developed countries. Improving the yields and processing of such crops in developing countries will thus depend in large measure on research and development conducted by the developing countries themselves, either domestically or through such internationally cooperative efforts as those conducted by organizations under the umbrella provided by the Consultative Group for International Agricultural Research.

The need for educated scientists and engineers in developing countries will also become more critical as applications involving chemicals become more sophisticated.

This need will be especially true for plant growth regulators and for other chemicals that will be used in increasingly smaller and smaller amounts. In these applications, misuses measured in grams per hectare may well result in the difference between success and failure. Only trained personnel in both management and operations positions will be able to use such sophisticated chemicals and methods properly.

Finally, unless developing countries have well-educated native scientists and engineers, persons in policy positions in government agencies and in public and private institutions dealing with agriculture and food processing will not have access to sound advice based on indigenous understanding of the proper use and development of agricultural and food science and technology.

THE ROLE OF CHEMISTRY

Attendees of the CHEMRAWN II conference heard abundant evidence of the role that chemistry has and can have in ensuring that the world’s food needs are met. It was also clear that there is great concern among some chemists that the level of risk associated with the use of the present range of chemical agents is an unacceptable one. This concern led during this conference and leads elsewhere to a tendency to emphasize and even overemphasize alternative approaches to solving agricultural problems and to encourage the allocation of additional resources to such approaches.

The task of feeding present and future populations is too great and too important for energy to be wasted on confrontations among organizations and people concerned with accomplishing the task.

All tasks facing society involve applying solutions that entail some cost or risk as well as benefit, and solving the world’s food problem is no exception.
The job facing society is to find solutions that make the benefits the greatest while reducing the costs and risks to the minimum. Chemistry’s role in helping solve the food problem must be viewed in this light.

The risks and benefits of using the same chemical will differ from country to country, and each country must judge whether the relationship is or is not an acceptable one for it. In the developing countries with inadequate means to make these judgements, assistance should be made available by international agencies and by government agencies and private companies and institutions in the developed countries.
At the First International Conference on Food and Agriculture convened by President Roosevelt in 1943 in Hot Springs, Virginia, United States, it was resolved “This conference, meeting in the midst of the greatest war ever waged, and in full confidence of victory, has considered the world problem of food and agriculture and declared its belief that the goal of freedom from want of food suitable and adequate for the health and strength of all peoples, can be achieved.”

At the Second World Food Congress held 20 years later in Washington in June 1963, President J. F. Kennedy declared “So long as freedom from hunger is only half achieved, so long as two thirds of the nations have food deficits, no citizen, no nation, can afford to be satisfied. We have the ability, as members of the human race, we have the means, we have the capacity to eliminate hunger from the face of the earth in our lifetime. We need only the will.”

Again, at the World Food Congress held in Rome in November 1974, it was resolved that the problem of hunger and malnutrition should be solved by 1985. The United Nations Assembly in a resolution on the Third United Nations Development Decade declared in 1980 that hunger and malnutrition should be eliminated as soon as possible and certainly by the end of the century.

At the World Food Day Colloquium held on 16 October 1982 at the FAO Headquarters in Rome, the eminent panelists drawn from different parts of the world made the following statement: “We believe that it is indeed possible to end world hunger by the year 2000. More than ever before, humanity possesses the resources, capital, technology and knowledge to promote development and to feed all people, both now and in the foreseeable future. By the year 2000 all the world’s people and all its children can be fed and nourished.”

Director General, The International Rice Research Institute, Manila, Philippines.
“Only a modest expenditure is needed each year — a tiny fraction of total military expenditure which amounts to about $650 billion a year. What is required is the political will to put first things first and to give absolute priority to freedom from hunger.”

Thanks to good harvests during the last few years, it is estimated that the world cereal stocks may reach 300 million tons by the end of the 1982/83 season. However, an important component of the stocks is coarse grains located in North America and a few other countries and these to a great extent will be used as animal feed. In spite of such grain mountains in some countries, the queues for grain rations and for free or subsidized food grains are becoming longer in many developing countries. It has been estimated that in Southeast Asia alone over 300 million children, women and men may be going to bed hungry. According to the FAO study “Agriculture: Toward 2000” at least 600 to 650 million people are likely to be seriously undernourished by the end of the century. In other words, about 300 million tons of grain stocks and over 500 million hungry people are co-existing in our planet today. Thus, hunger is not related only to adequacy of food supplies. Access to supplies is equally important. This is the principal lesson of the Great Bengal Famine of 1943 when several million people died due to starvation, although more equitable distribution of the available food would have made such deaths unnecessary (Sen 1981).*

---

1. World increasing dependence of the grain exports of a few countries; USA and Canada supply most of the grain.

VULNERABILITY OF GLOBAL FOOD SUPPLY

The vulnerability of the world food production systems arises from the following factors:

(a) Very few countries have surplus grain stocks for provision to others, either on commercial or concessional terms. The most important source at present of surplus grain stocks is North America (Fig. 1).

(b) In spite of all the scientific progress made in capture and culture fisheries, over 90% of the world's food supply comes from the land. Although the flora of the world has over a million species, only about 30 of them make a significant contribution towards human nutrition (Fig. 2). Wheat, rice and maize are the dominant food crops of the world. If one or more of these crops are damaged by weather abnormalities and/or pest epidemics, the world food production becomes critical. In fact on a global scale, about a 10% increase or decrease in food grain production can make all the difference between an uncomfortable glut and acute scarcity at current levels of consumption.

Table 1. International commodity market prices (November 19, 1982).

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Latest quotation (US$/ton)</th>
<th>1 year ago</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>156</td>
<td>181</td>
</tr>
<tr>
<td>Rice</td>
<td>254</td>
<td>440</td>
</tr>
<tr>
<td>Maize</td>
<td>105</td>
<td>113</td>
</tr>
<tr>
<td>Palm oil</td>
<td>362</td>
<td>500</td>
</tr>
<tr>
<td>Coconut oil</td>
<td>416</td>
<td>575</td>
</tr>
<tr>
<td>Sugar</td>
<td>139</td>
<td>260</td>
</tr>
</tbody>
</table>

(c) From the early 70s, the rapid escalation in the price of fossil fuel led to an increase in the cost of important agricultural inputs like fertilizer, gasoline and diesel fuel. Consequently, crop land is also looked upon as a source of producing energy. There are thus competing demands for scarce land resources.

(d) While the cost of production is going up, farmers usually suffer whenever there is a bumper harvest. The growing stocks of food grains is tending to reduce the international commodity market prices of food grains and other agricultural products (Table 1). Many developing countries are experiencing serious balance of payment problems as a result of a steady decline in the price of the agricultural commodities they export (Fig. 3). Consequently, the share of developing countries in the world trade in agricultural production is tending to go down. While the

share of developing countries in agricultural exports was 36% in 1977, it has come down to 28% in 1981. The world trade in agricultural products in 1981 was of the value of US$300 billion. Consequently, small farmers in developing countries have very little resources to invest on the land. The capital requirements for the modernization of agriculture are not available in most developing countries.

(e) In the pre-modernization state of agriculture, weather aberrations and pest epidemics are largely responsible for year to year undulations in production. Once the process of modernization involving the use of purchased inputs sets in, marketing opportunities assume importance. Under such conditions, public policies followed by Governments both to stimulate production and improve consumption by the poorer sections of the population play a dominant role in influencing farmers' decisions on land and input use. Thus, weather, pest epidemics and public policies now influence stability of production.

TRENDS IN FOOD PRODUCTION DURING THE 70s

In spite of considerable technological progress, the per capita food production has declined in sub-Saharan Africa. In contrast, Asia and Latin America have registered impressive gains (Fig. 4). In as many as 37 low income food deficit countries with a population of 370 million, there was negative growth rate in per

---

4. Index of per capita food production in Asia, Latin America and Sub-Saharan Africa during 1961-1978.
caput cereal production. However, some of the densely populated countries of Southeast Asia were able to keep food production above the level of population growth. The data compiled by FAO on food production, consumption and trade during the period 1969 to 1981 are given in Table 2.

INTERNATIONAL AGRICULTURAL RESEARCH IN THE 70s

In 1971, IRRI, the first of the International Agricultural Research Centers, became part of a global family of IARCs funded through the newly established Consultative Group on International Agricultural Research (CGIAR), jointly sponsored by the Food and Agriculture Organization of the United Nations, the United Nations Development Programme, and the International Bank for Reconstruction and Development (World Bank). In 1983, 36 countries and donor organizations will contribute an estimated US$164 million to support the core research programs of 13 International Centers through the CGIAR. Donor members now include Third World countries such as Brazil, India, Mexico, Nigeria, the Philippines, and Saudi Arabia. The crops and livestock on which the International Centers focus provide 75% of the food for the Third World. The 600 senior scientists who work at these Centers are drawn from 40 nations. The location of these centers is shown in Figure 5.

The International Centers working with national research systems in cooperative partnership have been able to make significant contributions to increase and stabilize the yields of several food crops. I would like to illustrate the research

Table 2. Population, cereal production, and cereal imports in 54 selected low-income food-deficit countries.a

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>37</td>
<td>370</td>
<td>48.0</td>
<td>52.9</td>
<td>14.4</td>
</tr>
<tr>
<td>negative growth rates in total cereal production</td>
<td>19</td>
<td>142</td>
<td>20.1</td>
<td>18.4</td>
<td>1.4</td>
</tr>
<tr>
<td>positive growth rates in total cereal production but less than population growth rates</td>
<td>18</td>
<td>228</td>
<td>27.9</td>
<td>34.5</td>
<td>6.1</td>
</tr>
<tr>
<td>Countries with positive growth rates in per caput cereal productionb</td>
<td>17</td>
<td>2,095</td>
<td>393.4</td>
<td>518.4</td>
<td>12.6</td>
</tr>
<tr>
<td>All countries</td>
<td>54</td>
<td>2,465</td>
<td>441.4</td>
<td>571.3</td>
<td>20.1</td>
</tr>
</tbody>
</table>

aOut of 69 food-deficit countries with per caput incomes of US$730 and below in 1980, which is the level used by the World Bank to determine eligibility for IDA assistance. bExponential growth rates for 1971-1981.
strategies followed and their impact on production from the work of the International Rice Research Institute (IRRI).

MAJOR RESEARCH STRATEGIES

Some of the major research thrusts, all based on inter-disciplinary and inter-institutional collaboration, followed by IRRI are indicated below to show how agricultural research contributes to producing more food, income and jobs.

Increasing and stabilizing rice production in irrigated areas. Developing countries are making considerable investments on bringing more land under irrigation. Most of the rice cultivated in China is irrigated. In India, nearly 2.5 million hectares are brought under irrigation each year. In the Philippines, about 100,000 hectares are added to the irrigated area every year. Therefore, a priority area of research relates to the optimum use of water so that the yield per liter of water can be maximized. In this context, much research has been done on all aspects of water delivery and on-farm management of water. Methods of achieving equitable distribution of water in the head and tail ends of a command area have been developed (Fig. 6).

Prior to the introduction of the Dee-gee-woo-gen and Norin dwarfing genes in rice and wheat respectively, lodging was a serious problem under conditions of good soil fertility. This is why varieties of rice and wheat possessing a semi-dwarf and non-lodging plant type became popular with farmers very speedily. The first high yielding rice variety developed by IRRI by crossing Peta, a tall strain from Indonesia, and Dee-gee-woo-gen resulted in the variety IR8 (Fig. 7). Soon it was found that when the ecology of the rice field is changed by the application of more

7. Pedigree of IR8.
8. Pedigree of IR2071 (IR36).
water and fertilizer, the threat to yield caused by the triple alliance of weeds, pests and pathogens could become serious. Small farmers obviously can invest on inputs only when risks are low. Therefore, high yielding varieties characterized by stability of performance were needed. IRRI, hence, introduced in its breeding programs the following approaches in order to combine yield potential with multiple resistance to pests and diseases:

- Continuous identification of new genes for resistance to each of the major diseases and insects
- Sequential release of improved germplasm with different major genes to combat new races of diseases and biotypes of insects
- Pyramiding of two or more genes into the improved rice germplasm using pedigree method or population breeding approach
- Gene rotation to reduce the chances of development of races or biotypes
- Development of multi-line varieties
- Development of several varieties for a region with different genes for resistance
- Development of varieties with horizontal resistance
- Wide hybridization combined with disruptive mating to incorporate genes for resistance from wild germplasm
- Use of cell culture techniques to develop resistance to toxins produced by major fungal and bacterial diseases

The pedigree of IR36 which is now cultivated in over 10 million hectares in Asia is an index of the breeding strategy designed to bring about a pyramiding of major genes for resistance (Fig. 8). IR36 includes in its ancestry 11 different varieties from 6 countries and a wild specie, *Oryza nivara*. IRRI breeders have been able to combine in recent years multiple resistance to pests with earliness and good yield potential (Table 3). Earliness enables multiple cropping wherever there is irrigation.

To make broad based breeding work possible, there is need for the collection, conservation and evaluation of rice genetic resources. IRRI has, therefore, established an International Rice Germplasm Center. At present, over 65,000 strains are available in this collection. This is estimated to represent over 50% of the world’s genetic variability in rice.

All the collections are systematically screened for nearly 40 different characters under a Genetic Evaluation and Utilization (GEU) program.

A great advantage of regional and international collaborative research is the possibility of identifying breeding material suited to different ecological conditions. Under the International Rice Testing Program (IRTP), the best available varieties from all rice growing countries are tested in common trials at many locations. Consequently, varieties developed in one country have been found to be suitable for release in some others (Table 4). International cooperation also helps to screen segregating material at “hot spot” locations for major pests and diseases as well as adverse soil factors. Thus, IR36 is the product of selection at a hot spot location for tungro virus in Indonesia, for gall midge in India, and for other pests in the Philippines.
Table 3. Disease and insect reactions of IR varieties in the Philippines.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Growth duration (days)</th>
<th>Blast</th>
<th>Bacterial blight</th>
<th>Grassy stunt</th>
<th>Tungro</th>
<th>BPH biotypes</th>
<th>GLH</th>
<th>Stem borer</th>
<th>Gall midge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>IR5</td>
<td>140</td>
<td>MR</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>MR</td>
</tr>
<tr>
<td>IR8</td>
<td>130</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>MR</td>
</tr>
<tr>
<td>IR20</td>
<td>125</td>
<td>MR</td>
<td>R</td>
<td>S</td>
<td>MR</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>MR</td>
</tr>
<tr>
<td>IR22</td>
<td>125</td>
<td>S</td>
<td>R</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>IR24</td>
<td>120</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>MR</td>
</tr>
<tr>
<td>IR26</td>
<td>130</td>
<td>MR</td>
<td>R</td>
<td>S</td>
<td>S</td>
<td>R</td>
<td>S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>IR28</td>
<td>105</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>S</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>IR29</td>
<td>115</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>S</td>
<td>R</td>
<td>S</td>
</tr>
<tr>
<td>IR30</td>
<td>110</td>
<td>MS</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>S</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>IR32</td>
<td>140</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>S</td>
<td>R</td>
<td>MR</td>
<td>MR</td>
</tr>
<tr>
<td>IR34</td>
<td>130</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>S</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>IR36</td>
<td>110</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>MR</td>
<td>MR</td>
</tr>
<tr>
<td>IR38</td>
<td>125</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>MR</td>
<td>R</td>
</tr>
<tr>
<td>IR40</td>
<td>120</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>MR</td>
<td>S</td>
</tr>
<tr>
<td>IR42</td>
<td>135</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>S</td>
<td>MR</td>
</tr>
<tr>
<td>IR44</td>
<td>130</td>
<td>MR</td>
<td>R</td>
<td>S</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>MR</td>
<td>MR</td>
</tr>
<tr>
<td>IR46</td>
<td>130</td>
<td>R</td>
<td>R</td>
<td>S</td>
<td>R</td>
<td>R</td>
<td>S</td>
<td>R</td>
<td>MR</td>
</tr>
<tr>
<td>IR48</td>
<td>140</td>
<td>MR</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>S</td>
<td>MR</td>
<td>S</td>
</tr>
<tr>
<td>IR50</td>
<td>105</td>
<td>MS</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>MR</td>
<td>R</td>
</tr>
<tr>
<td>IR52</td>
<td>115</td>
<td>MR</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>MR</td>
<td>R</td>
</tr>
<tr>
<td>IR54</td>
<td>120</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>S</td>
<td>R</td>
<td>MR</td>
</tr>
<tr>
<td>IR56</td>
<td>110</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>MR</td>
</tr>
<tr>
<td>IR58</td>
<td>100</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>MR</td>
</tr>
</tbody>
</table>
After the release of high yielding varieties of rice, the production and productivity of rice have gone up considerably in several countries of Southeast Asia. For example, in the Philippines, rice production has more than doubled between 1960-1980. What is even more significant is the doubling of the yield per hectare (Fig. 9). This is particularly important in Asia where the ratio of land to people is at present 0.21 hectare per person. The progress made by Indonesia is another outstanding example of the role modern technology can play in improving production and yield provided the technological package is supported by appropriate packages of services including credit and public policies particularly in the area of pricing and marketing.

The new varieties of rice and wheat are insensitive to photoperiod; hence, they can be cultivated at different times of the year provided water is available and temperatures are favorable. Hence, plant breeders have introduced productivity per day as an important criterion in selection programs (Table 5). New crop rotations have consequently become possible. Multiple cropping involving different crop combinations chosen on the basis of their yield potential as well as on marketing opportunities are now being introduced (Fig. 10). Rice-wheat rotation has become popular in several parts of India and Bangladesh. Consequently, wheat production has gone up very considerably in Bangladesh and in the West Bengal State of India (Fig. 11):
Increasing production under favorable environmental conditions. Large areas under rice are either drought prone or flood prone. In recent years, considerable emphasis has been placed on breeding varieties for rainfed upland conditions. The growing conditions in such areas can be classified into 4 broad categories depending upon the number of months when rainfall is received, the moisture holding capacity of the soil and other soil factors such as alkalinity and salinity (Fig. 12).

The technology for stabilizing production under adverse weather conditions include:

- Crop life-saving techniques
- Alternative cropping strategies to suit different weather models
- Compensatory production programs in irrigated areas

In flood prone and deep water (50 cm and above of standing water) areas, there is need for varieties which can stand submergence and which can divert a larger proportion of the dry matter to grains. At present, the harvest index (i.e., the
Table 5. Productivity per day of some rice varieties.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Wet season</th>
<th>Dry season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duration (days)</td>
<td>Yield (kg/ha per day)</td>
</tr>
<tr>
<td>IR8</td>
<td>104</td>
<td>21</td>
</tr>
<tr>
<td>IR36</td>
<td>90</td>
<td>57</td>
</tr>
<tr>
<td>IR42</td>
<td>117</td>
<td>44</td>
</tr>
<tr>
<td>IR50</td>
<td>87</td>
<td>65</td>
</tr>
<tr>
<td>IR9743-46-2</td>
<td>77</td>
<td>53</td>
</tr>
</tbody>
</table>

10. Jute-paddy-wheat multiple cropping pattern made possible because of short duration varieties in West Bengal of India and in Bangladesh.

11. Growth of wheat production in Bangladesh:
12. Classification of upland rice environments.

The proportion of total dry matter used for producing grains) is very low in deep-water rices (Table 6). Hence, a better partitioning of the dry matter will have to be achieved in order to increase the grain yield potential. Also under such conditions it is possible to combine rice cultivation with aquaculture. This will call for the cultivation of varieties with a high degree of pest resistance so that the application of chemical pesticides with long residual toxicity can be avoided.

Table 6. Comparison of grain yield, total dry matter production and harvest index between irrigated and deepwater rices.

<table>
<thead>
<tr>
<th>Water regime</th>
<th>Variety</th>
<th>Total dry matter (t/ha)</th>
<th>Harvest index</th>
<th>Grain yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated lowland</td>
<td>IR36 (dry season)</td>
<td>13.7</td>
<td>0.45</td>
<td>7.13</td>
</tr>
<tr>
<td></td>
<td>IR36 (wet season)</td>
<td>11.2</td>
<td>0.44</td>
<td>5.74</td>
</tr>
<tr>
<td>Deepwater (floating rice)</td>
<td>Kwian Hak</td>
<td>13.3</td>
<td>0.25</td>
<td>3.29</td>
</tr>
<tr>
<td></td>
<td>Pin Gaew 56</td>
<td>12.2</td>
<td>0.19</td>
<td>2.31</td>
</tr>
<tr>
<td></td>
<td>Hing Hoy</td>
<td>23.2</td>
<td>0.10</td>
<td>2.23</td>
</tr>
</tbody>
</table>
**Problem soil areas.** About over 86 million hectares in South and Southeast Asia suffer from various soil health problems (Table 7). In addition to problems of salinity and other adverse factors, nearly 70% of the rice lands in this region suffer from nitrogen deficiency. Unfortunately, however, there is considerable loss of the applied fertilizer during the monsoon season. Formerly, it was believed that much of this loss is due to leaching and denitrification. However, recent experiments carried out jointly by IRRI and the International Fertilizer Development Center (IFDC) have shown that a considerable proportion of the loss is due to ammonia volatilization (Fig. 13). Through appropriate placement procedures, the volatilization losses can be greatly minimized and even eliminated. For doing this on a large scale, suitable fertilizer placement equipment will be needed.

In addition to mineral fertilizers, it is possible to harness various organic and bio-fertilizers such as Azolla, blue-green algae, straw, waste materials, and legume nitrogen. Azolla is already used fairly extensively in China and Vietnam. Experiments carried out at IRRI have shown that if the following 3 conditions are followed, Azolla application would save to some extent expense on mineral fertilizer:

- Adequate phosphorus availability in the soil
- Effective control of Azolla pests, whenever necessary
- Favorable labor wage rate

The scope for introducing nitrogen fixing genes in rice through genetic engineering techniques is being explored. However, this pathway of minimizing the need for mineral fertilizers is not likely to become available for commercial use during this decade.

**Adding a nutritional dimension to cropping systems research.** A major scientific challenge is to make the leguminous plant utilize more energy. Many grain legumes which are energy rich are unfortunately grown under conditions of energy deprivation. Success has been achieved in reducing the duration of several grain legumes like cowpea and pigeon pea. Research on improving the yield potential of grain legumes needs intensification.

Work on the improvement of the nutritive quality of grains has been slow. It takes many years of patient plant breeding work before a desirable gene can be placed in a productive genotype. For example, Opaque-2 maize has high lysine content but suffers from the following drawbacks:

- Reduced kernel weight
- Soft chalky unacceptable phenotype

<table>
<thead>
<tr>
<th>Problem</th>
<th>Area (millions of ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity</td>
<td>53.2</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>7.0</td>
</tr>
<tr>
<td>Acid sulfate soil condition</td>
<td>5.3</td>
</tr>
<tr>
<td>Peat soil condition</td>
<td>21.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>86.5</strong></td>
</tr>
</tbody>
</table>
• More vulnerable to ear rots
• More damage by stored grain pests
• Slow drying following physiological maturity

The work done at CIMMYT in Mexico during the last 10 years has however helped to overcome several of these handicaps. Good maize material with improved nutritive quality is now becoming available (Fig. 14).

Technologies for small farmers. The question is frequently asked whether high yielding varieties of rice, wheat and other crops have been built-in characteristics of social discrimination. Carefully conducted studies, however, have shown that the technology is beneficial irrespective of the size of the farm holding (Table 8). A small farm in the tropics and sub-tropics has a good production potential since it affords the possibility of intensive agriculture. However, the small farmer with often fragmented landholdings suffers from several handicaps. The handicaps are partly economic and partly technological. For example, technologies such as
water harvesting, water shed management and integrated pest management can be adopted efficiently only by a group of small farmers working together. It is in this context that the pattern of land ownership and management becomes exceedingly important. Countries like China where land is socially owned are introducing techniques for combining social ownership with individual initiative and incentive. In the case of individually owned lands, there is need for combining individual initiative and enterprise with social or group action in fields of activity such as water management, crop protection and post-harvest technology. Unless small farm management receives greater attention from the point of view of improving its operational efficiency and economy, it will be very difficult to improve the financial well-being of small farmers.

The other area which requires attention is the enhancement of the employment potential of agriculture. A majority of the population in developing countries depend upon land and water-based occupations such as agriculture, animal husbandry, fisheries, and forestry for their living. Human labor is still the most important component of labor in many developing countries (Fig. 15). Here again

Table 8. Rice yields (t/ha) reported by farmers.

<table>
<thead>
<tr>
<th>Location</th>
<th>Smallest farm size group</th>
<th>2nd smallest</th>
<th>2nd largest</th>
<th>Largest farm size group</th>
</tr>
</thead>
<tbody>
<tr>
<td>India (11 studies)</td>
<td>3.1</td>
<td>3.2</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Indonesia (3 studies)</td>
<td>3.3</td>
<td>3.1</td>
<td>3.4</td>
<td>3.8</td>
</tr>
<tr>
<td>Pakistan (2 studies)</td>
<td>2.9</td>
<td>2.6</td>
<td>2.6</td>
<td>2.8</td>
</tr>
<tr>
<td>Indonesia (5 villages)</td>
<td>3.7</td>
<td>5.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Philippines (9 villages)</td>
<td>2.7</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malaysia, Pakistan, Thailand (6 villages)</td>
<td>3.0</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
studies have shown that modern varieties will enable more labor to be used. This is particularly so in areas characterized by multiple cropping. A proper assessment of the employment impact of new technology should be done and it should be ensured that labor diversification and not labor displacement occurs following the introduction of new technology. Particular attention should be given to new technologies for women-specific occupations being subjected to an employment impact analysis prior to their introduction.

Examples of new technologies which are labor intensive are:
- Hybrid rice in China
- Hybrid cotton produced from hand-emasculated and pollinated seeds in India
- Cultivation of potato from sexual seeds

Also mixed farming techniques involving crop-livestock integration and aquaculture and agriculture techniques should be promoted. There are considerable opportunities for 3-dimensional crop planning involving the optimum use of cubic volumes of air and soil. Post-harvest technology is another area which can provide considerable opportunities for the preparation of value-added products.
from the entire plant. For example, the rice biomass consisting of straw, bran and hull can provide more income and employment if properly processed and utilized.

**STEPS TO DEVELOP A GLOBAL FOOD SECURITY SYSTEM**

Since the World Food Conference held in Rome in 1974, several steps have been taken to promote the development of a global food security system. The following are some of the more significant steps:

* **A Global Information and Early Warning System** started in 1975 by FAO: This system provides useful data for initiating suitable preventive and remedial action in order to overcome the difficulties that may arise if the early warning proves to be correct. While FAO provides the early warning system, it will be for national governments to develop a mechanism for timely action.

* **International Emergency Food Reserve (IEFR).** This was started in 1975 and since then, a total of 1.8 million tons of food grains and about 150,000 tons of other foods have been distributed through this channel. IEFR’s annual target is 500,000 tons of cereals.

* **International Fund for Agricultural Development (IFAD).** This was established in 1977 for the purpose of promoting increased flow of external resources for food production and rural development. In its 4 1/2 years of operation, IFAD has committed $1,400 million for projects and programs in 100 developing countries.

* **World Food Council (WFC).** This was established by the U.N. General Assembly through Resolution 3348 (XXIX) in December 1974 for the purpose of “coordination and follow-up of policies concerning food production, nutrition, food severity, food trade and food aid, as well as other related matters, by all the agencies of the United Nations system.” It is enjoined to “review periodically major problems and policy issues affecting the world food situation, and the steps being proposed or taken to resolve them by Governments, by the United Nations system and its regional organizations” and recommend remedial action. WFC is an organ of the United Nations and reports to the General Assembly through the Economic and Social Council.

The World Food Council has been organizing annually a conference at Ministers’ level to review the global food situation and develop regional and national food security systems. Its major goal is to raise the political priority for food.

* **International Wheat Council (IWC).** The International Wheat Agreement 1971 consists of two separate legal instruments: the Wheat Trade Convention 1971 (as extended) and the Food Aid Convention (as revised in 1980 and subsequently extended). The Wheat Trade Convention is administered by the International Wheat Council while the Food Aid Convention is administered by a separate body, the Food Aid Committee. The Food Aid Committee (which is limited to contributor countries) does not have its own secretariat and is serviced by the secretariat of the IWC.

* **Food Aid Convention (FAC).** This convention was enlarged in 1980 and has a target of 10 million tons of food grains.

* **International Monetary Fund Compensatory Facilities.** This facility was established in 1981 and is intended to provide assistance to a country which has to
import additional food grains to meet the needs of the population. This new financing mechanism has so far made available credit up to $300 million to 5 developing countries.

*Other FAO Programs.* Several other programs like FAO's Food Security Assistance Scheme, International Fertilizer Supply Scheme, and Action Program for the Prevention of Food Losses are also relevant in the context of food security measures.

*Regional Food Security.* A good example of this is the recently established ASEAN Food Security Reserve Agreement. Several other regional mechanisms of both consultation and establishment of reserves are under discussion.

*National Food Security Programs.* Food reserve programs have been initiated in 72 countries including 60 developing countries. The United States has taken, on its own, an important food policy initiative to set up a Food Security Wheat Reserve of up to 4 million tons to meet emergency needs, which is in accord with the International Undertaking. The U.S. farmer-owned reserve as well as the large national buffer stocks built by some major food deficit countries — such as China, India, Indonesia, and Japan — have also contributed to world food security. However, reserve stocks are often below target levels. National early warning systems are being slowly improved, and devices have been introduced into bilateral grains contracts to limit large-scale pre-emptive buying.

The above steps indicate a movement in the positive direction. Thus, the overall balance sheet both with regard to food production and food security is one of hope. A new General Agreement on Tariff and Trade (GATT) Committee has been set up to recommend by 1984 methods of achieving greater liberalization in agricultural trade. If this Committee is able to work out a pattern of trade which will increase the flow of resources to the agricultural and rural sectors of developing countries, it would have done a great service not only to the poor nations but also to the industrial sector of developed countries since agrarian and rural prosperity stimulates the demand for a variety of industrial products.

**COMPONENTS OF A NATIONAL FOOD SECURITY SYSTEM**

Regional and global food security will become possible only if every country develops a strong national food security system. An effective national food security system will have the following components:

- Ecological security in order to protect the basic life-support systems upon which sustained agricultural advance depends
- Technological security in order to ensure that yield improvement is coupled with stability of production
- Grain reserves, safe storage and improved post-harvest technology
- Social security to provide the needed purchasing power to the urban and rural poor through greater opportunities for gainful employment
- Water security both for drinking and irrigation
- Nutrition education
- Population stabilization

Thus, an integrated National Food Security System should give concurrent and integrated attention to ensuring adequacy and stability of food output and supplies
as well as security of access to supplies. Above all, it should ensure that the short
term goals of agricultural development do not endanger long term prospects for
producing more food from limited land resources.

CONCLUSION

FAO estimates the number of seriously undernourished people in the developing
market economies rose by about 75 million in the first half of the 1970s. The same
figures also suggest that it was possible to nourish fairly adequately more than two
thirds of the 230 million persons added to the population in these countries during
this period. This achievement is seldom mentioned. Similarly, it is often stated
that in more than half of the developing countries food production did not keep up
with population growth. This also means that it succeeded in doing so in about half
of them. These more successful ones have well over half the total population of the
developing countries.

The expansion of food and agricultural production in the 1970s in the
developing countries as a whole failed by a wide margin to reach the target of an
average of 4% per year set in the International Development Strategy for the
Second U.N. Development Decade. The increases actually achieved (3.2% a year
in food production and 3.1% in total agricultural production) still represent a
remarkable performance, when viewed against past trends. In India, for example,
food grain output increased by about 2.8% per year during 1950 to 1980, as
compared to a growth rate of about 0.1% between 1900-1950. Science and
technology have played a dominant role in this transformation of the agricultural
scenario. Science can only show the way and provide the tools. The magic wand
which can eliminate hunger is however not in the hands of scientists but in the
hands of political leaders who determine priorities and set goals. If those who
move science and those who move society will work together with the will and
determination to succeed, no human being need to go to bed hungry.

Until this happens, we should strengthen the existing instruments for fighting
hunger. In particular, programs for promoting agricultural development through
the effective utilization of surplus foods deserve careful design and widespread
support. The World Food Program initiated in 1961 by the United Nations and
FAO is an excellent medium for organizing food production through food aid.
WFP’s recent initiative in buying food from developing countries in order to
ensure a fair price to farmers is praiseworthy. Such initiatives, if supported widely,
will provide the breathing spell necessary for enabling the growth of enduring
national food security systems.

ACKNOWLEDGEMENTS

The data cited in this paper are largely from the work of different departments and
scientists of the International Rice Research Institute. I am exceedingly grateful to
all my colleagues in IRRI for making available recent data on the various points
discussed in the paper. I am also grateful to Mrs. Victoria Sebastian for her
assistance in getting the paper and illustrations prepared for publication.
Economists will tend to approach problems – even one of the magnitude of feeding the world – in terms of supply and demand. That will be my context, but I will consider it in terms primarily of the next twenty to thirty years.

The nearer term is perhaps not so great a problem, albeit with exceptions and qualifications. New varieties have raised grain yields substantially. Governments have improved land through the extension of irrigation. With irrigation, it is possible to increase the intensity of land use by improving the yield per hectare per day through a combination of intercropping, sequential cropping, adjusting maturity times and similar agronomic techniques. These two factors, irrigation and improved agronomy, have permitted the most populated area of the world, Asia, to keep the food output ahead of population growth at a time when most Asian countries are well into a demography transition, with death rates dropping precipitously and birth rates declining, but much more slowly. These two sources of current increased food output should be a satisfactory generator of food output growth in Asia for the next twenty to thirty years.

Food production should stay ahead of population in this most populated region of the world, but it will need continued, very substantial investments in the factors that do permit this high density of plants per hectare, and the expansion of the potentiality of using that land again and again over the course of the twelve months of the year. Investments, substantially larger than for traditional irrigation systems, must move into the irrigation sphere. Our estimates show that traditional irrigation systems can be built in areas in India or in Bangladesh for approximately $3,000 to 34,000 per hectare. We are now investing only about $1,000 per hectare, and some would argue that our technology requires a move to $2,500 to $3,000 per
hectare. When applied to two or three hundred million hectares, the result is some very, very sizeable amounts of money. However, this is precisely the kind of agricultural development expenditure that governments are being asked to make, and that aid and development institutions, such as the institution with which I am associated, are being asked to assist in underwriting. Further, we will see that development expand in Asia. In China, we have a situation where the irrigation systems are very old, but they are very comprehensive. The potential for large investments in new irrigation systems are very limited but there is still a great potential for increasing the yields per hectare on existing irrigation systems, provided the plant populations are available.

In Latin America, we still have potential for substantial land expansion, especially if we can adapt crops and crop varieties to the utilization of the acid and other difficult soils, and if we can find technologies that will improve the livestock-carrying capacity of the soils. In the next thirty years, we are not likely to see a major food problem in Latin America.

Dr. Swaminathan has pointed out that sub-Saharan Africa represents the great tender spot of the world. It does. At the present time, however, if sub-Saharan Africa has substantial supply difficulties, international food assistance would and could be available to meet the food requirements of what is still a fairly small population. It is worthwhile noting that the population of India is larger than the populations in Africa, Central and Latin America combined. The food requirements of the population of sub-Saharan Africa could still be met on an assistance basis from the reserves that are available to the surplus food-producing nations, primarily those of North America. However, at the growth rate of the African population, this will not be true for long.

I would place on the agenda of our concerns as world citizens today the technological and associated policy problems that underlie the issue of the supply of food in the African subcontinent. It has soils that are very difficult to handle; there are range management problems; there are substantial livestock problems that we still don’t know how to overcome; and there are crop adaptations that are necessary. There is little possibility of major irrigation such as we have in Asia. The fundamental supply problem in Africa is to match a set of technologies, having potential for the future, with appropriate policies. I would hope that before long we will have the technology that is necessary for the Africans.

Now, when I say that I think we can handle the problem on the Asian and Latin American scenes for the next twenty to thirty years, this makes certain assumptions. The assumptions are that the present research efforts continue and be fruitful. That will probably mean, in the economist’s terms, that we are now running into diminishing returns on research and that new avenues, additional resources and larger expenditures are going to be necessary to maintain the research momentum. These are what I call the “betters” and they are being discussed in detail at this conference. They include the better use of fertilizer; improved nitrogen efficiencies for the use of fertilizers; the better development of biological techniques of fixing atmospheric nitrogen in the soil; and better methods of controlling pests and pathogens, some of which will be genetic and some chemical, accompanied by better methods for applying them and assuring
the safety of materials so applied. We need better water management techniques and the better use of water through better distribution. This is a farm water management problem that has to be solved. We must also be adapting other forms of water technology that will serve to expand the area that can be brought under irrigation for the same quantity of water, or, alternatively, assure enhanced yields per unit of water applied. We’ll need better varieties, varieties that are better adapted to the soil types in which they will be used, and we’ll probably need some new plant species: some of the neglected species that didn’t do very well in Europe when we opened up North America, but which hold good potential for mountain areas, desert regions, and so on. Dr. Borlaug has often talked about a wide cross between cactus and maize and corn, one that I am hoping very much that we will have. That will give us corn that will sustain itself very well under desert conditions. We need the opening up of mountain areas. Just before I came here, I was in Nepal. One cannot take a look at Nepalese hill agriculture, really mountain agriculture, without realizing the paucity of agricultural technology that is relevant in these circumstances for assisting what are a very, very poor people, but who are growing in very large numbers, to wrest more from a difficult environment.

All of these “betters”, and there are many more that we could touch on, will add marginally to our capacity to produce food. Our total will be the sum of the increments that come from these marginal gains. Providing that agricultural research is sustained, and I represent an institution that does put a fair premium on the support of agricultural research, I think that we can stay ahead of population rates at least on the average, for the next 20 to 30 years. Of course, there will be times when there are aberrations of weather, or other such circumstances to affect production. The margins in countries like Indochina, Bangladesh, etc., are going to be exceedingly thin. They are now, and the failure of a monsoon can result in a major short-term catastrophe when food assistance and international trade in food products is going to be necessary to assist such governments to feed their hungry peoples. However, on the whole, for the next 20 or 30 years, providing research is sustained, providing investment continues, and providing also that there is special effort made for Africa, we can feed most of the world’s peoples.

The above discussion relates to the technical side of the supply function. What about the social and political side? Fundamentally, I think we are now very much more knowledgeable about the role of farmer incentives and the role of various governmental actions to promote agricultural growth and agricultural development. Twenty years ago, I would have had to say “Look, I don’t know how to get food agriculture moving”. At the same time, you could have taken me out to the plots and fields in India or in Sonora, and said, “Well, there is one of the technological solutions”. I would have replied, “Fine, but how do you get governments to move?”. At that time, there was a series of governments — important governments, such as the Government of India — that were quite happy farming the fields of Kansas and Saskatchewan, living ship-to-mouth on food assistance and getting paid for doing it, because they took the food and sold it in their market places. In effect, they were lent the money they received for the food, and it was an important item in balancing the government budget.
We now know that technology and farm incentives are basic to what we can do in agriculture. The African nations generally have to learn that fact. The policies of most governments in Africa have been policies against agricultural growth and agricultural output, and it is necessary to turn these policies around before much can be done to ensure that even former output levels in Africa are reached.

Dr. Swaminathan has touched on one other factor in this question of farmer action, that is, the individual versus the social role. His comment dealt with small, fragmented farms. It does not do much good for one farmer to apply pesticides to his field and leave his neighbour’s field infected. Collective action, social action of some kind, must be taken in order to handle these systems. We are still not very good at finding out how that social action can be undertaken, how it is organized, and how it is handled. I think we will be before thirty years are over. We will see substantial movement in most of the developing countries on that optimal mix between individual incentives to farmers and the social action that farmers, especially small farmers, must participate in, if they are to gain the real advantages of the technologies offered.

There is also the question of the political role. Dr. Swaminathan ended his statement by considering this matter. We heard much about it from President Marcos on the issue of political will in the Philippines. Political will is very much tied to national budgets, and the capacity of national treasuries to meet the requirements of agricultural development. The kind of priority that national treasuries can assign to agricultural development is affected by the degree to which it is becoming a very expensive development proposition. Today, we probably have more constraint in the forward movement of agriculture because of the cost requirements, and the difficulties that all nations have in balancing their budgets and staying within the framework of resource mobilization capacity, that is, their ability to tax and raise money. That constraint by itself is, probably, much more important now than the shortages of fertilizer, or the difficulties of applying new seed or new technologies. These are constraints, however, that I think are temporary, and which will be removed if we can engender a worldwide economic recovery.

Fundamentally, there are three legs to the stool of agricultural progress in the developing countries that we have learned about in the last 20 years. The first is technology. It must be technologically feasible to increase yields to raise outputs. There must be a transfer mechanism that exists between the research stations or the scientists’ laboratories where these technologies are discovered, developed and refined, and the farmer’s fields. This leads us to an extension service or a technology transfer service, which is the communication link or demonstration link between the technological base and farmers in their farming practices.

The second leg of the stool is economics. There have to be incentives. We have learned that it is not sufficient just to go out and tell farmers to raise yields and increase their farming activity because there is a national need for food and there is not enough foreign exchange to import it. There has to be some price mechanisms with profit elements, with the kind of assistance whereby the farmer will find it profitable to undertake the risks of innovation, and to carry that innovation to higher levels through his own experimentation and his own farming practices.
The third leg of the stool is organization. In simplified terms, this becomes “how do you deliver fertilizer?”. For some countries in Asia, increase in fertilizer consumption has been on the order of 40-45% per annum over the past four or five years. In the developing countries, in general, the increase in fertilizer consumption has been on the average, globally, almost 14% per annum over the last decade. These are very large increases in fertilizer, and behind them must lie an industrial policy in either the producing country or the purchasing country. There has to be a transport system (the lack of which is one of the problems in the Nepalese hills). There has to be a whole set of institutions that can carry the fertilizer from the factory or the port of landing, to the farmers’ fields. It has to be accompanied by credit to make it available to the farmers, and if the farmer is going to pay back his creditors, he has to have a market in which to sell his products. The requirements for product markets and everything related to the whole post-harvest distribution must be met.

These three legs of the stool, technology, economics, and organization have to be there. The lack of any one of them or any part of one can jeopardize the whole process. For example, one thing that has now occurred with fertilizer for many areas, arises from the fact that the non-ultraviolet-degradable plastic bags for fertilizer are now a very important factor in moving it substantial distances into the hills of a place like Nepal. Sometimes, it can take up to two seasons to move fertilizer from an Indian factory through the import ports, up the hills to an outpost, and then on heads of porters into the far reaches of a hill-farming community. In that two seasons, if the fertilizer is packed in a plastic bag that degrades under high ultraviolet conditions, the farmer receives a crumbled or caked mass of fertilizer. A plastic bag that does not do so degrade will bring him granular urea that he can apply. That one factor alone has made a very significant difference to the consumption of fertilizer in the Nepalese hills. So each element must be coordinated and the three legs of the stool assembled together: the organization matching with economics and economic policies, and with the technological feasibilities.

Now, let me turn briefly to the demand side of my equation. It is sobering to recognize that today, in Asia, in that arc from Afghanistan through Japan, including the sub-continent, China, but excluding Soviet Union Asia, the population has just reached about 2.5 billion people. That was the world’s total population in 1950. Asia added almost 800 million people in the last two decades, due to the population growth rate. Between now and the year 2000, just 20 years hence, Asia will add about 380 million people, now born, to the reproductive age group between 20 and 39. Industrial countries, including Japan, will add 80 million people in that period of time. This raises the spectre that Dr. Swaminathan talked about. How are you going to provide them with employment? But it also raise the spectre, with that number coming into the reproductive age group, of where are we going to put what they reproduce? What are the implications of that for the long-term growth rates of population? I do not wish to be Malthusian about this. Malthus propounded his thesis in the mid-18th century, but it has not come true, first because of the great explorers and developers, and secondly, because of the great technologists.
It is fashionable in many circles to talk about the end of population explosion, but it is unseemly for me here in the Philippines to talk about it when the Philippines has just reversed its population policies. However, we must confront the fact that, on the population side, there will not be major lessening in the demands for food over the course of the next thirty years. It is true that birth rates are beginning to drop in most Asian countries, although not in most African countries. They are dropping from the levels between 40 and 46 per thousand down to between 30 and 40 per thousand, with some exceptions substantially below the thirty level. However, it is also true that death rates have a long way to go. The Chinese death rate is about 7 per thousand. The death rates in the bulk of South Asia are about 15 per thousand. The decline in death rates will not easily stop, so that the population trends will not be stationary. Indeed, I think it will be another 100 years before we reach a level of stabilized populations. Family planning programs and disincentives for population growth will be placed higher on the agendas of most nations over the course of the next two decades.

In addition to the population factor affecting the demand side, there is a much more insidious and more important component of growth in demand. This will arise when people have higher incomes, and they will have higher incomes. Development is taking place, and economic growth rates of Asian countries have been about 6% per annum, substantially ahead of population growth. Per capita incomes are rising, and as per capita incomes rise, people demand better quality diets. They move from taking just 400 pounds of grain, to demanding more milk, more meat, more poultry products, and the grain equivalence of these begins to increase. The Asian family of four, certainly the Indian family of four, now eats about eight-tenths of a ton. There is no question in my mind but that, 20 years from now, it will have increased from the 400 pounds per capita to about 700 pounds per capita, and that will put higher pressure on food prices. It will be 700 pounds per capita, providing we can produce it at present prices. If we don’t, food prices world-wide will begin to rise in response to that demand. So the demand side, in my opinion, includes not only the population pressure but also the phenomenon of rising incomes.

To this point, I have considered the next 20 to 30 years. However, I want to go beyond that because it is of fundamental importance to this conference. What Borlaug did with wheat, and what Chandler and his colleagues did at IRRI with rice, was to raise the yields of tropical wheat and rice to the levels of yields that had been obtained some time ago in the temperate zones. Examination of the maximum yield trials for these commodities reveals that it matters little whether they come from irrigated wheat in the Dakotas or in Canada, or from India, or whether rice comes from the rice deltas of the United States, or the Po valley, or Egypt, or from the International Rice Research Institute. We now seem to have reached a yield plateau somewhere between 6 to 8 tons per hectare in the case of wheat, and about 10 to 12 tons per hectare in the case of rice. Thus, we have a group of farmers producing at a much lower level, but slowly pushing upward. They’re still a long way from the plateau. They will never attain it, because the circumstances in their fields will not permit them to attain it. But they will come
within 50% or 60% of it, and some of them will get within 75% of it. These will be the maximum potential yields.

We must be concerned for the very long run, because in 30 years, we start running out of irrigated land, the potentialities for intensification and the productivity improvements of the “betters.” Malthus did not anticipate North America and its huge production potentials, and the fact that grain could be moved very cheaply by canal systems, and later, by railroads. He did not anticipate either the application of plant breeding or modern genetics to the technologies of food production. But as we try to see ahead 30 years from now, I am not certain where we go. I know of work on C-4 pathways, I know of work that attempts to get at improved photosynthetic efficiencies, I know of work that is taking a look at better disease control techniques breeding antigens into plants, and so on. I know of a series of chemical changes that can occur at the genetic level, now that we have control of various forms of cultures trying to cross intergeneric “roulette wheels.” All of these will have their play, and all of them are important. However, I leave you with one sobering thought. Borlaug began his work on wheat in Mexico in 1944. It was 1974 before they really began to make a breakthrough in this part of the world. That was a thirty-year time span. That is about what we face as the time span from the laboratory research to its application in farmers’ fields. These are not the incremental “betters” which can be moved into application fairly quickly, because we have fairly good extension services to do it. But to go through the process of making substantial changes, and of finding new areas of discontinuity in the production function in our capacity to produce food, does involve us with about that 30-year time span. At this stage, I am not certain where to find the next Borlaug for the next round of food production growth one generation hence. I would hope that this conference will also be concerned about that.
ABSTRACT

The chemical industry is already playing an important part in improving the world’s food supply, but it could play a bigger one. Present scientific knowledge and the potentially fertile land available would already suffice to feed the world’s population if various political, economic, financial and organizational questions could be resolved. A plea is made for greater cooperation between commercial enterprises, governments and international advisory organizations.

With full regard to universal and local environmental and human needs, and within the priorities set by host country governments, the chemical industry is able and willing to use its knowledge and experience in the service of food production and to intensify its research efforts for the future. The role of the market economy as a spur to research is explained, together with the impossibility of “one-way street” technical aid, which would rapidly deplete the financial resources on which the industry’s research activity, and hence its viability, depends.

INTRODUCTION

The aim of this Conference is to investigate what contribution chemistry and the related sciences can make to the solution of the world’s food problems. Implicit in this wording is the acknowledgement that there can be no solution of the current world food problem — and above all the future problem — without the aid of chemistry and its sister sciences.

Chairman of the Board of Directors and Managing Director, CIBA-GEIGY Limited, 4002 Basle, Switzerland.
The discussions during the next few days will be mostly of a scientific nature. This is undoubtedly right; for to science falls the task of supplying the fundamental knowledge needed to solve the problem. But the road from scientific discovery to the practical realization of concrete projects in the field is a long one. A decisive part is played along this road by governments — which are politically responsible for solving food problems within their territory — and industry, which performs the functions of research, production and distribution. Optimal solutions are possible only when all the partners cooperate harmoniously, each partner pulling his full weight in that area for which he is responsible.

I should like to approach the problem from the point of view of an industrial enterprise that is actively engaged in research, production and distribution of chemical products whose ultimate purpose is to improve the world’s food supply.

**THE GOAL OF AGRICULTURAL POLICY**

I may surely say with confidence that all the partners concerned — that is to say, science, political bodies, industrial enterprises and agriculture — are in agreement about the goal to be achieved. It is nothing less than the defeat of hunger among a large portion of the world’s population. Because this is one of the gravest problems facing mankind at the present time, progress ought to be possible on the basis of the good will and knowledge of all the participants. This is especially true when we realize that, with the aid of scientific knowledge and the available chemical products and other agricultural methods, there is enough potentially fertile land on our planet to provide sufficient food for its population. What is wrong is not so much a fundamental deficiency as the failure of human beings to resolve the associated political, economic, financial and organizational questions. It is thus of little use for chemical research to create good products which are then prevented from making their full contribution to the world’s food supply for reasons which lie on a completely different plane.

I am well aware that the difficulties to be overcome are huge and complex, and that consequently no spectacular solutions can be expected in the short term. The food problem is an important part of the North-South dialogue, because the population explosion and hence the problem of hunger are currently affecting the developing countries above all. Now it is exactly this dialogue that contains many misunderstandings prejudicial to constructive solutions. An essential precondition for fruitful future collaboration between the various partners is thus the creation of a basis of mutual trust and understanding. It must also embody respect for the partner’s various needs and possibilities, without which genuine progress is scarcely possible. Furthermore, the areas of responsibility of the different partners — governments, industry, agriculture and international institutions — in solving the problem must be clearly marked out.

**DEMARCAION OF DUTIES AND RESPONSIBILITY**

If we wish to consider what part chemistry has to play in all this, we must first define what we mean by chemistry. It cannot mean only chemistry as a pure
science, but must comprehend all the chemical activities — research, product development, production and distribution — carried out by individual chemical enterprises, which themselves derive their activities from the results of basic research.

Chemical industry is a part of the industrial economy, which in its turn represents an important part of human social life as the provider of the material prerequisites for human survival. However, human society as a whole is shaped by the political authorities. It is the political authorities, too, who lay down the rules on which the economy in their territory is to run, and they set the corresponding framework which we call the economic system. The modern world contains innumerable systems occupying the range between the two extremes of the planned and centralized state economy on the one hand and the free economy on the other. Companies with international operations must respect these various systems and behave as good citizens in every territory. Conversely, however, governments must accept that the freedom of action of the individual enterprise is determined by the economic system of its home country. This is true especially of enterprises from countries with a market economy system, which can survive only as long as they operate profitably.

I imagine that nobody today still holds the opinion that the state and industry are two independent institutions. Industry acknowledges that it is a part of the state and is also prepared, within the framework of its responsibility, to contribute to the objectives set by the state. For internationally operating companies, this means subordinating their business operations to the sovereignty of the governments of the host countries. This is especially true for the chemical industry whose activity extends, among other things, to the field of nutrition, in other words to an area with an important political content and hence one of the proper concerns of the state.

If we speak today about the role played by chemistry in connection with human nutrition, and look at chemistry beside the governments of individual countries, we must be clear in our minds that chemistry is not a homogeneous entity but comprises a large number of enterprises, each with its own programmes and objectives. This constellation may lead to difficulties of an organizational nature; but it has great advantages to which I shall refer later. One thing, however, is clear: chemistry cannot simply be expected to solve the problem of the world’s food by itself. It needs the active cooperation of governments, in whatever form their political philosophy may dictate. On the other hand, it is a fact that even governments will not succeed in finding practical solutions without involving the chemical industry; and if governments wish to take the maximum advantage of chemistry’s activities, they must create the overall conditions that will permit chemistry to contribute its best work.

The chemical industry has shown in the past — and there are figures to prove this — that it is capable of making a contribution to solving the food problem. It is also convinced that, under improved external conditions, its contribution can be increased even further. And even if the food problem should become still more difficult in future, as is to be expected, there is no reason at all for resignation: for the instruments to solve future problems are largely already available, and it is, as
I have already mentioned, chiefly a question of securing their application. In practice, the question is chiefly one of making better use of cultivable land, exploiting existing chemical products appropriately, improving the distribution of agricultural produce by expanding the infrastructure, and preventing produce from becoming spoilt during storage and distribution.

The problems, however, are not only of a material nature: they are further complicated by the traditions, and the political and sociological structures existing in different countries. These traditions and structures must be respected and, as far as possible, preserved. It is therefore not enough for the chemical industry to offer agricultural products, such as fertilizers and pesticides, that are good in themselves — it must look for solutions that meet the specific circumstances and requirements of the individual countries. The desired increase in agricultural yield and productivity, in other words primarily the rationalization of agriculture, must not be given its head at the cost of existing social structures. Let me give an example. In countries where agriculture is chiefly carried on in small individual holdings, it is not permissible to encourage the industrialization of agriculture if this leads to a migration of displaced small farmers to the slums and shanty towns of the cities. The social damage and human misery that would result from this could be out of all proportion to any benefit obtained from increased agricultural production.

Naturally there also remains the problem of financing future agricultural policy. A discussion of how to solve this complex problem is outside the scope of my address, especially since the financing of new agricultural programmes cannot be the business of the chemical industry. It can be said, however, that the investments concerned will not only be dictated by social considerations but will also have to be assessed alongside other programmes competing for the allocation of limited resources.

THE SPECIAL CONTRIBUTION OF CHEMISTRY

The decisive contribution that chemistry is in a position to offer, above all in solving future problems, lies in its broad and manifold research and development potential. Properly exploited, this should permit adequate solutions to be devised for the individual countries. Not only do the diversified structure and inherent competitive atmospheres of the chemical industry offer a broad palette of possibilities; they are also a guarantee for a continuous adaptation of what is offered to changing conditions. Conditions change not only in the countries concerned, but also, above all, in the research-based industry, as a result of constant scientific discovery. The industry by no means claims to possess already the ideal solution for all problems. Exactly because scientific knowledge is expanding all the time, we are well aware that the good solutions of today may be superseded by even better ones tomorrow or the day after. But it is important that the world should be able to profit from the results of continuous human invention; and for this reason, the preconditions for ensuring and maintaining innovative power must be created.
CONDITIONS IMPOSED BY THE MARKET ECONOMY

It is a fact, supported by experience, that a large number of inventions that have led to creative practical solutions, in a very wide range of fields, have originated in enterprises operating under the pressure of the market economy systems. This pressure, which is due to the necessity of achievement and profitability in the struggle with competitors, guarantees variety in thinking and approach, stimulates innovation, and hence brings progress. The market economy system appeals directly to the efficiency and responsibility of the individual, and thus ensures that the problems to be solved are spread among a large number of people and companies, which undoubtedly increases the chances of success. These are not small groups of people dictating from their planning centres what they imagine to be good and proper for the world outside; for if such planners should happen to be wrong — and it is easy to be wrong in planning under today’s rapidly changing external conditions — then disaster is not very far away.

Under the market economy system, a commercial organization must operate profitably if it is to continue to exist at all and hence also to perform satisfactorily. This is the point at which major misunderstandings exist in the international dialogue, where profitability is often alleged to be synonymous with greed and exploitation of the weak by the strong. On this it should be said that profitability is not an end in itself. Profits are, however, essential to the commercial enterprise, with its manifold responsibilities, including its very important responsibility to society as a whole. The compulsion to profitability is also in this sense a healthy spur to research, which thereby feels compelled to develop and offer better solutions — and by better, I mean solutions better suited to the requirements of the individual user.

The chemical industry stands ready to make investments not only in research and development but also in products information, toxicological data, safety instructions and application techniques. However, it must have some reasonable opportunity to recover these investments through the sale of its products and services. Moreover the data supplied to governments to support registration applications must be treated as industrial property and not made freely available to others.

TECHNICAL AID

Setting objectives in agricultural policy involves fundamental political questions that are capable of altering the social infrastructure. As such, it is clearly a matter on which the government makes the decisions and takes the responsibility. An individual commercial enterprise cannot and must not involve itself in this process. Nevertheless, it is a fact that multinational enterprises, more than almost anyone else, possess a large store of experience in the field of agriculture and would be capable of furnishing valuable aid to governments, especially in scientific and technical matters. The multinationals know the conditions and requirements of each country from the technical and scientific standpoint. They possess substantial
knowhow and are also able to evolve and offer specific, differentiated solutions. It is for the governments concerned to decide whether they wish to accept this technical aid and to what extent. There is one precondition: an enterprise is able to offer technical aid only if a country is prepared to guarantee the rights of industrial intellectual property, and is further willing to give a fair return for the technical knowledge utilized.

Moves exist at the present time to reduce the protection given to intellectual property, and a revision of patent practice is under discussion. There is a widespread opinion that reducing patent protection will somehow benefit the transfer of technology between North and South. This opinion overlooks the great danger that the interests of both partners — of the makers of technology and of those who receive technology — may suffer if protection is reduced. New technology is the result of much work and the spending of a great deal of money. In this sense it represents a product of industry. If the technology-maker is compelled to part with the fruits of his labour without compensation, his resources for future research are depleted. This means that research will grind to a halt, and new, urgently necessary results will fail to appear. There could be a further consequence: technology-making enterprises could withdraw their activities altogether from developing countries, and concentrate on those countries in which intellectual property continued to be protected. I personally am convinced that many of today’s world food problems could be solved if the knowledge possessed by enterprises could be exploited better and more comprehensively. However this desirable end is often prevented by the fact that technical aid is far too frequently regarded as a one-way street. There is too little realization of the fact that technical aid must also involve a giving and a taking in the interests of both partners. I believe that a considerable contribution to this process could be made by international institutions such as the Food and Agriculture Organization. They possess extensive information on the possibilities possessed by industry and on the needs of individual countries. In addition, they have long experience in contacts with this partner. They could help to bridge the often conflicting interests, and to find a synthesis interesting for both partners.

INDUSTRIAL PRODUCTION

It is often demanded that multinational enterprises should transfer more of their production operations to developing countries. This demand is understandable, since every transfer of production is also a transfer of technology: new jobs are created in the recipient country, and centres for job training are set up. For this reason industry is not fundamentally opposed to wishes to this kind. However certain basic economic rules continue to apply here. First of all, there is the principle of economy of scale — one that applies in a different degree to each product field. It does, however, mean that, at least for certain products, production units cannot be set up in every interested country. Furthermore, suitable provision must be made for the supply of raw materials and transport, and finally, trained production personnel must be available either at once, or, as a minimum, after suitable training. A pragmatic approach is therefore the one most
appropriate in this matter, with a phased procedure beginning with the simpler stages of production, such as formulations.

CONSERVATION OF RESOURCES

At first sight, this requirement seems elementary and self-evident. But in practice it is not always easy to solve. Above all, the temptation to make political capital out of it must be resisted, for it would be of no service to either partner to do otherwise. This is, in my opinion, the case with the recent publication “Circle of Poison, Pesticides and People in a Hungry World”. It is a matter for regret, because the book contains some valuable ideas. But when the authors conclude that a “circle of collusion between national and international companies, banks and government and UN agencies” exists with the object of flooding the world with poisonous chemicals, they show distinctly that their concern is not with the well-being of the individual countries, but with an alteration of political structures. In actual fact it is the government of each country that decides what chemical products shall be used in its agriculture. It is unfair to portray the governments as ignorant and helpless; for they have independent advisers at their disposal, especially those from international institutions, and these must surely be assumed to have the preservation of the national interest as their goal. But one must also realize that each country has to make its own risk/benefit analysis as regards the use of chemical products; and it is perfectly possible that such analyses in one country may indicate the desirability of using products which are no longer on the market in other countries whose preconditions are different. Finally, I should like to state expressly that chemical enterprises — and especially those operating worldwide — also have consciences. They are aware of the great responsibility that they carry and they take it seriously. For their ranges of products they have set up safety standards of their own which are the same all over the world. In other words, they market only products for which they can take full responsibility in a safety-technical sense. In this, no distinction is made between developing and developed countries. One must, of course, realize clearly that industrial enterprises — exactly like governments and state organizations — are made up of more or less imperfect human beings and are thus not immune from error. However it is not permissible to use isolated instances of human error to condemn a whole system.

THE FUTURE OF CHEMISTRY IN THE LIGHT OF NEW SCIENTIFIC KNOWLEDGE

It would be arrogant to pretend that definitive technical and scientific solutions to the multitude of existing agricultural problems are already available, or even that it is already known for certain in which direction these solutions should be sought. It is a constant duty of governments, science and industrial research, in optimal coordination, to work stepwise towards new solutions that will bring the desired goal within reach. One thing is, however, clear, namely that three preconditions must be observed in all future activities:

• Natural resources, such as energy, soil, water and air, must be conserved by
reducing environmental stress and by improving resource management.

- Full use must be made of the current and forecast advances in the biological sciences, especially biotechnology. It is already clear that biology will offer complementary or even alternative solutions to chemistry for a series of agricultural problems. For this reason, biological approaches must be closely integrated with chemistry to achieve optimum effects and efficiency. We are all aware that recent years have seen rapid developments in biotechnology, including genetic engineering, in which the new methods developed are rapidly being perfected. They open up possibilities in all fields of agricultural technology, including plant protection, animal health, seed-raising, fertilization and soil management, disposal of wastes, etc. How long it will be before this new knowledge can be put to practical use is not yet certain, and in certain fields it may take some time. It would therefore be wrong to assume that chemistry will soon be a back number in agriculture. Quite the contrary: as far ahead as we can see, chemistry will remain an important part of agricultural activity.

- Since we know that the use of chemical products to solve agricultural problems, in the interests of world food supplies, will continue to be necessary for a long time to come, we must ensure that their use is adapted to the particular environmental, economic, social and institutional conditions prevailing in each individual developing area.

CONCLUSIONS

The chemical industry is ready and able to make a genuine contribution, within the framework of its possibilities and using the knowhow at its disposal, towards solving the world food problems of the future. It regards this contribution as an important part of its industrial responsibility.

The chemical industry is prepared to respect the specific requirements and conditions of the individual countries.

The chemical industry is also prepared to make special efforts in the research field in order to satisfy the specific circumstances and requirements of the individual countries. But it is up to governments to set priorities in their economic policy, and hence also in their agricultural policy. It is for governments to decide whether they wish to use their available funds for industrialization, defence, civil aviation, or the development of agriculture. Within agricultural policy itself, there are multiple possibilities. In setting these priorities, the advice of international organizations, above all the Food and Agriculture Organization, can render valuable service.

The chemical industry attaches great importance to cooperation with the governments of the individual countries in formulating general objectives and specific projects, and it is also prepared to make its technical and scientific knowhow available.

The common objectives can be attained by means of this collaboration. However the chemical industry for its part must ask governments to recognize that every commercial enterprise is compelled to operate profitably on the principles of
the market economy systems. The chemical industry is not in a position to give away its knowledge for nothing; for if it were to do this, it would starve itself of the funds needed, above all for research. And it is new impulses of the type that must emanate from research that are urgently required to solve the problems of the world’s food supply.
ABSTRACT

The production of food in the developing tropical world is considered within the context of a number of biological constraints (insects, pathogens, weeds, etc.) and how new and innovative approaches might be brought to bear to trigger an accelerated and sustainable food production. The lowland humid tropical zones are considered especially fragile; and the question of conserving the rich and diverse tropical biota is related to the long-range problem of widening our genotypic base for domesticated plants. The mixed cropping system, which is prevalent in Africa and other tropical developing regions is an especially difficult problem, and must be thoroughly investigated and rationalized to effect better crop production levels in modern subsistence farming. Overall is the long-range pest problem, which is a pervasive and endemic problem, needing mission-oriented basic research for equally long-range solutions. Institutional innovations that might bring in a more participatory and interactive tropical crop production system are envisaged.

BACKGROUND TO THE PROBLEM

Food production in the tropical and sub-tropical developing regions of the world is facing a sombre future. We had been led to believe that the Green Revolution, ushered in by the new technological packages for wheat and rice in the mid-1960's, would spread throughout these regions and be repeated for other food crops. We had further believed that the food losses of the magnitude experienced during the unfavourable weather period of 1965-1972 would not occur again. But all evidence
reveals that the Green Revolution, as we know it now, can only flourish in the fertile lands, under favourable environmental and technological conditions, and that year-to-year variability in food yields is likely to be a permanent feature of our planet, notwithstanding the progress in agricultural research and in the development of technological packages. Thus, while technology has raised the yield of wheat, rice and other crops, the potential for substantial variation in crop production due to weather is real, and the range of these perturbations might well become more extreme under improved technology (Barker, Gabler and Winkelmann, 1979).

This is a rather startlingly different view from the conventional implicit assumption that adoption of modern technology will lead to greater stability of crop yields. Indeed, one would conventionally see the period between 1929 and 1962, when yield increases of major crops in the USA (and dramatically so for maize) were the result of the application of high-yielding varieties, improved cultivation, and heavy application of fertilizers and pesticides, as the period which saw yields becoming more stable in the decades of the 1950’s and 1960’s than in the earlier ones of the 1930’s and 1940’s. But there is no real evidence of this, according to Barker, Gabler, and Winkelmann (1979). They demonstrate from a variety of analyses that there is “a tendency for the absolute variability to increase even though relative variability may in some cases remain unchanged or even decline.”

This situation holds true even when several components of modern technology (e.g. breeding for insect and disease resistance, breeding for tolerance to adverse environmental factors, and the expansion of water management) seem to lead to yield stability when considered independently of each other. This startling finding should not discourage the development and adoption of modern technological packages: rather, it suggests that we should, in Green Revolution levels of agricultural production systems, invest in maintenance research — to keep up with the gains we have already achieved, when new obstacles arise, such as the resurgence of a disease or pest previously under control through chemical means, or the appearance of a new one.

Such considerations, which apply to industrial agriculture in the USA and other industrialized countries, will equally well apply to the developing countries. Equally important to food security may be the effect of a changing climate on the frequency and severity of pest outbreaks. Although current models of crop production do not take into account the occurrence of pests as a function of varying climatic factors, it is now recognized that, at least in the case of wheat production in North America, changing climatic conditions have a role to play in the occurrence of wheat diseases (Kellogg and Schware, 1981). For instance, the severity of stripe rust on winter wheat in the Pacific Northwest region has increased since 1961, and it has been explained as a result of the higher winter temperatures. Our understanding of this and related phenomena need greater effort on our part, and the extension of this type of investigation to the tropical regions. Certainly, if there were to be global climatic warming, the stability and distribution of food crops would be greatly affected just as during the Altithermal Period 4500-8000 years ago when much of Northern and Eastern Africa was wetter than it is now, and people lived and probably grazed their livestock in many
parts of the region presently occupied by the Sahara Desert. Likewise, the American “corn belt” was then a dry prairie, and could not support the forests that luxuriantly occupied the area later on.

The sombre note I struck at the beginning of this presentation does not address these global phenomena of a macro-kind. Rather it shows that we must be concerned with the more proximate factors and systems — the rising food deficits, the growing number of jobless and under-employed, a re-examination of the institutional arrangements for more productive crop research and development in the Third World, and the constraints (particularly those of the biological type) that we must overcome to reach our goal of self-sufficiency in food.

In this respect, the Second Asian Agricultural Survey (AAS-2) carried out in rural Asia in 1976 is instructive, as it identified the problem-areas that are likely to beset the region in the decade of the 1980’s (Asian Development Bank, 1979). These are:

- Widespread under-employment and poverty among the rural people.
- Unsatisfactory performance of agricultural production and distribution systems.
- Inadequate capacity for implementation — at the level of both the government and the rural communities themselves — for the task of development.
- Continuing neglect of certain vital eco-systems, since efforts for crop production have concentrated investment and scientific skills on irrigated areas and lands potentially suitable for irrigation.

Although the nations of the regions have, since the mid-1960’s, reached a degree of self-sufficiency in domestic food production, this level varies: some have substantial market surplus and are accumulating stocks (India, Korea), some are exporting (the Philippines), while some others have found their production significantly curtailed because of pests and weather and have resorted to importation (Indonesia, Vietnam).

Let’s take rice as an illustrative example. Rice production in the region increased by less than 2% a year between 1963 and 1975, and there is an enormous range of variation in individual country performance, which might well be correlated with the level of the development of national irrigation systems, the level of fertilizer application, and the adoption of high-yielding varieties, in short, the Green Revolution technological packages. However, it needs to be observed that the high-yielding varieties of rice that have been produced up to now have not given the range of adaptability to a variety of agro-climatic conditions that they promised — except in those conditions, wide but still specific to those individual varieties, for which the varieties were tailored — and they have not outperformed the traditional varieties under conditions where the three inputs (adequate water, fertilizers, and pesticides) have not been optimal. Indeed, one can firmly state that the level of performance of rice under the best national programmes in rural Asia is still far below what has been achieved in the temperate industrialized regions, and that the gap between the actual production level and the potential is too wide (Table 1). Even more serious is the fact that adequate resources have not yet been directed to researching and developing the requisite technology for rainfed agriculture, (e.g. for upland rice). As the AAS-2 notes, “There has been no
Table 1. Potential and actual rice yields (t/ha).

<table>
<thead>
<tr>
<th></th>
<th>Temperate zone</th>
<th>Humid tropics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential yields</td>
<td>15 - 17</td>
<td>13 - 15</td>
</tr>
<tr>
<td>Actual yields</td>
<td>4.5 - 6.0</td>
<td>1.5 - 2.5</td>
</tr>
<tr>
<td>% actual over potential</td>
<td>25 - 40</td>
<td>10 - 20</td>
</tr>
</tbody>
</table>

Source: N. C. Brady (1979)

Table 2. Trade in major food crops in third world countries.

<table>
<thead>
<tr>
<th></th>
<th>Annual Growth Rate (%)</th>
<th>1961/65 - 1973/77</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exports</td>
<td>Imports</td>
</tr>
<tr>
<td>Asia</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>North Africa/Middle East</td>
<td>-2.0</td>
<td>7.3</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>-4.6</td>
<td>7.1</td>
</tr>
<tr>
<td>Latin America</td>
<td>3.6</td>
<td>6.9</td>
</tr>
<tr>
<td>Total</td>
<td>2.1</td>
<td>5.4</td>
</tr>
</tbody>
</table>


breakthrough in agricultural research here comparable to the scientific advances which triggered the Green Revolution.” Consequently, it is a challenge to breeders to produce the high-yielding rainfed crop varieties (as a starting component for a balanced technology) that most of developing regions so desperately need.

The food production in sub-Saharan Africa is even worse; indeed, it has reached a continuing crisis situation for the foreseeable future. Over the last two decades, the annual overall growth rate for exports of major food crops from Africa have registered a major and steadily increasing decline, while the rate of growth of food imports has soared (Table 2). This in contrast to the situation in other developing regions of Asia and Latin America, where modest increases of exports are available and the rates of importation are equally modest, except for Latin America (Table 2). These modest increases in exportable surplus are reflected in the modest but steady growth in the yield of several major food crops in Asia, although there are national variations as already noted (Table 3).

The serious and persistent food deficit situation in Africa is not made easier by the high rate of population increase which the continent is experiencing at this time (Table 4). While the rate of natural increase is slowing down in the rest of the world, that of Africa is actually accelerating at an alarming rate (Table 4). At the same time, the growth rate of crop production in the region began to decline between 1960 and 1980, and in the 1970’s was less than the rate of population growth; likewise, food production per capita was stagnant in the 1960’s and actually fell in the 1970’s; finally, commercial imports of food grew more than three times as fast as the population growth, and food aid grew substantially (World Bank, 1981). If we were to reverse the food production performance in
Africa, therefore, and provide adequate food for all, we would probably need to increase crop production output by about 3.5% per year (McNamara, 1979). Such a strategy would require, in the opinion of McNamara (1979), at least five major operational targets.

- Expansion of the farmed areas planted with high-yielding crop varieties, from the prevailing 25% of total cultivated area to at least 50%.
- Increase of the application of fertilizers at the level of 10% per year.
- Increase of the supply of irrigation water by utilising the river systems as yet untapped, and the planned exploitation of ground water.
- More focused research on multiple cropping, the traditional cropping system in Africa, and rain-fed agriculture (a point made forcefully also by the AAS-2).
- Bringing greater effort to bear on effective extension work to the resource-poor farmer.

The first three prescriptions closely parallel the factors which appear to have been responsible for the Green Revolution (Jennings, 1974). Seed improvement for rice and wheat seem to have resulted from two basic varietal changes: firstly, the drastic shortening of the stem, in order to reduce lodging and to increase the proportion of metabolic products going into the grain; and, secondly, the

<table>
<thead>
<tr>
<th>Table 3. Growth rate (% P.A.) of Harvested Area (H.A.) and average yields of paddy rice (1963-67 and 1973-77) and wheat and sorghum (1963-87 and 1972-76).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Afghanistan</td>
</tr>
<tr>
<td>Bangladesh</td>
</tr>
<tr>
<td>Burma</td>
</tr>
<tr>
<td>India</td>
</tr>
<tr>
<td>Korea</td>
</tr>
<tr>
<td>Philippines</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Table 4. Rates of population growth, 196080.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Industrialized</td>
</tr>
<tr>
<td>Developing</td>
</tr>
<tr>
<td>Africa</td>
</tr>
<tr>
<td>Latin America</td>
</tr>
<tr>
<td>Asia</td>
</tr>
<tr>
<td>World</td>
</tr>
</tbody>
</table>

considerable increase in adaptability over latitudes, altitudes, and a range of other environmental factors. Although these improved varieties are still environment-specific, and were directed primarily to the more favourable areas of soil, water, and climate (as we have already noted), the area of impact was broad and it resulted in the quickest way to get the Green Revolution going (Jennings, 1974). This approach does not quite fit the resources and traditions of the resource-poor farmer in such disadvantaged regions as Africa — where we are dealing largely with problems of mixed cropping, rainfed agriculture, and an acute lack of resources available to the farmer (including the necessary knowledge base).

There is no doubt that the questions surrounding the overall productivity of multiple or mixed cropping are difficult ones: mixed cropping looks messy, it is not amenable to present-day agricultural machinery which was largely developed for the monoculture system of agriculture (Odhiambo, 1979a); and its being associated with peasant farming is linked in people’s mind with low levels of productivity (Agboola, 1982). Indeed, it has been said that “doubts have been expressed as to whether any of the positive benefits of multiple cropping can be exploited at more advanced levels of farming” and that “attempts to improve production by the application of technology developed in temperate cropping systems have failed in Nigeria and in most other tropical countries, not because of farmers’ conservatism but because the approach is inappropriate” (Agboola, 1982). If there are good ecological reasons for mixed cropping systems, and there are, it surely behooves us to explore these reasons in depth and then to rationalize and develop these systems into a modern version which is appropriate to present-day needs.

In this respect, it is interesting to note that approximately the same inputs per hectare will produce only 2.5 t of maize in the humid tropics as against 7 t in the USA (Bowers 1982). This seems to arise from the industrialization of agriculture in the latter, which is a high-input enterprise, requiring agricultural machinery, fertilizer, pesticides, etc. As an example, industrial agriculture of the USA achieves a profit of US$0.05 on every $1.00 of maize produced; on the other hand, in Nigeria, a loss of $1.20 per dollar produce is made (Table 5). Likewise, the farm

<table>
<thead>
<tr>
<th></th>
<th>Cents input to produce $1 output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U.S.A.</td>
</tr>
<tr>
<td>Land</td>
<td>20</td>
</tr>
<tr>
<td>Infrastructure and Machinery</td>
<td>15</td>
</tr>
<tr>
<td>Seed and Agricultural Chemicals</td>
<td>35</td>
</tr>
<tr>
<td>Management and Labour</td>
<td>10</td>
</tr>
<tr>
<td>Finance and Taxes</td>
<td>15</td>
</tr>
<tr>
<td>Total cost of production (Cents)</td>
<td>95</td>
</tr>
</tbody>
</table>

BIOLOGICAL CONSTRAINTS ON FOOD PRODUCTIONS

Gate price of maize in the USA is about $150/t; in Nigeria it is $450/t. Consequently, subsistence farming appears to be the inevitable result of the unfavourable input:output ratios associated with the production of annual crops in the humid tropics (Bowers, 1982). Some suggestions have been made to the effect that the option of adopting an agro-forestry system, tree crops interspersed with annual food crops in a multi-storeyed relay cropping system, might be the most effective long-range solution to increased and assured crop production in the humid tropics (Agboola, 1982; Getahun, Wilson, and Kang, 1982).

An illustration of traditional agro-forestry in the lowland humid tropical Africa is to be found in southern Nigeria, where the traditional cropping systems are bush fallow-food crop rotations, or taungya, or permanent compound farming, all being characterized by a tree component, amounting to a total of 67% of cultivated land devoted to trees, while arable crops occupy 25% (Getahun, Wilson, and Kang, 1982). It is believed that the deep root systems of trees release nutrients brought up from lower layers while adding to the enrichment of the soil by depositing litter, which releases additional nutrients on decomposition. Furthermore, the tree cover provides stability to the fragile soils found in these zones when they are cleared or left uncovered.

We have already seen that crop production in Africa has reached a continuing crisis point. Productivity, over the period 1960-1980, has remained stagnant, or actually declined. In a few cases, where output has increased, it has been largely the result of an expansion of the area under cultivation. There can be no more serious indictment than the fact that this state of affairs has come to pass in spite of the large investments — both domestic and external — that have been focused on food production projects during this period. Between 1973 and 1980, approximately US$5 billion were devoted to agricultural projects. Nevertheless, there has been no overall significant increase in crop production output (World Bank, 1981). One can say a great deal about the causes for this misadventure; but if we are to rectify this situation in the next two decades, it seems that we must draw up a different priority in policy planning and implementation (World Bank, 1981):

- Focus more single-mindedly on production problems of the smallholder, and seek innovative ways to overcome them.
- Expand mission-oriented agricultural research, and give it continuing support on a substantial basis.
- Change the incentive structure for small farmers, who form an overriding majority of the farming community in Africa and other developing regions.

This programme of implementation is far-reaching and almost daunting. In the face of the horrendous problems of food production in Africa, which are only an acute form of what is prevalent in other tropical developing regions, I am tempted to join in Reinhold Niebuhr’s wistful prayer:

“O God,
Give us the serenity to accept what cannot be changed,
Courage to change what should be changed,
And the wisdom to distinguish the one from the other.”
THE YIELD POTENTIAL AND THE KNOWLEDGE GAP

There have been observations by several workers that a marked difference exists between optimum yields that are potentially attainable and those that are actually reached under farm conditions. There may be many factors responsible for this so-called “yield gap”: lack of good seed varieties and their production and distribution; lack of crop varieties that are adapted to farm conditions, especially with respect to mixed cropping systems; abundance of insects, diseases and weeds; low soil fertility and insufficient fertilizer applications; soil salinity problems; and uncertain and inadequate rainfall, to mention some of the major constraints (Waugh and Martinez S., 1976). If actual rice yields, for instance, could be raised in the tropics (now merely 10-20% of the potential, in contrast to the level of 25-40% in the temperate zones) to approximately 20-25% of the potential yields, there would then be a good chance that there would be no rice shortage in the medium-term future (Brady, 1979).

Intensive crop production research in rice has given us some clue as to the nature of the yield gap, and how it may be possible to narrow it (IRRI, 1982a). One type of yield gap in rice production is that which becomes evident between experimental station yields and what scientists can attain when they conduct experiments in farmer’s fields (“yield gap I”), a difference brought about by the differing environment of the experimental station and the farmers’ holdings. A second type of yield gap (“yield gap II”) presents itself when crop production experiments are conducted in farmers’ fields and a yawning gap becomes evident between the potential productivity and the present output, which is due to physical, biological, and socio-economic constraints (IRRI, 1982).

While closing yield gap I requires the active transfer of technological packages from the R&D scene to the specific environment of the farmer, the closing of yield gap II requires a much more fundamental approach to technology development — the further modification of the productive characteristics of the crop, both morphological and physiological, to quantum levels higher than those of existing varieties. Such modifications would include the increasing of biomass production (by fast leaf area development, and low maintenance respiration); the increasing of the crop’s sink size (through relatively larger spikelet number, redirecting of a greater proportion of assimilates into the formation of spikelets, and an increase of the harvest index); having better grain filling; and a higher level of lodging resistance (IRRI, 1982a).

The biological factors of the environment are a constant challenge to crop production, particularly so in the humid tropics. As production intensifies, the problems in this area become more acute. Thus, there are serious disease and insect problems in the humid tropics. Yet, our present technology cannot reduce these constraints sufficiently and on a long-range basis. Indeed, our present perception is that we do not possess an adequate knowledge base to utilize effectively the seemingly abundant resources and opportunities in the tropics on a sustainable basis (Wortman and Cummings, Jr., 1978).

Our knowledge base appears even thinner when we consider marginal lands, where ecological constraints become evidently paramount, and where close to one
billion people live out a poor and unfulfilled existence. Major advances in scientific discoveries and crop production have been carried out in the fertile, better endowed lands; this encompasses the areas first swept by the Green Revolution. On the other hand, the new challenge must be to make the marginal lands bloom. Since marginal lands are far more extensive than the fertile ones, even a modest upward swing in crop yields would make a significant dent in the food deficit situation (Plucknett and Smith, 1982). The challenge here is a much more difficult task than faced us prior to the Green Revolution. R&D activities will need to address not only physical and chemical constraints such as the ability to thrive in soils that are excessively saline, alkaline, or acidic, or soils that contain toxic amounts of aluminum, or those that are deficient in phosphorus, or soils that are fragile when shorn of their covering forest, but also the serious biological constraints that cause these marginal lands to be far more difficult to make productive — enhancement of drought resistance, tolerance of high insolation, ability to germinate under high soil temperatures, and the very serious pest problems (of weeds, diseases, and insect pests).

The high soil temperatures often found in the tropics are not only a serious constraint to germination of many types of seed but also usually discourage the full exploitation of microbial nitrogen-fixation prevalent among the legumes. The potential for improving legume-rhizobial nodulation, and therefore the nitrogen-fixation of legume, has been explored by many research programmes. Among them are the experiments by IITA (1982) on the cowpea, in which they have screened 750 cowpea rhizobial isolates from Nigeria (two localities) and Niger (Maradi). Many of the rhizobia from the hot, dry environment of Maradi grew as well at over 37-44°C as at the temperature of 30°C usually used in microbial cultures; on the other hand, few of the rhizobia from the cooler environment of Onne (Nigeria) tolerated temperatures as high as 37°C. When these high temperature-tolerant isolates were evaluated in the field, after preliminary testing in greenhouse conditions from which it was concluded that 13 isolates (4 of them from Maradi) were effective on several high-yielding cowpea cultivars, it was found that the grain yield of VITA-7 inoculated with 3 of the 13 isolates was markedly greater than that of uninoculated cowpea at Gusau (in Nigeria). Similarly, in the hot and dry environment of Maradi (in Niger) 3 of the strains

<table>
<thead>
<tr>
<th>Yield (t/ha)</th>
<th>VITA-7</th>
<th>TN88-63</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uninoculated</td>
<td>0.27</td>
<td>1.01</td>
</tr>
<tr>
<td>N fertilizer (100 kg/ha)</td>
<td>0.43</td>
<td>0.90</td>
</tr>
<tr>
<td>Inoculated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IRc 252</td>
<td>0.31</td>
<td>1.97*</td>
</tr>
<tr>
<td>IRc 400A</td>
<td>0.26</td>
<td>1.68*</td>
</tr>
<tr>
<td>IRc 430A</td>
<td>0.43</td>
<td>1.43*</td>
</tr>
</tbody>
</table>

produced more grain on the local cowpea cultivar (TN88-63) than either the uninoculated plots or those given N fertilizer (Table 6). One of the questions to be pursued further is the survival of such high temperature-tolerant rhizobial strains in the absence of the hostplant.

There is no doubt that the physical and chemical constraints besetting crop production in the tropics, particularly in the humid tropics, need a great deal more attention than hitherto. This problem-area is treated elsewhere. But there is equally no doubt that the biological constraints, because of the very attributes that make the tropical world so rich and diverse in its biota, also intensify the biological factors inimical to man-made crop production (Odhiambo, 1977).

BIOLOGICAL CONSTRAINTS

These biological stresses include such constraints as the seeming restriction of the exploitation of the vast diversity of plant species in the tropics to only a few species for food, and to the occurrence of pests (insects, diseases and weeds) which are probably the single most difficult biological constraint in tropical food production.

Many trees of the lowland humid tropics in Nigeria, which are not in the general market economy, are traditionally and usefully cropped for their fruit and other food products, especially in compound farming (Agboola, 1982). Similarly, a survey among the Turkana of semi-arid Kenya has compiled an impressive list of 53 species of non-domesticated plants that are regularly exploited for their fruit, items for snacks, and for the preparation of flour (Morgan, 1981). Thus, the current anxiety about our scientific ignorance of the vast majority of the tropical biota (perhaps 75% of whose species have yet to be discovered and described, according to the National Academy of Science, 1980) is that the biome supporting this richness and diversity is fast disappearing (see, for example, Table 7), and yet we know so little about their features of biological and agronomic interest.

This is a matter of tropical and global concern. It is, therefore, of some consequence that international efforts are being made to do something to rectify this situation. One such effort was the establishment, nearly 10 years ago, of the International Board for Plant Genetic Resources to collect germplasm of major crops from their centres of origin and diversification. A second such effort was the recent decision of the International Union of Biological Sciences, at its 21st General Assembly in August 1982, to establish a new scientific programme, “A Decade of the Tropics”, which is “directed at increasing our understanding of the biology of tropical systems, from genetics to ecology” and will include research on

Table 7. Conversion rates of tropical moist forest.

<table>
<thead>
<tr>
<th></th>
<th>Potential area (million km²)</th>
<th>Reduction to 1975 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>3.62</td>
<td>51.9</td>
</tr>
<tr>
<td>Asia</td>
<td>3.87</td>
<td>43.7</td>
</tr>
<tr>
<td>Latin America</td>
<td>8.03</td>
<td>37.0</td>
</tr>
</tbody>
</table>

Source: Research priorities in Tropical Biology. NAS, Washington, D.C.
themes such as the biology of agro-ecosystems in the tropics, and “the means by which special richness is maintained and the capacity for simplification of species-rich systems.” It is an ambitious programme, and crop production specialists should take a special interest in its implementation.

Although new sources of food might become significant through further development by domestication and the successful adoption of agro-forestry strategies, a most important factor in increasing food production in the tropics is undoubtedly the control of the multifarious and abundant crop pests. The loss of crop production through preharvest pests is staggering — and especially so in the tropics (Table 8). Added to this are the losses due to pests and processing at the postharvest stage (Table 9). If one disaggregates the preharvest losses by sources, one finds that in the USA, for instance, insects are the largest factor responsible for the overall 33% preharvest losses (equivalent to some US$35 billion in 1976): thus, insects are responsible for losses amounting to 13%, plant pathogens for 12%, and weeds for 8% (Pimentel, 1978).

The age of pesticides

When the “Age of Pesticides” arrived with the commercial introduction of DDT in 1946 (see Metcalf, 1980), it seemed that the possibility of controlling insect pests for ever, indeed their eradication, appeared a distinct possibility — and the “Era of Optimism” (1946-1962) was ushered in (Table 10). The synthetic pesticide model of DDT brought in a whole array of synthetic pesticides in quick succession. It seemed then that pests as a whole were destined to oblivion within a matter of time. Thus, in the USA, three large commercial crops (cotton, maize and apple)

<table>
<thead>
<tr>
<th>Region</th>
<th>Value (million U.S. $)</th>
<th>Loss (% of potential value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South America</td>
<td>9,276</td>
<td>33.0</td>
</tr>
<tr>
<td>Europe</td>
<td>35,842</td>
<td>25.0</td>
</tr>
<tr>
<td>Africa</td>
<td>10,843</td>
<td>41.6</td>
</tr>
<tr>
<td>Asia</td>
<td>35,715</td>
<td>43.3</td>
</tr>
<tr>
<td>World</td>
<td>137,439</td>
<td>33.8</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Country</th>
<th>Crop</th>
<th>Losses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical Africa</td>
<td>All crops</td>
<td>30</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Sorghum</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Cowpea</td>
<td>41</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>Rice</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>Maize</td>
<td>14</td>
</tr>
<tr>
<td>India</td>
<td>All grains</td>
<td>25</td>
</tr>
</tbody>
</table>

Table 10. The age of pesticides begun in 1946 by the commercial introduction of DDT.

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1946-1962</td>
<td>The era of optimism</td>
</tr>
<tr>
<td>1962-1976</td>
<td>The era of doubt</td>
</tr>
<tr>
<td>1976</td>
<td>The era of integrated pest management begins</td>
</tr>
</tbody>
</table>


Table 11. Estimated crop losses from insect attack, USA (as % of total crop).

<table>
<thead>
<tr>
<th>Year</th>
<th>Cotton</th>
<th>Maize</th>
<th>Apple</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900-0</td>
<td>10</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>1910-35</td>
<td>14.9</td>
<td>11.8</td>
<td>3.5</td>
</tr>
<tr>
<td>1942-51</td>
<td>15</td>
<td>3.5</td>
<td>10.4</td>
</tr>
<tr>
<td>1951-60</td>
<td>19</td>
<td>12</td>
<td>13</td>
</tr>
</tbody>
</table>

Note: Cotton, maize, and apple use 47%, 17% and 3% respectively, of all insecticides used in agriculture in USA. Source: USDA.

Between them utilized 67% of all farm-applied insecticides (Metcalf, 1980). Yet, over the 75 years since 1900 that the United States Department of Agriculture (USDA) has kept records, there is no evidence that crop damage from insect infestation has decreased: indeed, if anything, these losses have increased steadily for cotton and maize and we have not made much advance in mitigating losses in apple (Table 11). Furthermore, if one closely examines the quantity of insecticides applied as against the level of resulting crop production, one is startled to find that there is a distinct decrease in the production of maize per lb of insecticide employed, from a ratio of 29,160 bushels of grain/lb of insecticides in 1946 down to a ratio of 207 bushels/lb in 1971 (Table 12). Similarly, for cotton, the ratio has decreased from a production of 3.80 bales of cotton for each lb of insecticides applied in 1919 down to a ratio of 0.142 bales/lb in 1971.

A closely parallel picture is found in the case of crop pathogens (Pimentel, 1978). During the period 1942-1974, losses from pathogens have increased from 10.5% to about 12%, while those due to insects have doubled from 7.1% to about 13% (Table 13) — in spite of the 10-fold increase of insecticide application (and the concomitant use of high-yielding crop varieties and increased application of fertilizers). Losses from weeds have declined over the same period in the USA, largely because of improved technology for mechanical cultivation, in addition to the use of herbicides (Pimentel et al, 1978).

The marked decline in the responsiveness of plant pathogens and insects to pesticides in the USA is due to several important factors, which include the following: increasing pesticide resistance of pathogens and insects; the destruction of natural enemies of certain pests (and, therefore, the need for additional pesticide applications); reduced crop rotations and crop diversity, with increased reliance on continuous culture of monocrops; the planting of crop varieties, although high-yielding, which are susceptible to pests; and increased “cosmetic standards” (Pimentel, 1978). Similar factors are already operating in the tropics, to which
must be added the problem of resurgence of pests following repeated insecticide applications.

The first type of resurgence is one in which previously economically unimportant secondary pests suddenly move up to the first rank after insecticidal treatments to control the target pest species, perhaps due to the killing of the natural regulatory parasitoids and predators. The second type is exemplified by a pest population initially suppressed by insecticidal treatment which rebounds to excessive levels a relatively short time after insecticide applications. Such pest resurgence has been documented for the green rice leafhopper (*Nephotettix cincticeps*) and the planthoppers (*Sogatella furcifera* and *Laodelphax striatellus*) after the use of broad-spectrum insecticides, such as DDT and BHC, from the 1950’s to control such major pests of rice in South-East Asia as the rice borers *Chilo suppressalis* and *Tryporyza incertulas* (see Metcalf, 1980, for a review).

**Integrated pest management**

This is not to say that we should withdraw universally the use of pesticides. Pimentel et al. (1978) has calculated that if all pesticide use in the USA was withdrawn, preharvest crop losses would jump from the current level of 33% to a new high of 42%, adding $8.7 billion to the overall losses by pests (a figure which includes the incremental costs for employing alternative non-chemical pest management techniques). Such bioenvironmental control, defined as “non-chemical control method utilized to reduce pest populations by environmental manipulations and biological control” (Pimentel, 1978), has certainly been a long-standing, almost ancient recipe, going back 1,300 years in China (Corbert, 1981).

A control philosophy which goes beyond the bioenvironmental control strategy is that of integrated pest management (IPM), which over the last 20 years has

**Table 12. Relation of insecticide usage to maize production, USA.**

<table>
<thead>
<tr>
<th></th>
<th>1946</th>
<th>1956</th>
<th>1964</th>
<th>1972</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production (000’s bushels)</td>
<td>2,916,089</td>
<td>3,075,336</td>
<td>3,583,780</td>
<td>5,641,000</td>
</tr>
<tr>
<td>Insecticides (000’s lb)</td>
<td>100</td>
<td>3,000</td>
<td>15,668</td>
<td>27,315</td>
</tr>
<tr>
<td>Ratio (Bu/lb)</td>
<td>29,160</td>
<td>1,025</td>
<td>229</td>
<td>207</td>
</tr>
</tbody>
</table>


**Table 13. Pre-harvest crop losses due to pests in USA, 1942-1974.**

<table>
<thead>
<tr>
<th></th>
<th>Insects</th>
<th>Diseases</th>
<th>Weeds</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1942-1951</td>
<td>7.1</td>
<td>10.5</td>
<td>13.8</td>
<td>31.4</td>
</tr>
<tr>
<td>1951-1960</td>
<td>12.9</td>
<td>12.2</td>
<td>8.5</td>
<td>33.6</td>
</tr>
<tr>
<td>1974</td>
<td>13.0</td>
<td>12.0</td>
<td>8.0</td>
<td>33.0</td>
</tr>
</tbody>
</table>

gathered many advocates and disciples. In essence, IPM attempts to rationalise the use of naturally operating population regulatory mechanisms (predators, parasitoids, and entomopathogens), agricultural practices, selective insecticide applications where an essential need has been established (the so-called “strategic insecticide use”, which recognizes the fact that less than 0.001% of applied insecticide is usually needed), and the results of population monitoring and surveillance (by the use of pheromones and other means), to implement a coordinated programme of pest control on a continuing basis. The crux of the matter is that a deep knowledge of the behaviour and ecology of the insect, its plant host/insect relations, the phenology of the plant relation to pest attack, and the economic injury level are prerequisites to a successful IPM programme.

One frequently hears the defeatist statement that IPM is too complex a strategy for the developing countries. It is true that most of our research institutions are either engaged in basic insect scientific research with no clear application goals in mind, or they are too determined to be practical and neglect the fountains of entomological knowledge that might strengthen the basis of the technological pest management concerns. A new attitude, more innovative for IPM, needs to be fostered in the tropical developing regions which requires our pest management researchers to be mission-oriented and to build up the knowledge base required for the development of IPM technological packages required for our major food crops. This attitude would be fostered if we were to adopt Brader’s (1980) prescription: “The attitude to pest control has remained what it was centuries ago, i.e. pests and diseases are an integral part of agricultural production, and their control will thus continue to be considered an inseparable part of plant production, in the same way as, for example, sowing and fertilizer usage.” We should, in any case, take courage from the example of the People’s Republic of China, where very high priority is given to IPM, operationally as well as in educational institutions. In examining over 40 books of economic entomology published in China since 1973, Chiang (1976) was impressed by the very decided IPM approach they all adopted, the step-by-step instructions they gave for practical pest management, and the involvement of all pest management practitioners (scientists, administrators, and workers) in the editorial boards for these publications.

New challenges in pest management
Three particular events in the pest management research field in the last few years seem to herald a new, more methodological base for IPM. These are the discovery of the insect biotype problem, the development of kairomones for targeting commercially produced parasitoids to a pestiferous area, and the use of specific antigens to control arthropod vectors of livestock diseases.

The biotype problem — well known in the plant pathogen field — first hit the tropical agricultural world when high-yielding rice varieties (IR26) previously resistant to the brown planthopper (BPH), *Nilaparvata lugens*, became susceptible to the latter, after being grown in the Philippines and Indonesia for only three years. In quick succession, several countries of South and South-East Asia became subject to these new virulent BPH biotypes, four of which have now been
identified, and have made several rice varieties preferentially grown in this region subject to this pest which has now become a major preoccupation (for a summary, see IRRI, 1982b). There has followed, over the last 4 years, intense efforts to screen new rices which may have the gene for resistance to successive BPH biotypes; and these have been rewarded by the selection of new varieties which seem to carry single resistance genes. There is a danger that this type of effort, of screening for single genes which confer high resistance, may well parallel the situation very familiar in the development of new insecticides wherein the latter are introduced sequentially to take the place of previously effective insecticides to which the target insects have acquired resistance. The “resistant-varietal treadmill”, analogous to the “insecticidal treadmill”, could prove both endemic and expensive.

If one were to think about it, it would become obvious that insect biotypes would select against such high pressure, and evolve a new, more virulent biotype within a few generations. This is what has, in fact, happened in the case of BPH; and it behooves us to approach the questions much more biologically, and to seek, instead, moderate tolerance to BPH in our rice genotypes. Such rices are likely to possess several genes responsible for such moderate resistance. Indeed, we have a candidate rice of this sort in IR36. So far, this variety has been grown for 5 years, and there has as yet been no evidence of the emergence of a new BPH biotype to attack it: it seems to possess the \textit{bph 2} gene for resistance as well as minor, as yet unidentified, resistance genes (IRRI, 1982b). The factors responsible for such resistance, largely of the allelochemic and antifeedant type, are presently being investigated in depth by a small team of ICIPE scientists located at the Los Baños campus of IRRI (on the experimental side) and at the ICIPE Research Centre itself (on the chemical side). This collaborative research is already bringing out some crucial results (see, for example, Saxena, 1979; Pathak and Saxena, 1980) and this pioneer approach should be adopted elsewhere for similar problems.

The second development is in the use to which kairomones can be put to stimulate host-seeking behaviour in parasitoids such as \textit{Trichogramma} and thus increase the level of parasitization of the host pest. Lewis et al. (1979) has demonstrated that moth scales left by ovipositing \textit{Heliothis zea} are a source of a kairomone which, when it is applied on the entire surface of an experimental arena, elicited (i) host-seeking behaviour of \textit{Trichogramma} immediately, and at the same time (ii) reinforced continuously their searching behaviour throughout the target area. They further showed that such behaviour is elicited when the kairomone extract is applied to such artificial dispensers as diatomaceous earth (rather than the natural scales of female moths). The ability to undertake commercial production of \textit{Trichogramma} (Brader, 1980), linked to the prospective availability of synthetic kairomone in large quantities in the near future, may well enable us to design methodically components of IPM utilizing such parasitoids in inundative or programmed releases more widely, as is already happening in the USSR, China, and Mexico for \textit{Trichogramma} (Brader, 1980).

The third development is concerned with the artificial boosting of livestock resistance to disease transmitters by immunological methods. A prime example, now being intensely studied by ICIPE scientists, is that of experimentally
increasing the resistance of cattle to the tick vector (the brown-ear ticks, *Rhipicephalus appendiculatus*) of East Coast Fever (ECF), a major disease of cattle in tropical Africa caused by the protozoan parasite, *Theileria parva*, which causes enormous losses each year. In susceptible cattle exposed to ECF, and this includes both exotic breeds and improved Zebu or Zebu for non-enzootic areas, morbidity and mortality may well approach 100%. In the case of the indigenous cattle in enzootic areas, mortality is low, and is generally confined to cattle. Calves that survive exposure to ECF become immune, and remain completely resistant to subsequent challenge. However, in different circumstances, such as prolonged drought which severely lowers the population of *R. appendiculatus*, the calf crop may not be appropriately challenged and consequently may fail to become immune; thus, exposure to *T. parva* of such non-immune indigenous cattle at a later stage may result in enormous losses.

The ECF tick vector (and other tick species), and therefore the diseases they transmit, have been controlled for many years by the use of acaricides. But the use of acaricides has many disadvantages, including those of cost, danger of toxicosis in livestock and humans handling and applying the acaricides, unacceptable pesticide residues in meat and milk, and the danger of environmental contamination. Furthermore, acaricide-resistant tick populations are now widespread in the enzootic areas, which necessitates the development of new chemical products, which in turn leads to the “acaricidal treadmill.” Finally, the unremitting and close-interval application of acaricides at 3-4 day intervals necessary for the control of the ECF vector in Eastern and Central Africa, produces an inherently unstable situation where cattle become highly susceptible to tick-borne diseases because of lack of tick challenge. If for any reason acaricide control breaks down, catastrophies can occur, and large numbers of cattle may die of disease and debility caused by massive tick infestations. Such a situation arose in Zimbabwe in the mid-1970’s, when acaricide control broke down during the liberation war, and more than a million cattle were lost. It was for these reasons that the ICIPE turned to a biocontrol route for the ECF tick vector — and we became intrigued by the seeming resistance of indigenous cattle when exposed to ticks at an early growth stage.

Detailed studies in experimental paddocks soon showed that when cattle are infested with adult *R. appendiculatus* they quickly become resistant - resistance being acquired whether the cattle are left to graze in tick-infested pastures or following the single application to each animal of 500 female ticks (confined in ear-bugs). Resistance does not develop following a single application of 5,000 tick larvae or 2,000 nymphs. The resistance produced is long-lasting, for at least three years; it is manifested most markedly against larval ticks, less so against nymphs, and least of all against adults. When normal ticks are applied to such resistant cattle, only reduced numbers are able to feed to engorgement, and the weight of the engorged ticks is also reduced; the larvae and nymphs which do feed to engorgement moult into nymphs and adults, respectively, although they are greatly reduced in size, and have a reduced survival potential when exposed to environmental stress. When larvae, nymphs, and adult ticks are fed sequentially on the same resistant animal, the adverse effects on the tick are enhanced and very
few adult ticks are produced. The latter are greatly reduced in size, and produce only small batches of eggs, which are of low viability (Newson, Chiera and Cunningham, unpubl. observ.). ICIPE scientists have developed a number of tests for identifying such resistant cattle, the simplest and most characteristic being the intradermal hypersensitivity test, in which a two-protein extract from *R. appendiculatus* larvae is inoculated intradermally into the test animals. Native cattle show no reaction; in resistant cattle, however, a hypersensitivity reaction occurs within 30 minutes, consisting of a marked swelling at the site of inoculation. More than 150,000 doses of this extract are now available at the ICIPE, and more can easily be made (Binta, Cunningham and Rurangirwa, unpubl. observ.). Preliminary experiments have shown that when resistant cattle are introduced into a paddock infested with ticks, the population of the latter decreases rapidly, and second generation larvae and ticks can only be detected with difficulty, and there is little likelihood of second-generation adults becoming established (Newson, Chiera and Cunningham, unpubl. observ.). Hence, tick-resistant cattle may well become a potent technique for controlling field populations of *R. appendiculatus*.

A serious problem in utilizing live ticks for experimentally boosting the resistance of cattle to *R. appendiculatus* is that there is no sure way of selecting only *Theileria*-free ticks for this purpose. The ICIPE has therefore turned to an alternative method for boosting resistance in cattle to *R. appendiculatus*. This is the possibility of experimentally producing antibodies against tick antigens. Thus, when hormogenates of fully engorged *R. appendiculatus* females were prepared, inoculated into rabbits with an adjuvant, and boosted 3 weeks later with the same preparation, high-titre antibodies were produced. When adult ticks were applied to these experimental rabbits, the ticks were unable to feed properly, and the majority of the females died before producing eggs. The few survivors produced very small batches of eggs from which few larvae hatched. A similar experiment has been performed with steers, with similar results (Binta, Cunningham and Rurangwira, unpubl. observ.). The identification of the target antigens from the tick homogenate is now in an advanced stage, using several immuno-electrophoretic and other techniques. Six antigens have now been purified and concentrated (Mongi, Shapiro and Cunningham, unpubl. observ.). Once confirmation of the target antigens has been achieved, a procedure for the biotechnological production of the latter will be attempted.

If this immunological control of a tick vector of a major livestock disease succeeds, it will open up an important new avenue for the control of other arthropod-born livestock diseases. Indeed, an attempt of this sort is already being sought at the ICIPE for the control of animal trypanosomiasis by increasing its resistance to the insect vector, the tsetse species (Kaaya, Mongi and Otieno, unpubl. observ.).

**New approaches to pathogen and weed control**

Just as insects are posing enormous problems as crop pests in the tropics, so are plant pathogens (including those that are transmitted by insects and mites), and they exact an enormous toll in crop production. There are already techniques for plant disease control, including the use of fungicides and other pesticides to
control pathogens, the control of the arthropod transmitters, and the selection of plant varieties resistant or tolerant to those pathogens. A technique that might well have a profound impact on the small farmer, just as has the development of resistant varieties, is that of producing virus-free plants from meristem culture (Table 14). There is no physical or chemical treatment which can currently effectively eradicate viruses from infected plants. Nevertheless, shoot and apical apices of virus-infected plants are frequently free of viral particles. Meristem culture, from a meristematic explant of such apices in a nutrient medium, results in a plantlet which subsequently grows into a virus-free plant. Transfer of such a plantlet into cytokinin-containing medium releases several auxiliary buds from apical dominance, which afterwards grow into multiple shoots (Wang and Hu, 1980).

Finally, do we have innovative new approaches to weed control, other than mechanical cultivation (which is expensive to the resource-poor farmer in the tropics)? Ker (1980) has summarized R&D work on strigol analogues and their use in controlling the parasitic witchweeds (*Striga* species) and broomrapes (*Orobanche* species), which cause serious crop losses (of over 30-50%) over a wide range of tropics and sub-tropics, respectively. Cook *et al.* (1972) identified and characterized the natural root exudate of cotton, strigol, which stimulates *Striga* seed to germinate. In nature, *Striga* seed, which may lie dormant in the soil for several years, will only germinate if strigol is released by the root of a growing host plant. The parasitic weed then attaches its root to that of the host plant, and in this manner derives its nutrients. Investigations by Professor A. W. Johnson and his colleagues at the University of Sussex in the U.K. have produced a number of synthetic analogues of strigol for testing in the field in semi-arid tropical areas for the control of *Striga* and *Orobanche* by stimulating the germination of the parasitic weed seeds in the absence of the host plants. Some of these analogues (GR7, GR24, and GR28) are proving effective, and give a high percentage of germination of some species of *Striga* and *Orobanche* at concentration between $10^{-4}$ and $10^{-6}$ ppm (Ker, 1980).

### Table 14. Some species in which virus-free plants have been obtained by vitro culture.

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>No. of viruses eliminated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cocoyam, garlic, gooseberry, ginger, soybean, sugarcane, taro</td>
<td>1</td>
</tr>
<tr>
<td>Banana</td>
<td>2</td>
</tr>
<tr>
<td>Brassica</td>
<td>3</td>
</tr>
<tr>
<td>Cassava</td>
<td>4</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>6</td>
</tr>
<tr>
<td>Potato</td>
<td>0</td>
</tr>
<tr>
<td>Strawberry</td>
<td>12</td>
</tr>
</tbody>
</table>

It seems to me that the three important components of a programme of accelerated food production in the tropical developing countries are:

- Firstly, the focusing of the R&D effort on the food production problems of the small, resource-poor farmer.
- Secondly, the development of the capacities of national programmes to undertake mission-oriented research and technological adaptation.
- Thirdly, the strategic placement of regional and international research centres (RIRCs) to generate the knowledge base from which the national programmes can select information essential for their R&D work.

I see the role of the RIRCs very much as a partnership with the national research centres, much in the way that Thomas (1973) analogises the ways of the honeybee and science:

“If you want a bee to make honey, you do not issue protocols on solar navigation or carbohydrate chemistry, you put it together with other bees (and you’d better do this quickly, for solitary bees do not stay alive) and you do what you can to arrange the general environment around the hive. If the air is right, the science will come in its season, like pure honey.”

The RIRCs should, as the national research centres become competent and strong (as has already happened in India, Taiwan, Brazil, and other developing countries), see that their role is much more that of fundamental knowledge search and phase themselves out of the more locale-specific functions of variety screening, pest management field testing, and the generation of technological packages suited to particular environments (see also Javier, 1982).

Although financial resources for agriculture have been increasing in developing regions in recent decades, crop yields have been falling, and this is particularly severe in the case of Africa. This fact seems to reflect the circumstance that research appears to have failed to provide the answers "which must confront African agriculture" (World Bank, 1981). It is not simply that the national research system in Africa is weak due to weak human resources. The cost of training high-level people is simply too high compared to that in other continents (see Table 15). The research funds that have been devoted to agricultural research,

<table>
<thead>
<tr>
<th>Region</th>
<th>Primary</th>
<th>Secondary</th>
<th>Higher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Africa</td>
<td>20</td>
<td>124</td>
<td>927</td>
</tr>
<tr>
<td>Western Africa</td>
<td>24</td>
<td>142</td>
<td>1,045</td>
</tr>
<tr>
<td>Asia</td>
<td>11</td>
<td>27</td>
<td>205</td>
</tr>
<tr>
<td>Europe, Middle East</td>
<td>15</td>
<td>47</td>
<td>306</td>
</tr>
<tr>
<td>Latin America</td>
<td>11</td>
<td>22</td>
<td>121</td>
</tr>
</tbody>
</table>

in the last two decades at least, have been too little (of the order of 1.4% of the value of agricultural output in Africa, about half of the proportion spent by industrialized countries, who do not depend so heavily on agriculture). Much of the research has been untargeted, lacking in continuity, suffering from recurrent funding scarcities, and mismatched with the national extension system (World Bank, 1981).

It is essential that the crop production problems of the small farmer take the central stage in the R&D process (Odhiambo, 1977, 1979a). His needs should not be pushed to the end of the conveyor belt, as it will be found in the end that he seems to ignore our beautiful technological packages, because they do not tackle his critical problem-areas. The problem-area of mixed cropping is a case in point. The adoption of this philosophy will mean training researchers in a manner which will allow them to be empathetic to the small-farmer problems, rather than through the traditional training programmes existing in industrialized countries and even in the developing regions. A vigorous initiative in this area has been taken by the ICIPE since 1981. Investigations of the status of major pests under intercropping conditions are being undertaken with target crops (e.g. maize, sorghum, and cowpea). One such investigation has been seeking to unravel the status of the striped bean weevil, *Alcidodes leucogrammus* Erichs, on cowpea under monocrop and intercropping conditions. It was already known that infestation by the weevil results in stunted growth or lodging of the stem (Singh and van Emden, 1979). The surprising results that came from the ICIPE investigations were that the main effect of *Alcidodes* infestation was the suppression of root nodule formation in all the cowpea cultivars studied (Table 16), and that the cowpea/sorghum dicrop effectively suppressed the pest status of *Alcidodes* in contrast to other combinations or monocrop (Table 17). This result was found in spite of the fact that *Alcidodes* is a specialized feed, and feeder, solely on cowpea. That the attacked plants become progressively deficient in nitrogen could be seen from the swollen-shoot symptoms and the yellowing of leaves which become persistent. What causes nodule suppression, which apparently causes nitrogen-fixing deficiency, and indeed the suppression of the weevil population in the cowpea/sorghum dicrop, is still to be identified (Amoako-Atta, 1983). Whatever the case may be, this series of experiments underscores the need to understand the

<table>
<thead>
<tr>
<th>Cowpea cultivar</th>
<th>Means + SD Root nodules per cowpea plant</th>
<th>Unattacked</th>
<th>Attacked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex-Luanda</td>
<td></td>
<td>61.89 ± 8.23</td>
<td>19.74 ± 2.16</td>
</tr>
<tr>
<td>Machakos</td>
<td></td>
<td>70.41 ± 7.32</td>
<td>14.95 ± 1.74</td>
</tr>
<tr>
<td>Machakos</td>
<td></td>
<td>62.88 ± 6.98</td>
<td>16.29 ± 2.23</td>
</tr>
<tr>
<td>Katuli</td>
<td></td>
<td>65.15 ± 11.04</td>
<td>16.96 ± 2.10</td>
</tr>
<tr>
<td>Katuli</td>
<td></td>
<td>60.37 ± 6.52</td>
<td>13.09 ± 1.82</td>
</tr>
<tr>
<td>Emma</td>
<td></td>
<td>74.58 ± 8.46</td>
<td>63.2 ± 6.46</td>
</tr>
</tbody>
</table>

mixed cropping entomology — a subject which has long been neglected (Odhiambo, 1979a).

We must rapidly increase the number of crop production researchers, especially in Africa, which has an acute problem of critical mass for the almost daunting work facing it. New and innovative training methods must be put in place. One such is the recently developed African Regional Postgraduate Training Programme in Insect Science (ARPPIS) which has been launched as a result of an agreement between ICIPE, as the executing agency, and a number of universities in Eastern, Central and West Africa, as participating universities. The ICIPE runs a Ph D programme (both course-work and project research), under the supervision of ICIPE senior scientists and the academics from the participating universities, and the latter award the degrees. The ARPPIS programme has just begun; it will be interesting to see if this programme will have stimulated the production of prospective leaders of IPM programmes in national programmes which are so desperately needed in Africa.

Finally, let me refer to a facet of institutional strengthening which is not usually fashionable to mention. This is the efficient management of the research enterprise in developing countries (Odhiambo, 1979b). As I have stated elsewhere, it is vital that the research manager regards his role as not only a maintenance one, but supportive of the institutional culture, and innovative. “Gaining a clear understanding of the mandate of the research institution, what it is supposed to do, whom it is supposed to serve is essential . . . Furthermore, it is essential to be aware of the circumstances under which the research institution must operate, the resources available to it, and how it incorporates the national policies for socioeconomic development. Finally, the research manager should perceive how his or her institution’s tasks complement the mandates of other institutions and agencies at the national, regional, and international levels. These tasks are related to the scientific environment” (Odhiambo, 1982).
CONCLUSION

The subject addressed is a complex one; and an attempt has been made only to skim over an essential understanding of the various constraints, and to offer some sign-posts as to the way their resolution might take. I feel like lamenting as Carl Rahner did in 1962:

“In the last depths a person knows nothing more exactly than that his knowledge is only a small island in an infinite and unexplored sea.”

REFERENCES


IDRC, Ottawa.


PHYSICAL AND CHEMICAL CONSTRAINTS TO FOOD PRODUCTION IN THE TROPICS

PLENARY LECTURE

ABSTRACT

The physical and chemical constraints to food production are more critical in marginal ecosystems than in the more fertile soils of the developing world: the humid tropics, semiarid tropics, acid savannas, tropical wetlands and tropical steeplands. The more widespread constraints in terms of area covered in these five ecosystems are: drought stress (60%), low soil nutrient reserves (36%), aluminum toxicity (33%), moderate to strong acidity (25%), steep slopes (23%), high phosphorus fixation (22%), shallow soil depth (19%) and poor drainage (19%). The use of chemical fertilizer inputs has been estimated to be directly responsible for about one third of the total increases in food production in developing countries and provides approximately 40% of the nutrients supplied to the world’s crops. Other sources of nutrients are release from soil reserves (46%), organic fertilizers (6%), biological N fixation (10% of N supply) and atmospheric deposition.

A series of worldwide assessments identified research and development priorities for the five ecosystems. Five priorities are related to resource appraisal: soil and land characterization, interpretation in agronomic terms, soil fertility evaluation, fertilizer marketing, fertilizer manufacturing technology. Three priorities address stress factors: selection of germplasm tolerant to stress, management of soil acidity and soil salinity. Five priorities address directly plant nutritional constraints: nitrogen fertilizer efficiency, phosphorus fertilizer management, nutrient balance, sulfur, and micronutrients. Biological constraints in-

clude nitrogen fixation, organic residue management; physical soil constraints include water management of oxisols and ultisols, multiple cropping, agroforestry, irrigated farming systems and low input systems. Priorities on technology transfer include strengthening national institutions through training, network development and other forms. Specific research priorities vary among the five ecological zones.

INTRODUCTION

The contribution of agricultural research to increased food production in the developing countries has been most impressive during the 1970’s. The President of the World Food Council attributed the developing countries’ annual 3.5% increase in food production during this period to the application of breakthroughs in agricultural research (Tanco, 1980). However impressive that increase, FAO’s Agriculture Toward the Year 2000 (FAO, 1979) suggests that it will be insufficient to meet the food demands of the developing countries for the remainder of this century, as a 4% annual growth rate in food production is needed.

To date, most of the food production increases have been accomplished by the use of high yielding varieties on relatively fertile soils, usually with irrigation and intensive fertilization. The FAO study suggests that this will continue to be the case during these next two decades as two-thirds of the additional food will be produced on soils already under cultivation. However, fully one-third of the needed food for the remainder of this century must come from 200 million hectares of soils brought into cultivation for the first time (Dudal, 1980). Beyond the year 2000, it is anticipated that these new lands will play an even greater role in food production. For the most part, the new lands are on marginal soils brought into cultivation due to increased population pressures.

Food production on the marginal soils, however, poses special problems. Among these are severe erosion, unnecessary deforestation and derived savannas when farmers do not use the appropriate technologies for the condition dictated by the marginal soils. Such can be the case in the steeplands, the humid tropics, the semiarid tropics and the acid savannas. The wetlands also experience unique problems when farmed with inappropriate technology. This paper will, therefore, concentrate on these five agroecological zones. The order in which they are discussed does not imply a priority ranking.

Figure 1 shows the approximate location of the five agroecological zones. The humid tropics comprise about 1400 million hectares of land with relatively constant temperatures and no more than a three-month period where evaporation exceeds precipitation. Although, most of the humid tropics are presently under shifting cultivation, areas in the Amazon and Indonesia are experiencing large-scale settlement attempts. Together with the acid savannas this ecosystem is likely to bear the brunt of the new lands that will be cleared during the remainder of this century (FAO, 1979).

The semiarid tropics are characterized by a protracted dry season of six to nine months duration. This ecological zone covers large areas of the three continents (Fig. 1) and its 550 million inhabitants are among the world’s poorest (Kampen
1. Location of the five priority agro-ecological zones (from NCSU, 1979).
and Burford, 1980). Many of them depend on small irrigated areas from most of their food supplies. Because of the limited amount of rain and its highly erratic distribution, farmers in the semiarid tropics suffer some of the most rigorous physical constraints to food production.

The acid savannas comprise about 550 million hectares characterized by a strong four to six month dry season, savanna vegetation and predominantly acid soils of the orders Oxisols and Ultisols. The largest expanses are in the Cerrado of Brazil and the Llanos of Colombia and Venezuela with significant areas in tropical Asia and Africa (Fig. 1).

The wetlands comprise poorly drained tropical areas and/or those devoted to flooded rice cultivation. The majority of rice farmers, 90% of whom live in the wetlands of Asia, cultivate farms of less than three hectares. There is little additional land that can be brought into rice production without serious soil constraints in Asia (Moormann and Van Breemen, 1979; IRRI, 1980). There is however, considerable potential for expanding rice cultivation in underutilized wetlands of tropical Africa and Asia (Moormann and Greenland, 1980).

The tropical steeplands are defined simply as those regions where slope is generally above 30 percent. Many are densely populated because of the generally high native soil fertility and more favorable climate than the adjacent lowlands. Population growth has fragmented the land to the point that crop intensification exceeds the stability of the soil and severe erosion often takes place. The location of the main steepland areas are shown in Figure 1.

**METHODOLOGY**

The procedure used in this paper consists of 1) identifying and delineating the geographic extent of the major physical and chemical constraints and, 2) describing the main research and development needs to alleviate such constraints in the different agroecological zones.

Analysis of the land resource base has been greatly facilitated by the advent of quantitative soil classification systems. Like plant taxonomy, these systems only consider those parameters that can be quantitatively measured (Soil Conservation Service, 1975; Johnson, 1980). The FAO world soil map for the first time brings together the world’s soil mapping units under a common terminology at the scale of 1:5 million (FAO-UNESCO, 1971-79). A follow-up study, the agroecological zones project (FAO, 1978-81) incorporates climatic constraints to the soil database. Sanchez et al. (1982b) have used this computerized data base and the Fertility Capability Soil Classification System (Buol et al., 1975; Buol and Nicholaides, 1980) to estimate soil constraints to agriculture. Analysis of these constraints led to establishment of research priorities.

**PHYSICAL AND CHEMICAL CONSTRAINTS**

Gross estimates of the extensiveness and importance of the main soil and climatic constraints are presented in Table 1 for the five agroecological zones (W. Couto, unpublished). These estimates are gross because of the small scale map used (1:5
Table 1. Main soil constraints in five agroecological zones in the tropics (Source: W. Couto, unpublished).

<table>
<thead>
<tr>
<th>Soil constraint</th>
<th>Humid tropics</th>
<th>Acid savannas</th>
<th>Semiarid tropics</th>
<th>Tropical steeplands</th>
<th>Tropical wetlands</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drought stress</td>
<td>100</td>
<td>100</td>
<td>77</td>
<td>67</td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td>Low nutrient reserves</td>
<td>66</td>
<td>55</td>
<td>17</td>
<td>27</td>
<td>3</td>
<td>36</td>
</tr>
<tr>
<td>Aluminum toxicity</td>
<td>57</td>
<td>50</td>
<td>13</td>
<td>26</td>
<td>4</td>
<td>33</td>
</tr>
<tr>
<td>Acid, but not Al toxic</td>
<td>18</td>
<td>50</td>
<td>29</td>
<td>16</td>
<td>29</td>
<td>25</td>
</tr>
<tr>
<td>Steep slopes (&gt;30%)</td>
<td>17</td>
<td>16</td>
<td>15</td>
<td>100</td>
<td>1</td>
<td>23</td>
</tr>
<tr>
<td>High P fixation by Fe</td>
<td>38</td>
<td>32</td>
<td>9</td>
<td>21</td>
<td>-</td>
<td>22</td>
</tr>
<tr>
<td>Shallow soils (&lt;50 cm)</td>
<td>7</td>
<td>5</td>
<td>16</td>
<td>54</td>
<td>-</td>
<td>19</td>
</tr>
<tr>
<td>Poor drainage</td>
<td>13</td>
<td>7</td>
<td>10</td>
<td>-</td>
<td>100</td>
<td>19</td>
</tr>
<tr>
<td>Low cation exchange capacity</td>
<td>11</td>
<td>4</td>
<td>7</td>
<td>-</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>Calcareous soils</td>
<td>-</td>
<td>-</td>
<td>8</td>
<td>-</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Gravel</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>10</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Vertic properties</td>
<td>1</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Organic soils</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Salinity</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Allophane</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Sodic soils</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Cat clays</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Total area (million has.): 1412 525 999 1050 559 4545

million). Similar analysis at larger map scales are available (Cochrane et al., 1979; Cochrane and Sanchez, 1982; Sanchez et al., 1982b) and are recommended for specific areas. The most extensive constraints are drought stress, low nutrient reserves, aluminum toxicity, acid soils, steep slopes, high phosphorus fixation, shallow soils, and poor drainage. Each covers at least 800 million hectares in the five zones. Their distribution varies among the agroecological zones.

**Drought stress**

The most extensive soil constraint is the presence of a dry subsoil for more than three consecutive months (technically defined as ustic or aridic soil moistures regimes in Soil Taxonomy). The degree of intensity varies with ecosystem, being occasional for the humid tropics, moderate for the acid savannas and protracted for the semiarid tropics. Most of the tropical steeplands as well as two-thirds of the tropical wetlands suffer from drought stress (Table 1).

**Low nutrient reserves**

This constraint identifies generally high weathered soils with limited capacity to supply phosphorus, potassium, calcium, magnesium and sulfur (nitrogen deficiency is almost universal, except in recently cleared land). This constraint occurs in the most extensive soils of the humid tropics and acid savannas, but it is less important in the steeplands, the semiarid tropics and the wetlands.

**Soil acidity**

Aluminum toxicity, the direct consequence of soil acidity to plants occurs in about 1500 million hectares of the tropics (Table 1). Its geographical distribution is...
similar to the previous constraint, as it tends to be associated with similar soils. Overall, one-third of the tropics suffers from soil acidity severe enough to cause injury to many common crop species and an additional 25% of the tropics presents lower but significant crops such as cotton. The acid- but not aluminum-toxic soils are widely distributed across the five agroecological zones.

**Soil erosion**

Three constraints in Table 1 identify severe soil erosion hazards. Slopes greater than 30% occur not only in the steeplands but also in parts of the humid tropics, acid savannas and semiarid tropics. Shallow soils covering 19% of the tropics are often very susceptible to erosion. Gravelly soils are also susceptible to erosion. The most dangerous combination occurs when steep slopes and prolonged drought stress occur together, because the land is often left bare at the beginning of the rainy season when intensive rains commonly occur. A total of about 1000 million ha of land portrays both constraints (Table 1).

**High phosphorus fixation**

Phosphorus fixation is the transformation of soluble fertilizer phosphorus into slowly available forms in soils high in iron and aluminum oxides. This is a major constraint to efficient fertilizer use in about 1000 million hectares of land located primarily in the acid savannas, humid tropics and steeplands. Some of them have high phosphorus fixation because of the presence of allophane, a clay mineral derived from volcanic ash.

**Poor drainage**

This constraint causes severe limitations for most crop and pasture species, but not for rice production. The chemistry of flooded soils, however, because of the oxidation-reduction processes, provides additional constraints to the efficiency of fertilizers applied to rice (Ponnamperuma, 1972). Flooding also produces some unique soil constraints not found in aerobic soils (Van Breemen, 1980; Porinamperuma and Bandyopadhya, 1980).

Other important constraints listed in Table 1 include low cation exchange capacity (indicative of low nutrient retention and leaching); calcareous soils (indicative of iron and zinc deficiencies); saline and sodic soils (normally requiring drainage or reclamation); organic soils (unique management) and acid sulfate soils (keep flooded).

**CHEMICAL INPUT USE**

The importance of fertilizers and soil amendments continues to increase in the tropics not only because of strong yield responses but also because of rising costs. The Consultative Group in International Agricultural Research sponsored a worldwide review of the plant nutrition situation in developing countries (Sanchez and Nicholaides, 1982) which concluded that food production in developing countries will be more heavily dependent on improved plant nutrition through added fertilizer inputs over the next 20 years than in the past. Estimated reserves
Table 2. Gross estimates of primary nutrients supplied annually to the world's 1414 million hectares of cultivated and permanent crops (Source: Sanchez and Nicholaides, 1982).

<table>
<thead>
<tr>
<th>Source</th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>Primary nutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg/ha/yr</td>
<td>% of Total</td>
<td>kg/ha/yr</td>
<td>% of Total</td>
</tr>
<tr>
<td>Soil release</td>
<td>30</td>
<td>42</td>
<td>34</td>
<td>15</td>
</tr>
<tr>
<td>Inorganic fertilizers</td>
<td>39</td>
<td>56</td>
<td>44</td>
<td>21</td>
</tr>
<tr>
<td>Organic fertilizers</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Biological N fixation</td>
<td>9</td>
<td>13</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Atmospheric deposition</td>
<td>6</td>
<td>9</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>88</td>
<td>126</td>
<td>100</td>
<td>39</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>10⁶ t</th>
<th>10⁶ t</th>
<th>10⁶ t</th>
<th>Total</th>
<th>10⁶ t</th>
<th>Total</th>
<th>10⁶ t</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil release</td>
<td>30</td>
<td>42</td>
<td>34</td>
<td>15</td>
<td>21</td>
<td>38</td>
<td>47</td>
<td>66</td>
</tr>
<tr>
<td>Inorganic fertilizers</td>
<td>39</td>
<td>56</td>
<td>44</td>
<td>21</td>
<td>30</td>
<td>54</td>
<td>19</td>
<td>27</td>
</tr>
<tr>
<td>Organic fertilizers</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>8</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Biological N fixation</td>
<td>9</td>
<td>13</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Atmospheric deposition</td>
<td>6</td>
<td>9</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Totals</td>
<td>88</td>
<td>126</td>
<td>100</td>
<td>39</td>
<td>55</td>
<td>100</td>
<td>71</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil release</td>
<td>34</td>
<td>34</td>
<td>34</td>
<td>34</td>
<td>34</td>
<td>34</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>Inorganic fertilizers</td>
<td>44</td>
<td>44</td>
<td>44</td>
<td>44</td>
<td>44</td>
<td>44</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>Organic fertilizers</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Biological N fixation</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Atmospheric deposition</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Totals</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
of feedstock sources for producing N fertilizer and phosphate, potassium and sulfur deposits are generally adequate to cover expected needs. Uneven distribution among countries or regions as well as rising costs, however, pose significant limitations in fertilizer supplies.

About 46% of the N, P and K supplied annually to the world’s crops comes from the release of soil reserves, 40% from inorganic fertilizers and the rest from organic fertilizers, biological N fixation and atmospheric deposition (Table 2). As nutrient demands increase with crop intensification while the amounts of nutrients released from soil reserves remain relatively constant, the need for additional nutrient inputs becomes more evident.

About a third of the increases in total annual cereal production in developing countries during the last decade is directly due to fertilizer response (Table 3). The recovery for applied fertilizers by crops in the tropics, however, is generally lower than in the temperate region. For example for every three bags of urea applied to paddy rice, the N equivalent in two bags is lost through various pathways.

**RESEARCH PRIORITIES**

Seven major assessment studies have been conducted during the past six years to identify research priorities on soil and land use constraints: Michigan-Kettering’s “Crop Productivity: Research Imperatives” (Brown et al., 1975); the Cornell-National Science Foundation study in fertilizers and food production (Lathwell, 1975; Ozbun, 1976); FAO’s “Improved Use of plant Nutrients” (FAO, 1978); the National Academy of Sciences, 1977abc), the IRRI-Cornell “Soil Constraints Conference” (IRRI, 1980); the North Carolina State University “Soil Management Planning” (North Carolina State University, 1979); and the Bonn Conference on Agricultural Production (Bentley et al., 1979; Levine et al., 1979; Wolff, 1979; Leach, 1979; Hanson, 1979). Over 300 scientists and administrators from more than 50 countries participated in these exercises.

A reasonably clear consensus developed which is summarized by Sanchez and Nicholaides (1982) and presented in Table 4. This table lists 22 research components arranged by agroecological zones. The table also shows the rankings according to six criteria developed by the Bonn Conference soils panel report (Bentley, 1979).

Table 3. Estimated contribution of fertilizer to cereal grain production in developing market economics, 1948-1952 to 1972-1973 (Calculated from IFDC/UNIDO (1978) by Sanchez and Nicholaides, 1982).

<table>
<thead>
<tr>
<th>Region</th>
<th>Increase in total annual cereal production</th>
<th>Estimated increase due to fertilizers</th>
<th>Increase due to fertilizers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia</td>
<td>81.5</td>
<td>26.2</td>
<td>32</td>
</tr>
<tr>
<td>Latin America</td>
<td>40.5</td>
<td>10.8</td>
<td>21</td>
</tr>
<tr>
<td>Africa</td>
<td>12.4</td>
<td>2.5</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>134.4</td>
<td>39.5</td>
<td>29</td>
</tr>
</tbody>
</table>
Table 4. Priority rankings of research components by agroecological zones (0 = none, 1 = low, 2 = medium, 3 = high (Source: Sanchez and Nicholas, 1982).

<table>
<thead>
<tr>
<th>Research and Development Components</th>
<th>Humid tropics</th>
<th>Semiarid tropics</th>
<th>Acid savannas</th>
<th>Tropical wetlands</th>
<th>Tropical steeplands</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. RESOURCES APPLAUSAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Land characterization and classification</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2. Map interpretation for agronomic purposes</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3. Soil fertility evaluation</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4. Fertilizer marketing, distribution and use</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>5. Fertilizer manufacturing technology</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>B. STRESS FACTORS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Selection of germplasm tolerant to soil stress</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2. Management of soil acidity</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3. Salinity</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>C. NUTRITIONAL CONSTRAINTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Nitrogen fertilizer efficiency</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2. Phosphorus fertilizer management</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>3. Potassium and nutrient balance</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>D. PHYSICAL SOIL CONSTRAINTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Water management in rainfed systems</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2. Erosion prevention and control</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>3. Mechanical impedances</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>4. Land clearing methods</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>E. IMPROVED FARMING SYSTEMS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Sustained production in Oxisols/Ultisols</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2. Multiple cropping</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>3. Agroforestry</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>4. Management of irrigated farming systems in arid areas</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5. Low input farming systems</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>F. TECHNOLOGY TRANSFER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Strengthen national institutions</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2. Training</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3. Networks and information services</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
Again, order of agroecological zone presentation does not imply priority ranking.

**The humid tropics**

Although there is reasonably good knowledge on production of perennial export crops in the humid tropics, little is known on how to do so for annual crops and pastures. Continuous annual crop production on tropical Oxisols and Ultisols has been attempted for decades. After a classic failure in the 1930’s of trying to transplant temperate region high energy technology to Zaire, progress has been limited to small areas with ample available capital for export crops. Systematic research toward developing realistic soil management practices for food production tropical Ultisols and Oxisols is underway at a few locations with significant international support (Greenland, 1975; Sanchez *et al.*, 1982a). Where present population densities are low, national governments do not feel the immediate political pressures to develop their “new lands” until it is too late. Crash programs or forced colonization projects without a sound agronomic base are then launched and usually fail (National Research Council, 1982).

These attempts are now proceeding at an unprecedented rate. The Indonesia transmigration program is moving about 2.5 million people from overcrowded Java and Bali to the humid tropics of Sumatra, Kalimantan and other islands. Significant proportions of the Amazon also are being rapidly settled, as new roads or petroleum drilling operations attract people from outlying areas. In the Amazon Basin, Peru and Ecuador are probably experiencing the greatest pressures, as well as certain parts of Brazil.

These developments have caused major worldwide ecological concerns about deforestation in the humid tropics. Many of these concerns have no scientific base, e.g., worldwide oxygen depletion and transformation of the soil into laterite (National Research Council, 1982). Nevertheless, it is most unwise to destroy natural ecosystems and replace them with unstable farming systems. There are real dangers of soil erosion and adverse hydrological changes if the humid tropics are cleared and not managed properly. This problem cannot be solved by government decrees even if strongly enforced. Land-hungry people will go to empty areas. The development of a set of practices to make these acid, infertile soils productive both economically and ecologically, is critically needed in order to assure that each hectare of land that is cleared remains productive (Sanchez *et al.*, 1982a). Table 4 gives a list of priority research components for the humid tropics including proper land clearing methods, improved fertilizer efficiencies, soil fertility management, low input production systems and sustained production systems involving combinations of annual crops, grass/legume pastures, tree crops and agroforestry appropriate to different landscape positions.

The projected effect of the successful application of the proposed research is envisioned by Bentley (1979) as follows: Achievements in the humid tropics during the next ten years are expected to be moderate due to the magnitude and complexity of this enormous task. Successful farming systems, however, are expected to have a large impact in the 1990’s and beyond. The cost of an integrated
The ease of transfer of a successful technology, once it is practically developed, is high. The long-term payoff is expected to be very high, since this program is the cornerstone for developing new lands for cultivation in the tropics, and for preventing environmental damage.

**The semiarid tropics**

Because of the exceedingly variable precipitation and growing conditions, agricultural research in rainfed semiarid tropical areas is especially difficult and has traditionally been meager in relation to the land area, numbers of people and agricultural production. Irrigation is practiced extensively in India, but frequently results in secondary salinity and drainage problems. It is, therefore, understandable that yields in the semiarid tropics have been rather static. The main constraints are both physical and chemical, but in contrast with the humid tropics, the physical constraints are more critical.

Lack of sufficient soil moisture and subsequent surface crusting severely affect food production on vast areas of semiarid soils (Nicou and Charreau, 1980). Brief, intense rainfall frequently causes turbulent runoff with loss of valuable moisture, as well as soil erosion, siltation and flooding. Because of sparse growth and the large numbers of animals, there is a general lack of crop residues, vegetative cover and mulch materials for soil protection. Table 4 identifies research components considered of high priority for the semiarid tropics. They focus primarily on water management in rainfed systems, erosion prevention and control, surface crusting, soil fertility evaluation and agroforestry.

The short-term impact of soil and water research for the semiarid tropics is expected to be moderately good and long-term prospects are considered good. Anticipated costs of needed research are moderate, while ease of transfer of proven technology is expected to be high. Results in terms of increased yields should be high. The research capability of national institutions is moderately good if there is adequate support and encouragement from both internal and external sources. Considerable capability gaps exist between the semiarid tropics of Asia as compared to those of Africa and Latin America (Bentley, 1979).

**The acid savannas**

It is within the vast areas of acid savannas, along with some of the humid tropics, that the bulk of agricultural land expansion during the next 20 years is expected to occur (FAO, 1979). Because of somewhat better infrastructure, the acid savannas of tropical America are being developed at a faster rate than the humid tropics. Cattle production systems are the principal activity but annual crop and crop/pasture successions are becoming increasingly important as the population frontier moves inland. Reviews by Spain et al., (1975), Sanchez and Tergas (1979), Marchetti and Machado (1980), and Sanchez and Salinas (1981) summarize ongoing research. Rapid development is often not accompanied by proper soil and water management technology and frequently results in crop failures, poor pasture persistence and soil erosion.
Table 4 identifies research components considered high priority for the acid savannas. They focus on selecting crop and pasture germplasm adapted to acid soil stresses, phosphorus fertilizer management and low input farming systems.

The acid savannas combine the fertility limitations of the humid tropics with a moisture stress of less intensity than in the semiarid tropics. The interaction of both factors as well as socioeconomic ones generally show more promise of success in the acid savannas than in the two previously described agroecological zones. Bentley (1979) indicates a high expected impact on both short and long-term, a moderate magnitude of cost, high ease of transfer and moderate existing institutional capabilities.

**The tropical wetlands**

In the past, most attention has been given to increasing rice yields in the wetlands and work on this aspect must continue. However, another avenue to increased production, increasing the number of crops grown each year, has been inadequately developed. Multiple cropping would not only increase production but would increase the period of time per year during which the farmer and his family are gainfully employed.

Diversified research is needed to increase food production from ricelands. Cropping systems are highly environment specific. Thus, if studies on cropping systems are to be widely applicable to small farmers throughout Asia and other parts of the world, research has to be done on a wide range of sites, and mainly in farmers’ fields. Considerable progress has already been made in relation to the dry seeding of rice to ensure that rice will germinate with the initial rains and mature at the earliest possible date. Substantial improvements have also been made in the yield potential and length of time required for new rice varieties to attain maturity. Another important factor is the selection of rice varieties which enable a ratoon crop to be obtained. The production of a ratoon crop involves a minimum of inputs and will often result in additional yields of 1 to 2 tons/ha.

Table 4 identifies priority research components for the wetlands. They focus on characterizing farming systems research sites, selecting germplasm tolerant to different soil stresses (Ponnamperuma, 1977), and increasing N fertilizer efficiency (Bouldin *et al.*, 1980).

Agroeconomic research in the wetlands is somewhat more advanced than in other agroecological zones, but the work on rice-based cropping systems in marginal soils is poorly developed. The short-term impact is expected to be moderate but the long-term impact will be high, the magnitude of the cost moderate, the ease of transfer moderate, and the existing capability moderate, but the payoff high (Bentley, 1979). These considerations must be weighed in relation to the overwhelming importance of rice production in feeding the world.

**The tropical steeplands**

Large areas of densely populated regions of the tropics and subtropics occur on high sloping terrain where population pressures are causing erosion to be a major concern. Farmers originally settled in these areas because of the generally high native soil fertility and a more favorable climate than the adjacent lowlands.
Population growth has fragmented the land in many small patches and farmers often carry crop intensification too far, resulting in widespread soil erosion. Often the more fertile valleys are under the control of large landowners or other kinds of farm enterprises, while the small farmers are concentrated on the steep areas. Examples of the steeplands are found throughout hill country of Southeast Asia, the Andean chain from Mexico to Bolivia, the Caribbean, and the mountain areas of tropical Africa.

Table 4 identifies priority research components for the steeplands. Erosion prevention and control is the overriding concern.

Unlike the other zones where systematic efforts are being made to alleviate soil and plant nutrition constraints, there is no comparable focus on the steeplands. There is also no recognized center of excellence for research in this agroecological zone. In addition, the operation aspects of carrying out the proposed research are quite complicated and costly. Effective solutions have to involve watershed studies, including both erosional and depositional landscape positions. Civil engineering and socioeconomic factors weigh heavily.

All these considerations led Bentley (1979) to indicate a low probability of impact in the short run but a high impact in the long term. The magnitude of the cost is high because of the watershed dimensions and the extreme variability in soils and microclimates encountered in steepland regions. The ease of transfer is moderate, again because of the variability. The payoff however, is envisioned as high, perhaps not in terms of making large contributions to world food production but in preventing the deterioration of the land resource base and subsequent social upheavals. The low rating for existing capabilities underscores the necessity for training and developing research programs with the components that have been outlined.

WATER MANAGEMENT IN IRRIGATED ARID REGIONS

In addition to the marginal ecosystems, the large scale developments of irrigation projects throughout the developing world pose both great potential food production increases as well as management difficulties. The yield potential of irrigated areas is enormous as they usually are farmed under high solar radiation, relatively low night temperatures that decrease crop respiration, and low atmospheric humidity that decreases the incidence of pests and diseases. Water management is the paramount constraint, while nitrogen and salinity are the most widespread plant nutritional constraints. Very high yields of wheat, rice, sugar cane and many other crops are produced in irrigated arid areas of Pakistan and North India, Egypt, Peru, Mexico and many other countries. The quantities of N fertilizers required are often very high because of the high yield potential triggered by high solar radiation and the considerable leaching losses of N under poor water management. Fertilizer applications, mainly N, are conducted at the higher reaches of the response curve, suggesting the need for important fine-tuning mechanisms.

Soil salinity reduces plant yields, renders irrigation enterprises uneconomical and causes in its extreme form the complete loss of agricultural production
potential. The causes of salinity have been thoroughly studied and are probably well known in most affected areas. However, the management and remedy are still debated and reclamation measures are not only expensive, but also unsuccessful in many cases. The problem to be addressed is in the forecast of conditions resulting from irrigation and the timely evaluation of salinity hazards. This requires elucidation of the interdependencies between climate, soil, water, and crop especially as related to drainage, cropping pattern, alkalinity tolerance and farm management.

The Bonn Conference soils panel (Bentley, 1979) indicates that the inefficiencies of irrigation are increasing concern and solutions will depend on new technologies as well as social changes. Because water is free to farmers or has only very modest charges in many irrigation schemes (usually excluding the ones based on groundwaters), the efficiency of water use and distribution systems is generally very low. Practical ways and means of reducing seepage losses, wasteful use and unnecessarily slow water delivery are urgently needed. Social research is required to develop techniques to win and expedite acceptance of land consolidation and canal rationalization schemes which would increase irrigation efficiencies and crop yields.

For irrigation, the Bonn Conference recommended the following specific research needs:

a) Improved design criteria for new or renovated irrigation projects whether for gravity sprinkler or drip irrigation methods. Requirements will vary considerably depending on soil characteristics.

b) Methods to attract and retain farmer participation in land consolidation and/or drainage projects under differing social and soil conditions.

c) Development of improved national, regional and local mechanisms for development and maintenance of irrigation schemes.

PERSPECTIVE

The rather cursory list of physical and chemical constraints affecting food production in the tropics does not do justice with the complexities of the research priorities outlined in Table 4. The reader is referred to more detailed reports, particularly the excellent book on Soil Constraints (IRRI, 1980), and the Bonn Conference Reports on water and soils (Wolff, 1979; Levine et al., 1979; Bentley et al., 1979) and the TAC plant nutrition and soil constraints study (Sanchez and Nicholaides, 1982). These documents provide depth and perspective to the problems just outlined.

The authors do not feel entirely comfortable describing physical and chemical constraints without direct reference to biological and socioeconomical constraints. Although these aspects are covered in the preceding paper, one cannot escape the conclusion that the farmer has to manipulate physical, chemical, biological and socioeconomical problems as a unit. Integrated technology to overcome these constraints together can and must be developed.
LITERATURE CITED


Ozbun, J. L. (1976). Researchable areas which have potential for increasing crop production. Panel report to Potential Increase in Food Supply through Research in Agriculture. Cornell University, Ithaca, N. Y.


PLENARY LECTURE
BASIC
CHEMICAL RESEARCH
AND FUTURE FOOD SUPPLIES

MELVIN CALVIN

ABSTRACT

The world food production on the whole has, until now, been able to keep up with world population growth. Both of these have grown largely because of the increase in our basic understanding of the chemical reactions involved in both processes. It is likely that we will very soon, if we have not already done so, reach one limit to the world food production and that is land area. We are rapidly approaching the limits of energy availability as well. It will, therefore, be necessary to do two things: (1) Increase by whatever means possible world food production per unit area of land, by increased photosynthetic efficiency, water efficiency, soil efficiency, energy efficiency; and (2) Learn something about the way in which population control may more easily be acceptably exercised, also a chemical problem. Both of these problems have large basic chemical components.

INTRODUCTION

The history of the development of mankind is really a history of his ability to generate the food necessary for himself, his family and, finally, for those who perform other services on behalf of the food producer. There has been constant improvement in man’s ability to control his food supply, which originally was a hunting and gathering operation accompanied by a shifting agricultural process. It was with the beginning of the domestication of wild plants and animals that
productivity became much more under human control. This domestication process continues to this day, but is largely a consequence of increased scientific knowledge with a gradual decrease in the pure empiricism with which it began.

Our improvements in the production of food and improvements in its nutritional content are fundamentally the result of basic chemical research, research which has been continuously underway for over 200 years (Fig. 1). Additionally, the production of food is based on the process of photosynthesis, upon which all life depends (Fig. 2a). As our knowledge of the primary and secondary avenues of plant metabolism increases, it is possible to select various parts of the process which can lead to increased production of carbohydrates, proteins and other products (Fig. 2b).

PAST AGRICULTURAL PRODUCTIVITY AND TECHNOLOGY

In the more recent history of man, the increase in food production has been dominated by an increase in the area of the land that could be brought into service, both for the growing of plants and the feeding of animals. The time is fast approaching when that will become increasingly difficult. In fact, it has already made itself apparent. For example, food production increases in the past 30 years have been due largely to the escape from dependence on natural manures as fertilizers with the production of synthetic ammonia, potassium and phosphorus fertilizers. Even at this early stage it was the application of our basic knowledge of thermodynamics by Haber which led to the synthesis of ammonia from nitrogen and hydrogen which was responsible for a substantial fraction of that increase.

1. Farm productivity and scientific revolution.
2a. Photosynthetic carbon reduction cycle.  
b. Photosynthetic carbon cycle showing primary and secondary metabolic sites (JAB).
This, of course, followed the earlier recognition of the chemical foundation of agriculture by Liebig. The introduction of mechanization, irrigation and chemical control of plant and animal pests were additional factors in increased agricultural productivity. All of this has accompanied the introduction of new plant varieties, either more generally productive or producing more specific foodstuffs.

An example of this recent history can be given by showing the increased corn yields in the United States (Fig. 3). Here, the expanded use of scientifically produced hybrid corn was the first real break in yield improvements, beginning in the middle thirties. This was followed, by a much accelerated yield increase due to the introduction of chemical pesticides, synthetic fertilizers, mechanization and other improved agronomic practices, so that the yield today for corn, at least in the U.S. corn belt, is over 100 bushels per acre, an improvement of a factor of four over what it was as late as 1935. A similar trend can be shown for other grains, such as sorghum (Fig. 4) as well as alfalfa, barley and rice.

PAST TECHNOLOGY: PESTICIDES/HERBICIDES

At about this time a number of relatively crude chemical pesticides such as copper, arsenic and especially mechanical weed control came into general use. Following, and growing out of the basic chemical science developed in World War I came much more effective pesticides. Some of these were the result of straightforward chemical research such as DDT, dieldrin and aldrin, named after the German chemists who discovered the basic conjugate reaction idea and used it for the synthesis of these compounds. A parallel development of synthetic chemistry and neurobiochemistry during the forties led to the discovery of the organic phosphates as insecticides. Two of these are still in use today as malathion and parathion.

Another development in our basic understanding of the way plants grow led to the discovery of plant growth hormones, primarily indoleacetic acid, and the ultimate synthesis of plant and weed control substances such as 2,4-D and 2,4,5-T.

All these pesticides, herbicides and insecticides, as well as a number of rodent control substances such as fluoroacetic acid are generally heavily toxic materials, relatively nonspecific in their targets, both plant and animal. In fact, aside from the direct toxicity of some of the pesticides, the chemical processes for the synthesis of certain ones had undesirable byproducts which were even more toxic than the pesticide itself. An example is the byproduct 2,3,6,7-tetrachlorodioxin formed in the synthesis of 2,4,5-trichlorophenoxyacetic acid by condensation of 2,4,5-trichlorophenol with trichloroacetic acid, the self-condensation of the phenol leading to the toxic impurity. This toxicity has been so severe in some instances as to have led not only to the curtailment of the use of 2,4,5-T, which is more potent as a herbicide than 2,4-D, but also, in some cases, has resulted in prohibition of its use. The general toxicity problem of our pesticides, which are so essential for the high productivity in agriculture to which we have become accustomed and which is necessary to feed the world’s population, is now leading to new developments in pesticides.

PAST TECHNOLOGY: TRACE ELEMENTS

The need for nitrogen, phosphorus and potassium in fertilizers was recognized quite early, but only more recently has the fundamental role of these elements been understood. To these basic macrofertilizers has been added the trace element requirement as a result of our study of plant and animal nutrition. The role of iron, manganese, cobalt and other trace elements, particularly in the mechanism of enzyme action (plant and animal), has been empirically recognized and their function is now better understood. They have long since found their place as additives in chemical fertilizers.

The role of trace elements in the primary photosynthetic process of plant metabolism is now known. For example, in the quantum capture process, the role of magnesium in the chlorophyll, the iron in the ferredoxin, the manganese in the
oxygen catalyst and the zinc and a variety of other elements in hydrogen transfer enzymes is understood.

PAST TECHNOLOGY: PLANT BREEDING

Classical plant breeding has, of course, played a large role in recent improvements in agricultural productivity. This development stems partly from classical genetics and partly from the understanding of the role of the gene in the production of enzymes. The enzymes, in turn, are not only foodstuffs in themselves but are the means of production of all the primary and secondary metabolites of the plant. The only net CO2-fixing enzyme in plants, namely, ribulose diphosphate carboxylase, is also a principal protein in all green material.

The realization that plant breeding involves the modification of the enzymes contained in the particular cross through the genetic process was an important step in the development of new varieties.

ENERGY REQUIREMENTS OF AGRICULTURE

Almost all of the steps which have been taken in the last 30 years which have led to the enormous increase of agricultural productivity are energy-demanding steps. This is particularly true of the mechanization step in agriculture and in fertilizer production. The increased demand with its concomitant reduction in the human labor component in productivity is shown in Figure 5.

There are various ways of illustrating the interdependence of food and energy, and one graphic method is shown for both energy costs of individual foods as well as their change with time (Fig. 6). It can be seen that primitive agriculture, with its huge land requirement, showed a net gain in food energy. However, as our land productivity improved, the energy requirement for production increased. This can be illustrated by the energy subsidy in the United States food system from

![Energy subsidy graph](image-url)

5. Use of selected farm inputs. Source: USDA.
1910-1950, during which time our energy subsidy increased by approximately a factor of five. That is, by 1950 we were putting in five calories of energy into the agricultural system for every one food calorie derived from it, even though the productivity per acre had increased enormously.

This correlation is again visible in farm output as a function of energy input from 1920-1970 (Fig. 7). An additional fact seems apparent from this information, and this is further increase in yield of various crops is not likely to be achieved by further increases in energy input, a trend already apparent in 1980 (Fig. 8). Only part of this is due to the changing character of our food consumption in which we use animals to convert the primary products of plants. Animals are not very efficient converters, one of the most inefficient being cattle, which convert feed calories to food calories at a rate of about 6%, broilers are somewhat better at 12%, hogs are still better at 20%, fish are over 30%.

It is likely that we are now reaching the limit of our present agricultural system to respond to additional energy inputs, and since the arable land has already become limiting, we must find more subtle ways of improving the food productivity of the land and the energy inputs as well.

Energy consumption is associated not only with agricultural productivity but with general national productivity (Figure 9). It is clear that the principal industrialized countries such as the United States, Sweden and Switzerland have high energy consumption, but also high national productivity. In the United States, Australia and The Netherlands, for example, high industrial and high agricultural productivity are apparent. However, some countries have a relatively
high place in the curve of gross national output per capita on the basis of a single product; this is particularly true for such countries as Kuwait and Saudi Arabia.

NEW TECHNOLOGY: SOIL CONDITIONERS

One of the methods which has already been used is to devise synthetic materials to condition the soil and prevent its degradation (erosion) by wind, rain and cultivation. This can be done classically by leaving the organic lignocellulosic residues of the plant material (not useful for human or animal food) in the soil and working it in, and more recently by the development of no-till farming. However, the efficiency of these processes is low in terms of the material and energy
requirements, and synthetic soil conditioners, such as polyacrylamide, have been devised which can accomplish the same end. Some of these synthetic materials have much smaller material inputs. Also, the development of more efficient synthetic soil conditioners will require a better understanding of soil composition, structure and deterioration, all of which are chemical problems by their very nature.

Nevertheless, the lignocellulosic wastes constitute a very substantial fraction of the plant's productivity and could be used as energy sources if they could be made available. This is exactly what is done on the sugar plantations of Brazil where the bagasse is almost entirely burned in the furnaces to produce steam and electricity for processing and fertilizer production. A similar use might be made of residues of wheat and rice straw as well as corn stover.

NEW TECHNOLOGY: PESTICIDES

A second approach which has already begun is the development of much more sophisticated pesticides than the generally toxic materials we are using today. This is limited at the moment by our understanding of insect physiology. We do know that the growth and development of an insect through the various phases is controlled by the secretion of insect hormones. We have already made synthetic hormones, and hormone analogs, which can be used for specific insect control. For example, the juvenile hormone of a particular insect can be applied, thus preventing the insect from maturing and providing the next generation. This can
effectively wipe out an insect population in a local area.

We are now aware that the mating of insects is dependent upon a chemical signal, usually emitted by the female to enable the male to find her. These signals are called pheromones, and many of them have been chemically described and synthesized. Their use in insect traps is already underway, both for determining the size and nature of infestation as well as controlling insect population.

This is only the beginning but illustrates the specificity with which pesticides might be constructed as our basic knowledge of the molecular mechanism of communication and development, as well as basic chemical reactions, evolves.

NEW TECHNOLOGY: HERBICIDES/ANIMAL HORMONES

We have already begun to use plant and animal hormones and hormone analogs not only as herbicides but also we are beginning to use plant growth control substances to either accelerate or inhibit particular aspects of the growth of a plant, to produce its fruit at a particular time, or to restrict a somatic growth of the plant in favor of its fruit-producing capability.

A similar approach is in use in the control of animal growth and fertility. For example, it is now possible to bring livestock into heat at a selected time so that the farming operation is less demanding both of energy and labor. It is also possible to select growth hormones to control meat production, at least in beef, and thus increase the efficiency of food production.

NEW TECHNOLOGY: GENETIC ENGINEERING

Perhaps the most exciting and promising of the new developments on the horizon is the possibility of modifying plants by molecular technologies. In recent years, we have called this “genetic engineering”. The simplest and most straightforward way of taking some steps in this direction derives from our ability to regenerate whole plants from a single protoplast, a technique which has already been applied to a substantial number of different plants. This is likely to allow us to hybridize plants which, for structural reasons, cannot be hybridized by classical plant breeding techniques. This type of hybridization will be achieved by cell fusion at the single protoplast stage followed by regeneration of the fused protoplasts. Steps toward this end have already been taken and it remains to determine how far such a cross may be spread.

The more intimate molecular technology of excising a particular gene from one plant and by various means, either a viral vector or a bacterial plasmid, introduce that gene into another plant is now in its beginning. We should not only be able to improve individual plant crop productivity but to modify the quality of plant productivity and perhaps even generate entirely new crops.

A simple listing of the types of things which are now being attempted in this area is perhaps worth examining. Some of these objectives have been attempted by conventional genetics, but are now being explored more actively by molecular genetics. These include: drought resistance, salt tolerance, disease resistance, nitrogen fixation, herbicide tolerance and, of course, improved efficiency of
photosynthesis itself. The activities just mentioned have already been started by somatic cell genetics as well as molecular genetics. We can expect the consequences of these activities to be apparent in agricultural productivity both for food and fuel within the foreseeable future.

NEW TECHNOLOGY: SECONDARY PLANT METABOLISM

Something somewhat closer to accomplishment is the possibility of modifying secondary plant metabolism. As we understand the intimate details of secondary plant metabolism, illustrated in Figure 2b, it will be possible to recognize the evolution of two major technologies which should have a great impact on plant productivity: (1) It should be possible to develop chemicals which could divert or control conversion of sugars into a variety of useful products for which plants are grown, such as proteins, amino acids, starches, vitamins and hormones for human consumption and (2) it should also be possible to develop a better understanding of primary plant metabolism, quantum capture and conversion which would lead to greater efficiency in the use of sunlight to produce food and fuel.

NEW TECHNOLOGY: ALTERNATE ENERGY SOURCES

Thus, the use of materials such as residues of wheat, rice and straw, corn stover as soil conditioners, as well as the use of bagasse from such sources as sugar processing, and no-till agriculture constitute an energy cost to agriculture which should be considered and met. An additional energy price, which must be met for the soil-conserving advantages of no-till agriculture, is the requirement for increased pest control which tillage usually provides.

The energy requirement for agriculture is large and must be kept constant in order to maintain its productivity. In the face of our dwindling global oil supplies which must be finite, the tendency has been to fulfill that energy requirement for agriculture with the fossil fuel in the largest supply, namely, coal. Most of the environmental degradations induced by the use of coal are already known, and to some extent can be resolved, at a price. These include acid rain, carcinogenic emissions, ash and all the land and human costs of mining.

There is, however, one other cost of increased dependence on coal which has only recently been recognized and that is not so readily rectified. This comes from the fact that coal contains very little hydrogen and therefore produces roughly twice as much carbon dioxide per unit of energy generated as does oil. Even today, when oil is still such a large component of our energy resources, the environment cannot keep up with the rate of carbon dioxide production. The CO₂ in the atmosphere has been rising for at least 100 years and at a constantly accelerating rate, as shown in the inset of Figure 10. This increase is a global phenomenon and not limited to the regions in which the CO₂ happens to be generated.

It is clear that neither the green plants of the earth nor the precipitation of limestone in the sea can match the rate of CO₂ generation from fossil carbon. Part of this is due to the fact that in general most plants are not limited by CO₂ and will not respond to increasing carbon dioxide levels (Fig. 11), especially for corn and
10. CO$_2$ in the earth's atmosphere 1860-2040.
other grasses. In fact, it appears that at medium and average light intensities CO₂ may actually depress the net photosynthetic rate for some plants.

A consequence of the excess rate of CO₂ production over its reduction by photosynthesis or precipitation in the oceans must be a rise in the average global temperature. Some evidence of this consequence is already in hand in the form of the melting of the South Polar ice cap and the rising sea level.

We therefore must find an alternative way to fulfill the energy requirement of agriculture. This, it seems to me, must be found in plant productivity in the first instance and in synthetic devices based on the principles of plant quantum conversion in a more distant future.

We have already seen that some of the plants’ productivity might be harvested (as mentioned earlier). It is quite clear that a selection of plants for their ability to capture and store energy in the most useful form is possible. There are plants which can reduce CO₂ all the way to hydrocarbon as well as halfway to carbohydrate. Such plants could give rise to an energy agriculture which would not be competitive with food production but rather supportive of it, provided they are chosen to suit the climate and soil that is available.

RESULTS OF INTENSIVE AGRICULTURE

It is clear that the foundations of a much more specific chemical assistance to agriculture have already been laid, but much more remains to be done. Changes
have already occurred in crop yields, such as those obtained for corn and wheat, where the yield was increased by a factor of three over the last 30 years, shown for corn in Figure 12. This is probably not maximal improvement, as theoretical
Table 1. Maximum photosynthetic productivity and measured maximum yields in selected plants.

<table>
<thead>
<tr>
<th></th>
<th>g/m²·day</th>
<th>tons/acre·yr.</th>
<th>metric tons/hectare·yr.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non C-4 plants</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar beet</td>
<td>31</td>
<td>(51)</td>
<td>(113)</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>23</td>
<td>(37)</td>
<td>(84)</td>
</tr>
<tr>
<td>Chlorella</td>
<td>28</td>
<td>(46)</td>
<td>(102)</td>
</tr>
<tr>
<td><strong>Annual yield C-4 plants</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar cane</td>
<td>31</td>
<td>50</td>
<td>112</td>
</tr>
<tr>
<td>Sudan grass</td>
<td>10</td>
<td>16</td>
<td>36</td>
</tr>
<tr>
<td>Corn (Zea mays)</td>
<td>4</td>
<td>6*</td>
<td>13</td>
</tr>
<tr>
<td><strong>Non C-4 plants</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td>8</td>
<td>13</td>
<td>29</td>
</tr>
<tr>
<td>Eucalyptus</td>
<td>15</td>
<td>24</td>
<td>54</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>9</td>
<td>15</td>
<td>33</td>
</tr>
<tr>
<td>Algae</td>
<td>24</td>
<td>39</td>
<td>87</td>
</tr>
</tbody>
</table>

*6 T/acre  215 Bu/acre

estimates suggest that it might be possible to improve the yields by perhaps twice as much (Table 1).

Intensive agriculture leads to large exports from certain areas. Intensive agriculture also leads to large areas of a monoculture (single cultivars of one crop).

The global supermarket

Net world trade in wheat and coarse grains, 1981/82 (m tonnes) *

Major net importers ▶ Major net exporters

United States
Canada
Argentina
Australia
South Africa
EEC
Africa (excl. S Africa)
E Europe
W Europe (excl. EEC)
China
Japan
Russia

Production, 1981
Total: 1,252 m tonnes

Exports, 1981/82
Total: 198 m tonnes

(%) 26 United States 57
10 EEC 8
3 Other W Europe
19 Asia
7 Latin America of which:
2 Argentina 9
4 Canada 12
2 Australia 7
13 Russia
6 E Europe
10 Other 7

14. The global supermarket.
The widespread appearance of single cultivar crop monoculture throughout the world is very high risk — two or three years of a single crop failure, either as a result of weather or pest infestation, can have a devastating effect on world food supply. This risk creates a social and economic problem in certain areas of the world.
The use of intensive agricultural practices also leads to a high level of soil erosion. Soil, of course, is a nonrenewable resource on a human scale, and unless stringent restrictions on the monoculture agricultural practices are developed, the productivity of the soil itself will decline or it will disappear, leading to widespread changes in food growth and consumption with an accompanying change in human societies.

In the United States, as a result of the intensive agricultural practices and farm subsidy program of the government, a substantial amount of grain has accumulated, creating an inventory of about one-third of a current annual crop, shown for corn in Figure 13; a similar situation exists with other grains, particularly wheat.

Also in the United States about one-third of our grain production is exported, especially to Central and South America and the Far East (Fig. 14). It is those same people, with the highest rate of population growth, who are at risk because of the huge monoculture food production methods developed and used primarily in the United States. One or two bad years in succession, or the appearance of an entirely new pest, could obliterate the food inventories which have historically been available in the United States, and the crop as well, thus producing large scale hardship through the world as well as massive soil erosion. These problems are not only indigenous to the highest food producing areas of the world, but to the food importing areas as well, whose well-being depends, at least at present, on the monoculture agriculture of other areas of the world.

CONCLUSION

Almost every one of the steps that have led to increased agricultural productivity has involved basic advances in chemical knowledge. Even mechanization is dependent somewhat upon basic chemical research. The progress of our nutritional knowledge is also dependent upon the progress of our basic chemical understanding. This progress has led in part to the increasing life expectancy of mankind, but, of course, man is what he eats. This fact was recognized centuries ago, and most graphically presented by Giuseppe Arcimboldo (Milan, 1527-1593) whose pictures hang in the museum in Strasbourg, France. A modern photograph by Francois Gillet of fresh vegetables assembled after the manner of Arcimboldo illustrates this principle (Fig. 15).
ABSTRACT

The future availability of food is ultimately dependent on the availability of energy. Apart from relatively small contributions from nuclear and hydroelectric sources, energy, like food, is a product of the photosynthetic process. Can both food and energy be provided in future, on a renewable basis, by photosynthesis? Natural photosynthesis is inefficient, energy intensive and requires fertile soil. Artificial photosynthesis using purely chemical “in vitro” processes is potentially more efficient and adaptable to barren land. The present state of research in this field is summarized.

INTRODUCTION

The essential needs of mankind — food, fuel and the raw materials for clothing — are all provided by photosynthesis. Most of chemical industry is concerned with manipulating these products into more useful forms, particularly those which have been fossilised as natural gas, oil and coal. The first CHEMRAWN Conference considered photosynthetic products as chemical feedstocks whilst this Conference considers their most essential application of all, as foods. The principal concern of the developed nations at the present time is neither of these, but the impending shortage of energy. How can this be so when, in the developing countries, there are still large numbers of people near starvation?

The reason is neither irrational nor wholly selfish; the food and energy problems are inseparable and it might reasonably be argued that the principal factor limiting
food supply is a shortage of energy. “Arable land will increase by only 4% by 2000, so that most of the increased output of food will have to come from higher yields. Most of the elements that now contribute to higher yields — fertilizers, pesticides, power for irrigation and fuel for machinery — depend heavily on gas and oil.” (Global 2000 — Report to the President, commissioned by President Carter). At the simplest level, the staple foods such as cereals and root crops cannot be eaten until they are cooked and, in some parts of the world, the shortage of wood and dung for cooking is desperate. At the next level, agricultural productivity is highly dependent on the use of energy-intensive fertilizers and an indigenous source of fertilizer is the prime requirement of agriculture in many developing countries . . . provided the energy is available to run the fixation process. Finally, the notorious food surpluses in the midst of starvation and the huge amount of food which is wasted through decay would be alleviated by fast transport and refrigeration, which demand money as well as energy. Energy and the wealth that goes with it are far less equally distributed among the nations than is food.

The history and future prospects for food supplies would be quite different from those of energy supplies were it not for the fact that food production depends on energy. Peoples’ nutritional requirements have not changed much through the centuries and food production, although it has changed with fashion and living standards, has increased in quantity roughly in proportion to the population. The wealthy, if they are also healthy and wise, are more likely in future to decrease their consumption than continue to overeat. As to the future, given adequate energy we could be moderately optimistic that present land resources, coupled with continued improvement of plant and animal breeding and better distribution, could provide adequate food for a population of 10 billion people, after which there is some hope that birth and death rates will have stabilised.

The energy situation is quite different and gives little cause for optimism. The average energy consumption per person in the USA has increased by 3% times in the last 100 years. The appetite for energy, unlike that for food, seems to be insatiable and is limited only by economic pressures. But, worse still, whilst food is a renewable resource increasing in quantity with the population, energy from fossil fuels, which provide over 90% of the supply in developed countries, is a diminishing resource. It is quite unnecessary to dwell on this truism; Figure 1 makes the point that we live in unusual times and shall soon come crashing down from the crest of our oil wave. Insofar as food supplies for the increasing population depend on energy from fossil fuels, they would fall as well and the world would, for the first time, face famine on a global scale. I hasten to add that I do not believe this will happen, because we have the ingenuity and, I hope, the time to find alternatives.

It is not the purpose of this paper to discuss the energy problem in general; suffice it to say that, in the developed countries, most of our energy for a century or so after oil is depleted will probably be provided by coal and, to a lesser extent, nuclear fission. In the long term the only source able to provide energy on a global scale appears to be nuclear fusion, either in the form of reactors on earth, whose successful development is as yet uncertain, or by using the fusion reactor already operating very well at a safe distance of ninety-three million miles — the sun. Most
of this gives little encouragement to the poorest countries who have no coal, who cannot afford nuclear reactors and whose only source of energy is the rapidly depleting stocks of wood and the organic wastes which are better employed as fertilizers. They do, however, have their share of the sun.

This session has been given the title “The forward edge” which encourages me to discuss a futuristic but possible scenario. It envisages a world where photosynthesis continues to supply man with his energy needs, not only of food but also of fuel, where energy farming takes its place alongside food farming to provide, on a renewable basis, the essential requirements of modern life. Here “photosynthesis” and “farming” are used in the widest sense and do not exclude purely chemical, non-living, systems involving organic chemical fuels and feedstocks for the collection and storage of solar energy.

PHOTOSYNTHESIS

Photosynthesis is the only successful method for collecting the sun’s energy on a very large scale. The sun has several disadvantages as an energy source; it is intermittent and unavailable when most needed, at night and in winter, and it has to be collected over very large areas.

The green plant solves this problem by storing the energy as chemical potential which is transportable and can be converted into other, non-storable, forms of energy as and when they are needed. But the green plant was not made for burning and we may be able to improve on nature, at least to satisfy our own particular requirements. This has been done with spectacular success in agriculture by plant breeding; when it comes to photosynthesizing fuels and organic materials we may find it advantageous to depart from the living plant altogether and to develop a wholly artificial photochemical system. One can envisage combinations of natural and artificial photosynthesis even in the growing of food, such as, for example, a solar photochemical reactor which fixes atmospheric nitrogen on nearby barren land and supplies it to the irrigating water supply.
Natural photosynthesis is of course one route to solar energy fixation and, as already mentioned, it is the main source in the poorest countries. Biomass makes a useful contribution in special cases such as the burning of bagasse to supply energy for sugar processing and, in some countries, where it is plentiful, wood is a major fuel. More sophisticated applications are the manufacture of biogas (there are more than 5 million such plants in China) and the substitution of alcohol, made by fermentation, for petroleum, as is being done in Brazil. In the Philippines the most suitable species proposed is the giant ipil-ipil (*Leucena leucocephila*) tree which fixes nitrogen. Unfortunately, the energy efficiency of natural photosynthesis in the conversion of solar energy into chemical potential is low, as is illustrated by the figures given in Table 1.

We need to compare these figures with the efficiencies that are theoretically possible. Unavoidable losses which must occur in the conversion of the sun’s radiation into stored chemical potential are as follows:

**THE THERMODYNAMIC “SECOND LAW” LIMIT**

After scattering, the sun’s effective radiation temperature is 1300 K which, for a receiver at 300 K leads to a maximum Carnot efficiency of 77%. This can be improved by the use of concentrators, a concentrator giving 10 suns would improve the efficiency to 87%, but in practice this is unlikely to be economic for the purposes we envisage.

**FINITE POWER LOSS**

Just as extracting current from an electrochemical battery lowers the voltage, the extraction of material or charge from a photochemical system lowers the chemical potential. Under conditions of maximum power this results in a further loss in efficiency of 6%.

**INEFFICIENCIES DUE TO BROAD BAND IRRADIATION**

The sun’s radiation covers a wide band of wavelengths. The long wavelengths (e.g. those above 700 nm in the green plant) are not utilized and the shorter wavelengths have energy in excess of quantum requirements which is wasted as heat. For an absorber with threshold at 700 nm this means that only 38% of the solar radiation can be effective.

The above three causes reduce the maximum possible efficiency, without concentrators, of photosynthesis to 27%. Further small losses due to reflection, storage and lower efficiencies at lower levels of insolation reduce this further and

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>0.2 - 0.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Best</td>
<td>1-2</td>
<td></td>
</tr>
</tbody>
</table>
the maximum efficiency, if the photochemical reactions themselves resulted in no further losses, would be 20-25%. Whilst it may be possible eventually to approach this value in practice (silicon solar cells which have similar limitations have been made with solar efficiencies greater than 17%) we will assume, for our further assessments, that an efficiency in the field of 10% would be quite realistic.

RESOURCES AND REQUIREMENTS

Although there will always be some other sources of energy available, let us consider the possibility of a world scenario where all man’s energy, including his food, is provided by photosynthesis, natural or artificial.

The requirements are given in Table 2 in terms of present energy use, and also of future needs, for which we assume a population of 10 billion people all having a living standard, in food and energy terms, of the present-day European. Given the technology, the resources are the sun, and the surface of the earth as a collector. The insolation on the earth’s surface, averaged over the year, day and night, winter and summer, varies from 300 \( \text{wm}^{-2} \) (in some desert regions to less than 100 \( \text{wm}^{-2} \) near the poles but, between latitudes 40 N and 40 S, where 80% of the world’s population lives, 200 \( \text{wm}^{-2} \)) is a typical value. The areas of the earth’s surface required for collection, assuming an efficiency of 1% (natural photosynthesis) and 10% (artificial photosynthesis) are also given in Table 2.

These areas may be compared with the land surfaces of the earth given in Table 3.

First, we notice that 1400 million hectares are at present in use for food

<table>
<thead>
<tr>
<th>Table 3. Land resources excluding tundra and ice.</th>
</tr>
</thead>
<tbody>
<tr>
<td>million hectare</td>
</tr>
<tr>
<td>Cultivated</td>
</tr>
<tr>
<td>Cultivatable</td>
</tr>
<tr>
<td>Forest</td>
</tr>
<tr>
<td>Rocky/arid</td>
</tr>
<tr>
<td>Desert</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
production. Most of the increases in food production over the last few decades have been achieved without any great increases in the land area used for agriculture but some increase in areas under cultivation will probably be necessary in order to feed double the present population. The area of forest is twice the area used for agriculture but timber is an important resource in itself. Whilst it appears reasonably likely that sufficient new agricultural land can be found for food production, there would be very great difficulty in finding as much again for energy farming. If we are to grow energy products, even at 1% efficiency, good quality agricultural land and rainfall are required. To supply present requirements through biomass would therefore require 500 million hectares and future requirements are 5000 billion hectares in competition with the extra areas needed for food production.

Now let us turn to artificial photosynthesis. Whatever process is used the only resource needed, apart from the manufactured materials, is sunshine and it is almost a matter of definition that any land surface which is not too hostile geographically will be suitable. Additionally, the efficiency projected is 10% so that the area required is only 1/30th of that required for food production. Three per cent of the world’s desert areas would suffice to produce the present energy requirements and one third would be required for the rather extreme projection of 10 billion people at European standards. This is the challenge which faces photochemists; we will conclude with a brief summary of how far research in this area has progressed.

PHOTOCHEMICAL SYNTHESIS

The starting point for all research workers in this area has been, and still is for most of us, natural photosynthesis:

\[
\text{light} \quad CO_2 + H_2O \rightarrow (CH_2O) - O_2
\]

The essential energy storing reaction in photosynthesis is the splitting of water and the liberation of oxygen:

\[
\text{light} \quad 2H_2O \rightarrow O_2 + 4H^+ + 4e
\]

The electrons and protons may then be used to reduce carbon dioxide, as in green plant photosynthesis but they may also be combined to form hydrogen gas, or used to reduce nitrogen to ammonia or carbon dioxide to other products such as alcohols, any of which might be more useful than a carbohydrate such as cellulose. As is shown in Table 4, the energy stored in these overall reactions does not differ greatly from one to the other if it is calculated in units of electrons transferred or, what amounts to the same thing, the number of photons absorbed when quantum yields are the same.
Table 4. Energetics of photosynthetic reactions.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$G$ (kJ mol$^{-1}$)</th>
<th>$E_0$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{CO}_2 + \text{H}_2\text{O}$ &quot; (CH$_2$O) + O$_2$</td>
<td>498</td>
<td>1.29</td>
</tr>
<tr>
<td>2/3 N$_2 + 2$H$_2$O &quot; 4/3 NH$_3$ + O$_2$</td>
<td>452</td>
<td>1.17</td>
</tr>
<tr>
<td>2 H$_2$O &quot; 2 H$_2$ + O$_2$</td>
<td>475</td>
<td>1.23</td>
</tr>
</tbody>
</table>

In order to obtain reasonable solar efficiencies, it is necessary that long wavelengths in the red region of the spectrum are effective; the green leaf absorbs light of wavelengths up to 700 nm corresponding to an energy of 1.77 e.v. As already explained, only 72% of this, or 1.27 e.v., is available for conversion into chemical potential so that there is very little latitude for dissociation of water into its elements in their standard state, which requires 1.23 e.v. or for any of the other photosynthesis reactions shown in Table 4. Natural photosynthesis overcomes this difficulty by using two photons for each electron transfer which it achieves by having two separate photosystems working in series. Most attempts to improve upon or make models of the photosynthetic unit accept this two-step process as being a necessity unless one is restricted to the use of short wavelength light. The present status of research in artificial photosynthesis may be summarized as follows:

1. Although there has been a little preliminary work on reduction of nitrogen or carbon dioxide, most research at present is confined to the photolysis of water into its elements as the obvious first step which is, in itself, a potentially useful process. The production of both hydrogen and oxygen has only proved possible by using ultra-violet light and semiconductors or inorganic ions as absorbers.

2. Red-light photosynthesis consists of two steps, the reduction and the oxidation of water, and research usually divides itself into a study of one or the other: photosystem II for the oxidation of water to oxygen and photosystem I for the reduction of water to hydrogen or another reducing species which is able to reduce carbon dioxide or nitrogen. The objective is eventually to link the two photosystems together through a redox couple but, for research purposes at the present stage, it is convenient to use sacrificial substances which make it possible to study each photosystem separately.

3. Photosystem I has been reproduced in a number of laboratories with high yields of hydrogen. In our laboratory we have obtained a quantum yield of 60% corresponding to a solar efficiency of about 20% by using, as photosensitizers, metal porphyrins (P) which are closely similar to the chlorophyll of natural photosynthesis.

When excited by light in the visible region these substances donate an electron to an electron relay, methyl viologen (MV$^{2+}$), which in turn passes on the electrons to the catalyst, colloidal platinum (Pt), which liberates gaseous hydrogen. The oxidized porphyrin is restored to its reduced form by a sacrificial electron donor such as ethylene diamine tetraacetic acid (EDTA). The scheme of reactions is as follows:
Each porphyrin sensitiser molecule is able to oxidize 6000 molecules of water before chemical changes of the porphyrin become apparent, though MV\(^{2+}\) is more labile and alternative electron relays are being sought.

4. Photosystem II, and the oxygen production reaction are more difficult, partly because accumulation of four electrons is necessary for the liberation of one oxygen molecule. The best catalyst that has been found for this purpose, ruthenium dioxide, acts far more slowly than does platinum in the hydrogen elimination. Nevertheless, rapid progress is being made and quantum efficiencies of oxygen elimination up to 12% have been achieved, using ruthenium trisbipyridyl as sensitizer and sacrificial acceptors such as cobalt pentamine chloride.

5. The principal remaining step is the linking together of photosystems I and II through a reversible redox couple. Natural photosynthesis uses a quinone/hydroquinone couple for this purpose and, although both artificial photosystems I and II have been operated with the quinone couple, the reactions are reversible and the design of a complete and efficient reaction combining both systems will require considerable ingenuity.

For the time being, natural synthesis is the only practical way of converting the radiation potential of the sun into chemical potential. This will probably always be the case for such a complex product as food and there are those who believe that our best route to renewable organic fuels lies through the improvement of plant photosynthesis by breeding and genetic engineering. This would require a tenfold increase in efficiency of solar energy storage and the ability of the new species to survive and maintain this efficiency in very hostile environments. Difficult as the chemical problems of the artificial system may be, it seems to offer a better promise of eventual success. Nevertheless, if it is to be economic, the apparatus of artificial photosynthesis must cost little more than $20 (USA) per square meter which means that the process must resemble agriculture rather than manufacturing technology.

Research in this field is in its early stages and progress over the last few years has been quite encouraging. It is a relatively inexpensive subject to investigate and will probably remain so, even at the development stage, because there are few scaling problems. Like agriculture, small scale trials can rapidly be extended to large areas. There are good reasons for pursuing research now in this area; it may take longer than we think, in which case we need the time to achieve success before existing sources run out; we may be successful earlier than we dared to hope, in which case it might soon make a useful contribution to the existing problems in the Third World. The way to the future is less certain than it has ever been; in research at least, we should keep all the doors open.
INTRODUCTION

Chemrawn II has been a great success. It has, temporarily at least, broken down the walls between scientific disciplines and drawn aside the curtains of specialization that too often have restricted the flow of knowledge and information between the diverse scientific disciplines that bear on food production and utilization. Chemrawn II has done an excellent job of bringing together an outstanding group of scientists, who are all, in one way or another, working on food-related problems. Although we have been talking and communicating effectively over the past five days, we should not forget that the marriage between many related scientific disciplines has not been consummated. Let us hope we will not soon drift back into the isolation of our own individual specialties and that we will continue to broaden the breadth of our understanding into other realms of knowledge.

During the past five days, I have been fascinated by the wealth of scientific information and the new perceptions that have been presented by the participants of Chemrawn II. Many of the proposals, if implemented, could considerably increase world food production over the next several decades. Armed with this wealth of new information and ideas I now feel even more confident that the world can — if it commits itself to their implementation — produce the food that will be needed during the next doubling of world population. Here I will attempt to explain why I feel this is attainable and without wholesale destruction of the environment and extinction of large numbers of species.

ON THE POPULATION FRONT

Before we can talk intelligently about world food needs for the future, and the magnitude and difficulties of the food production problem that lie ahead, we must
examine the growth in human numbers in the past to gain some insight into what is likely to happen to population growth in the future.

The beginning
Homo sapiens and his near relatives are “latecomers” to the planet. Relating the date of his appearance to the imaginary 5-billion-year geologic clock of the planet Earth, he seems to have appeared at somewhere between 3 to 5 minutes before midnight, a mere 3 to 5 million years ago. For our purposes, let us accept the opinion of those archaeologists who say that man has been roaming the earth for at least 3 million years. Until very recently, he was undoubtedly a marginal or weak secondary species. The dominant species that were present when man appeared had seen many more formidable species flourish briefly and then succumb to nature’s demanding imperative, “Evolve and adapt, or perish”. More perished than adapted. Untold millions of species had flunked the biologic imperative before the appearance of man, and many since. Some of the extinct have left their direct imprint to posterity in the book of fossil rocks which is read and interpreted by archaeologists and anthropologists. Indirectly, and more importantly, some of them have also left their imprint in the deoxyribonucleic acid (DNA) in the gene pool of related surviving species.

Early man must have looked like another of the species that would soon become extinct. He was poorly equipped physically to survive in a hostile environment. He was inadequately equipped to protect himself from the adversities of climate and from the stronger, better-equipped predators. He survived as a hunter, gatherer, and fisherman with little control over his food supply. He had no protection against diseases and parasites except for the innate. Finally he was helpless, or nearly helpless, against the onslaught of stronger predators for about one-third of his life span. He would have been a deserving candidate, at that time, for the endangered species list of modern environmentalists and ecologists.

The one characteristic that undoubtedly saved man from extinction was his brain power — his ability to reason, invent, and learn — which set him apart from all other species. Nevertheless, because of his many weaknesses, and the many hazards to survival, infant mortality must have been staggering. Man must have hovered on the brink of extinction many times during the first million years. Is there any wonder then that he heeded the biological commandment of survival, “be fruitful and multiply”, which was essential for survival during most of the first 3 million years. That survival creed became incorporated much later into all of the world’s major religions, and continues to persist to an exaggerated degree today, resulting in the explosive population growth which is adversely affecting the standards of living of many countries of the world. Excessive human population pressure is already reducing the carrying capacity of the land in many areas of the world. This, in turn, will make it more and more difficult to produce the food needed for a growing population.

Population growth since the beginning of agriculture
After man, or probably more correctly, woman, discovered agriculture and domesticated animals (a mere 12,000 years ago), his condition began to improve
markedly and his numbers began to increase at an accelerated rate. World population at the time of the discovery of agriculture is estimated to have been approximately 15 million. With a stable food supply, resulting in better nutrition and the development of a sedentary way of life, man had more time to devote to the improving of his physical environment (e.g., housing and clothing) which contributed to his increased survival and a further acceleration in population growth.

Population presumably doubled four times from the time of discovery of agriculture to the beginning of the Christian era (to about 250 million). The first doubling to 500 million occurred by about 1650. The second doubling required only 200 years, arriving at a population of 1 billion by 1850. That was about the time of the discovery of the nature and cause of infectious diseases — the dawn of modern medicine — which began to further reduce the death rate. The third doubling to 2 billion had occurred by 1930, only 80 years after the second doubling. Shortly thereafter, sulfa drugs, antibiotics, and improved vaccines were developed, substantially reducing death rates, especially among infants and children. The fourth doubling to bring world population to 4 billion was reached in 1975. This doubling took only 45 years and represented an increase of 256-fold or eight doublings since the discovery of agriculture, 12,000 years before.

Figure 1 graphically depicts world population growth from the discovery of agriculture to 1975 and with a projection to the year 2015. If the world population growth were to continue at the 2 percent level that prevailed in 1975, it would double to 8 billion in about 40 years, or by 2015. There is fortunately, some evidence that world population growth is beginning to slow. In general, it has slowed to manageable levels in the developed industrial countries, and in a few countries, has dropped to near zero. It remains frighteningly high, however, in most of the developing nations, many of which have large populations who are already undernourished. The population of some of these countries is doubling every 20 to 25 years, making it virtually impossible to increase food production to keep pace with population growth and, in fact, resulting in a worsening standard of living than the miserable level that now prevails.

THE MAGNITUDE OF THE WORLD FOOD PRODUCTION PROBLEM

There are two distinct aspects to the global food problem. The first is the complex task of producing sufficient quantities of the desired kinds of food to satisfy the needs of the entire population. The second major obstacle, equally as complex as the production problem, is to distribute the food equitably to all of the world’s population. The chief impediment to equitable food distribution is poverty — lack of purchasing power — resulting from unemployment and underemployment. The shortage of foreign exchange by governments of many food-deficit developing nations further limits the amount of food that can be imported to meet their people’s needs. Moreover, even when there is an adequate food supply available within such countries, the low-income sectors are often unable to purchase the quantities they need.

In attempting to give some insights into the magnitude of the world food
production requirements, I will use 1975, the year that world population reached 4 billion, as a point of reference. In 1975, world production of all kinds of food reached a new record of 3.3 billion metric tons (1.67 billion tons of edible dry matter). Using a 2 percent rate of population growth, the 8 billion people projected to be on the earth by the year 2015 will require 6.6 billion tons of food each year, just to maintain per capita consumption at the less-than-adequate 1975 level. These projected food production requirements for the future are staggering. This means that in the short period of 40, 60, or 80 years, depending on how population rates change, world food production must again be increased by at least as much as was achieved during the 12,000-year period from the beginning of agriculture up to 1975.

THE SOURCES OF OUR FOOD SUPPLY

The diversity of the human food supply is very great. It is made up of cereal grains, roots and tubers, legumes or pulses, oilseeds, nuts, fruits, vegetables, sugar and the animal products — meat, milk and eggs — and finally, fish, crustaceans and mollusks. Of the 3.3 billion metric tons of total food harvested in 1975, 98 percent of the tonnage came from the land and only 2 percent from the ocean and inland waters. An examination of the history of the world’s food supply clearly indicates that the land has always played the dominant role in food production. It will continue to do so in the foreseeable future.

Food from the land
Cereal grains which include wheat, rice, maize, barley, sorghum, oats, rye and millets, constitute the largest single group of foods. Cereals are of primary importance from several points of view. In 1975, they comprised 1.36 billion tons, representing 41 percent of the total food harvested on a tonnage basis. They are grown on approximately 50 percent of the world’s cultivated land area. Cereal
grains play a unique role as foods because, in addition to high caloric and protein content, they possess an unequalled combination of desirable characteristics (including low moisture content), which makes them easy to store and transport. They directly contribute about 52 percent of the total calories to human diets worldwide, and about 62 percent of the calories to the diets in developing countries. Moreover, they supply nearly 50 percent of the protein intake.

Indirectly, cereals also contribute greatly to the intake of protein in human diets, since approximately 33 percent of the total world production of cereals is fed to livestock to produce meat, milk, cheese and eggs. As standards of living rise, there is an increasing demand for animal products, which in turn results in an increased demand for grain for livestock feed. The Winrock International Livestock Research and Training Center predicts that by 1985, the percentage of world cereal production (excluding rice) fed to livestock will increase to about 47 percent. This shift in grain utilization patterns will put additional pressure on the world food production system. It will likely result, to the detriment of food-deficit developing nations, in higher grain prices, unless world grain production is increased substantially faster than the growing demand.

One of the most pertinent questions of our time is how the food-deficit nations of the developing world, those generally burdened by the double curse of overpopulation and fragmented, miniplot, stagnated agricultural sectors, can industrialize fast enough to siphon off part of the excess population from the land into better opportunities in industry, while at the same time increasing food production and slowing population growth to manageable levels.

Food from the waters
After World War II, there was a rapid expansion and improvement of the equipment of the world’s fishing fleets. The harvest of fish, mollusks and crustaceans increased dramatically during the 1950’s and 1960’s. Harvests began to taper off during the early 1970’s when the total catch reached 70 million metric tons, of which approximately 70 percent was utilized directly as human food, and the remainder as sources of meal and oil. In recent years, the harvest has leveled off and in some years, actually declined. By harvesting less desirable species, however, the total tonnage can be increased substantially.

During the next several decades, there will almost certainly be a large increase in the production of fish, mollusks and crustaceans resulting from the improvement and more widespread use of aquaculture technology in estuaries, lakes, ponds and reservoirs. Although these advances will add substantially to the production of food from the waters, the percentage of the total food harvested from this source will continue to be very modest. Consequently, to continue to perpetuate the illusion of unlimited food production potential of the oceans is both an irresponsible and dangerous course to pursue.

INCREASING AGRICULTURAL PRODUCTIVITY

An examination of the evolution of the American agricultural production, I believe, has a bearing on this question of increasing food production worldwide. It
provides a perspective into the complexities involved in bringing about a constructive change in agricultural production and an insight into the long gestation period that is involved.

The development of American agriculture from colonial times up until 1935 followed a traditional pattern for increasing food production. As sons and daughters of farm families married and formed new families, and as new immigrants came to the United States, they opened new land to cultivation. During most of this period, there was an abundance of land available as demands for agricultural products increased. Improvements in farm machinery led to expansions in the area that could be cultivated by a family, and also modestly increased yields per acre through better seedbed preparation, better conservation and utilization of moisture, and better weed control.

The foundation for the development of high-yield American agriculture was laid in 1862 when President Lincoln signed into Law three bills that in a large part were to give the great impetus to agricultural development for the next 100 years. These were: 1) the establishment of the Bureau of Agriculture, charged with responsibilities for guiding and coordinating agricultural development (which would subsequently evolve into the USDA); 2) the Land Grant College Act, which established publicly supported colleges of agriculture and mechanical arts in every state; and 3) the enactment of the Homestead Act, which made land available to the landless who committed themselves to living on the property and developing it.

These laws did not promptly produce magic results. The development of new technology designed to produce increase in crop yields, production and farm income still lagged. There was criticism, both from leading farmers and the Congress, to the effect that the university agriculturists were too theoretical and that their recommendations were often inappropriate and/or unreliable. The Hatch Act was passed in 1887 to strengthen research and correct these weaknesses. It provided for the establishment of agricultural experiment stations in juxtaposition to, and as a research arm of, the colleges of agriculture. It also provided for closer collaboration between the USDA and the agricultural colleges.

But again, there were no research discoveries forthcoming to increase yields materially in the last half of the 19th century. During this period American agricultural researchers drew heavily upon the research on soil fertility and crop rotations that was being carried out by Liebig in Germany, Laws and Gilbert in England, and Bassingault in France. The pioneer work of Pasteur, de Bary, Koch, etc., strongly influenced the early U.S. research efforts in plant pathology, veterinary medicine and entomology. During the last decade of the 19th century and the first decade of the 20th, isolated useful discoveries were beginning to be made in the cause of certain diseases of plants and animals and in the selection of improved crop varieties from mixed populations or land races. Even the limited discoveries that were made were slow in reaching the farmer. In 1914, the final key organization of the American agricultural science triumvirate — the Cooperative Extension Service — was established and charged with the responsibility of extending the new technologies, as they became available, from researchers to farmers and ranchers.
Over the period from 1910 to 1925, many important research discoveries were made in the fields of agronomy and soils, plant breeding, plant pathology, entomology, animal breeding and nutrition, and veterinary medicine. Many of these isolated discoveries were important components in the jigsaw puzzle of crop and animal production. Unfortunately, before these pieces could be assembled into an effective package of production technology and widely applied on farms, the entire U.S. agricultural economy was paralyzed by the general economic depression of the 1930’s. As a result, most of the research discoveries lay dormant and untried for 15 years.

It was not until World War II and the great demand for more food to support the European, African and Asian allies during and immediately following, that the economic parts of the American agricultural production jigsaw fell into place. Parts of the new technology began to be applied and yields and production began to rise. The most spectacular increases, however, took place during the 1950’s, 1960’s and 1970’s with the rapid expansion of the infrastructure for production and distribution of inputs such as improved seed, fertilizer, weed killers, pesticides, and machinery. The private sector played a major role in the development, introduction and distribution of these inputs, as well as in the development of better equipment for their utilization.

Between 1940 and 1980 the combined production of 17 major crops in the United States increased 242 percent, from 252 million metric tons to 610 million metric tons. This large increase in production, was obtained with an increase in area of cultivated land of only 3 percent. Had 1940 yield levels persisted in 1980, 177 million additional hectares of good U.S. cropland would have been necessary to equal the 1980 harvest.

The most impressive change in U.S. crop yields and production during the past 40 years has occurred with maize. Yields have increased 251 percent, due in large part to the introduction of high-yielding hybrids. A conservative estimate is that heterosis in hybrid maize contributed at least 20 percent to the 1980 harvest of 185 million metric tons. This was an increased production in 1980 of 37 million tons, worth approximately $4.5 billion in additional maize sales over what would have been achieved with the best open-pollinated varieties. As a result of the introduction of the new maize technology, 6.7 million fewer hectares were needed for maize production in 1980 than in 1940. Major yield increases in wheat and many other crops have also been achieved in the United States.

It is impossible to quantify the individual impact of the components of yield because of their interaction. Certainly in the case of crops grown in privileged ecosystems where moisture is not a limiting factor, the use of high-yielding varieties in combination with increasing amounts of fertilizer and improved weed control has been decisive in increasing yields. Over the 1938–80 period, fertilizer use in the United States for all crops increased from 1.4 million tons of nutrients to 20.1 million tons of nutrients, a 14-fold increase.

The USA’s spectacular successes in agricultural development points to the importance of establishing effective research and production institutions, the high returns that can be forthcoming as a result of well-focused agricultural research, the need for a trained manpower base of skilled researchers, production specialists
and farmers, and the need for unsatisfied market demand and price incentives to spur farmers to adopt productivity-increasing new technologies. The U.S. agricultural development story also illustrates that there can be substantial lag times between the scientific discovery and application of this knowledge at a practical, applied level.

ASSISTING DEVELOPING NATIONS IMPROVE THEIR AGRICULTURE

For the past 39 years, I have been privileged to participate in technical assistance programs designed to help increase food production in developing nations. In some cases I have seen dramatic changes in yield and food production in certain crops in a number of countries.

In 1944, I joined the staff of the Cooperative Mexican Agricultural Program. A joint program between the Mexican Ministry of Agriculture and the Rockefeller Foundation, this program was really the first attempt at international technical assistance in agriculture. As a result of the development and application of the improved technology — semi-dwarf varieties and improved agronomic practices — average wheat yields in Mexico increased from 0.8 metric tons per hectare in 1946 to 1.4 metric tons per hectare in 1980. Mexico became self-sufficient in wheat production in 1956 and remained so until 1976, when it was overwhelmed by the population monster. Self-sufficiency in wheat production has been nearly achieved once again during the past two years as the result of record yields. If self-sufficiency is to be maintained, however, new varieties and production technologies will be needed that will permit the extension of wheat cultivation into warmer, non-traditional, wheat-producing areas.

In 1963, I was invited by the government of India to visit their wheat research program. By then, the euphoria connected with the semidwarf Mexican wheat varieties had spread to many countries. Dr. M. S. Swaminathan, a brilliant young Indian wheat scientist, had obtained seed of five of the early dwarf Mexican wheat lines through an international wheat disease nursery, and was fascinated by their appearance. He asked me whether I thought they had any potential value for increasing Indian wheat production. I told him that I would withhold a decision until I had visited Pakistan and Egypt, en-route back to Mexico, to see how the Mexican semi-dwarf wheats were performing there, since I knew that former trainees from these countries who had been in Mexico had taken many experimental lines back with them. In Pakistan, I saw that the Mexican wheats were well-adapted to the Indian sub-continent and, indeed, had the potential of revolutionizing wheat production in areas thousands of miles away from where they were developed.

After returning to Mexico, I wrote a report to the government of India informing them that the Mexican semi-dwarfs, combined with proper production technology, could play an important role in increasing wheat production in both India and Pakistan. I will briefly describe what has happened to Indian wheat since the introduction of these wheats. The average production over the 1959-1966 year period was 10.95 million metric tons. The high-yielding dwarf Mexican wheats, together with improved agronomic practices which permit them to
express their high genetic yield potential, combined with government policies to stimulate production, were introduced into India on a commercial scale in 1966. Since then, both yield and production have increased spectacularly, as shown in Table 2. In 1982 Indian wheat production reached a peak of 37.8 million metric tons, more than triple the production of the 1959-66 period. Yields increased more than 99 percent in the same period. Had the 1959-66 yield per hectare prevailed, it would have required 42.7 million hectares to produce the 1979 harvest instead of the 22.6 million hectares that actually were involved.

The change in wheat production and yield in Pakistan have been every bit as spectacular as in India. Production in the 1959-66 period averaged 4.2 million metric tons; in 1982 it was 11.8 million metric tons. Yields in the same period rose from 0.87 t/ha to 1.52 t/ha in 1982.

These fantastic increases in wheat production show what can be achieved toward increasing food production in developing countries when research programs: 1) develop appropriate, economically viable, high-yielding production technologies; 2) verify their trustworthiness and demonstrate it on thousands of farms (and make whatever modifications are necessary); 3) marry these research findings to economic policy that encourages adoption of the new technologies; and 4) select the proper time and place to launch an aggressive enthusiastic production campaign.

IMPACT OF CIMMYT GERMPLASM

Today, the CIMMYT (Mexican) semi-dwarf wheats, or their derivatives, selected in developing countries' national programs are grown on 36 million hectares in the developing world. They have even invaded large commercial areas in the developed nations, for example, the United States, Canada, Australia, New Zealand, Spain, Portugal, and Italy. What were the factors that contributed to making the Mexican spring habit semi-dwarf wheat varieties so successful commercially, first in Mexico, and subsequently in many other parts of the world? Four primary considerations contributed to the intrinsic value of the CIMMYT-Mexican wheat cultivars.

Generating and maintaining genetic diversity

The CIMMYT program has maintained a broad germplasm base in the form of a diverse, dynamically changing crossing block of parental materials. The progenitors included in a crossing block include a range of outstanding genetic characteristics, e.g., yield potential, grain quality, sources of disease resistance. The make-up of the crossing block is generally modified each breeding cycle. New outstanding lines and varieties are added, while others are discontinued. The judgments for modifying the crossing block are made on the basis of new information that is accumulated by the breeder through multilocalational testing around the world.

The development of the shuttle breeding method

When the Mexican wheat breeding program was initiated in 1945, it was decided
that because of the history of repeated losses from stem rust, a breeding method was needed to drastically reduce the time required to develop new high yielding, early maturing, rust resistant varieties. Employing the standard breeding methods then used in the USA, Canada and other parts of the world would have required 9 to 11 years to produce a new variety from the time when the cross was made.

The philosophy and breeding dogma widespread at that time in the USA, Canada, Argentina and Europe was that if a breeding program was to be successful in developing high-yielding varieties suitable for commercial use in a given area, it, by necessity, had to focus on breeding (selecting) for adaptation to those local environments. This philosophy also bothered me from another point of view. Wheat was then grown in Mexico, mostly in many rather small isolated or restricted areas ranging from 32°N latitude in the northwest (Mexicali) to 14°55'N in the south in San Cristobal de las Casas, Chiapas. Moreover, it was grown from near sea level on the coastal plain of Sonora, up to 2,600 meters in small isolated valleys in the States of Mexico, Puebla, Tlaxcala, Chiapas, Michoacan and Chihuahua. How could we develop improved varieties for each of these many eco-niches?

To make matters worse, agricultural research in Mexico in 1945 was also severely handicapped by a shortage of trained scientific manpower, as well as by a shortage of funds for research. Moreover, it had no organization to multiply and distribute the seed of improved varieties. This task would be made even more difficult if the seed of a large number of improved varieties had to be multiplied and distributed.

Recognizing this dilemma, we began in 1945 a procedure which we call "shuttle breeding" and which CIMMYT continues to use with certain modifications up to the present time. This method basically involves growing breeding nurseries of all segregating populations twice each year, alternately in ecologically different environments. During the first five years, segregating populations were grown, selected and shuttled between six different locations (environments), a difficult tactical operation and also costly. Subsequently, it was found the same results could be achieved with less expense by using only two main locations.

The two locations used since 1950 are: 1) CIANO, located at 27°31'N latitude and 49 meters elevation in the Yaqui Valley on the coastal plain of the State of Sonora in Northwest Mexico; and 2) Toluca, located at 18°latitude and 2,600 meters elevation in the State of Mexico not far from Mexico City. These locations differ in soil type, temperature, and photoperiod (hours of daylight), and whether the day length is increasing or decreasing during the early weeks of seedling development. The locations also differ greatly in rainfall patterns.

At CIANO, wheat is grown as a winter crop under irrigation. Winter rains are rare, but heavy dew occurs frequently and is conducive to developing ecological conditions favorable for rust infection. Both stem and leaf rust are dangerous diseases, and one or the other — depending on temperatures — can become epidemic and can cause serious economic losses unless resistant varieties are grown. The wheat breeding nursery in CIANO is sown in November when the days are getting shorter. The segregating F₂, F₃, F₄ and F₅ populations are selected in late April in CIANO and seed of the best individual plants are shuttled
to Toluca for planting in the summer nursery in early May when day length there is increasing. At the highland Toluca site, rains are frequent and cool temperatures prevail throughout the summer providing ideal conditions for the development of stripe rust and several foliar disease epidemics, including those caused by *Septoria tritici*, *Fusarium nivale*, *Helminthosporium tritici repentin* and bacterial leaf blight. Selection of the best plants from segregating populations are made in October and shuttled back to CIANO, Sonora, for planting in November.

The use of the shuttle breeding method of selecting alternate segregating generations (of a genetically diverse group of populations) under these two very diverse environments, originally resulted in the identification of varieties with unusual gene combinations, adapted to the very diverse highland climates of Mexico, which, subsequently, were found valuable for commercial use in many other countries where spring wheats are grown.

A cooperative expansion of the shuttle breeding program into an international effort was established between Argentina and CIMMYT in the mid-1960s. The best individual plant selections from segregating populations were shuttled between the research station of the Instituto Nacional de Tecnologia Agropecuaria (INTA) at Marcos Juarez, Cordova, Argentina, and CIANO, Sonora, Mexico. As a result of this program, the variety Marcos Juarez INTA was developed. This variety, distributed in 1972, has become and remains the most widely grown and popular variety in the northern and central wheat-producing areas of Argentina over the past decade.

More recently, a cooperative breeding program has been established between EMBRAPA (The Brazilian National Agricultural Research Organization), FECOTRIGO and OCEPAR (the wheat research arms of the Farmers’ Cooperative organizations of the States of Rio Grande do Sul and Parana, respectively), and CIMMYT to develop high-yielding disease wheat varieties with tolerance to aluminum toxicity. Several low-yielding Brazilian wheat varieties, with poor agronomic type but with outstanding tolerance to soil acidity and to high levels of soluble aluminum, were crossed with several high-yielding, broadly adapted Mexican semi-dwarf varieties with good agronomic type that were highly susceptible to acid soils and aluminum toxicity.

The segregating populations have been shuttled among three acid soil locations in southern Brazil (where there are also heavy epidemics of foliar diseases such as *Septoria* spp., *Fusarium* spp., *Helminthosporium* sp. and powdery mildew) and between the two non-acid soil locations at CIANO and Toluca in Mexico. Strong selection pressure for resistance to the soil acidity and aluminum toxicity is exerted in each Brazilian location. In CIANO, selection pressure focuses on good agronomic type and stem and leaf rust resistance under alkaline soil conditions. In Toluca, selection pressure focuses on developing resistance to stem, leaf and stripe rusts, as well as a complex of other leaf diseases.

Currently, more than 80 advanced generation lines have been identified which appear to have combined high grain yield with tolerance to high levels of aluminum toxicity and resistance to the three rusts and, surprisingly, resistance, to a modest level, to a complex of leaf diseases present in both Brazil and Toluca,
Mexico. Even more surprising is that a considerable number of lines with good agronomic type, greatly outyield the Brazilian parent under the acid-aluminum toxic soil conditions of Brazil and achieve 85 percent of the yield of the Mexican parent when grown on the alkaline soils of CIANO. Such progress can only be achieved by exerting extreme selection pressure for tolerance to soil stress and disease resistance in each of the breeding sites (supplemented with data from laboratory tests), and shuttling the outstanding segregates between the sites so as not to lose the tolerance to soil stresses and diseases that are prevalent and serious at the other locations.

There are still many unexploited opportunities for using the shuttle breeding approach and resistance to different diseases in many parts of the world. One such opportunity is to broaden the stem rust resistance of the CIMMYT high yielding dwarf durum varieties so that they would be adapted to East African countries by establishing a shuttle breeding program between Ethiopia and CIANO, Mexico.

INCREASING FUTURE WORLD FOOD PRODUCTION

Until the 20th century, there was an abundance of potentially arable land available in many countries, and it was usually both cheaper and more expedient to bring new land under cultivation than to attempt to increase the yields per hectare of the land already under cultivation. Today, the situation is different. Now, in most densely populated food-deficit developing countries, the opportunities for solving their food production problem by expanding the cultivated area have vanished. There is little additional uncleared land that can be converted to arable land without huge capital investments in irrigation and/or drainage or in production inputs such as fertilizers and lime to correct soil infertility or toxicities.

Prior to hearing the presentations made at this Conference, I had underestimated the amount of new land that can still be brought under cultivation, as well as the amount of currently underutilized land that can be converted to economically arable land during the time frame of the next doubling of the world population.

There are certain areas of Central Africa where there are enormous well-watered tracts of land, estimated by some to be about 10 million km², which are currently largely precluded from human settlement. These areas are currently largely uninhabitable or underutilized by humans because of vector-borne parasitic disease, e.g., trypanosomiasis and theileriosis that decimate domestic livestock, and also because of vector-borne human diseases: malaria, trypanosomiasis (sleeping sickness) and yellow fever.

There are also vast sparsely settled or largely vacant areas of acid savannas, estimated by Sanchez et al at about 550 million hectares in the Cerrados of Brazil and the Llanos of Colombia and Venezuela, with significant similar areas in tropical Asia and Africa. These areas are heavily leached acidic oxisols and ultisols with complex problems of multiple plant nutrient deficiencies, strongly acidic, often with associated toxic levels of soluble aluminum or manganese. In the past, the low level of productivity of this ecosystem has largely precluded human settlement or at best has resulted in very sparse settlement and low levels of utilization.
Similarly, in South America, there are vast areas of tropical rain forests in the Amazon drainage of Brazil, Bolivia, Peru, Ecuador and Colombia, as well as smaller similar areas in Indonesia and South Asia, that are largely uninhabited. Here, also, both human health problems and lack of an appropriate agricultural technology have, up until recently, limited human settlement. Dr. Felix Ponnamperuma has presented data which indicate there are 100 million hectares of land in South and Southeast Asia, where rainfed rice could be grown successfully with the introduction of new technology, involving only modest costs. This entails the correction of minor element deficiencies, e.g., zinc or iron, etc., combined with the use of new rice varieties which have the genetic capacity to grow reasonably well in soils with low levels of essential minor elements, e.g., zinc or iron. In other problem soils, he indicates varieties are required with genetic tolerance to strong acidity and to toxic levels of soluble aluminum, or to high levels of alkali. He predicts that the potential yield of rice, on vast tracts potentially suitable for rainfed rice production in these areas can be raised from 800 kg/ha to 1500-2000 kg/ha, with the simple inexpensive application of the proper minor nutrient which now limits yield, combined with the use of a rice variety tolerant to soil toxicities.

Dr. Sanchez et al have presented information which indicates that with the application of phosphate fertilizer and the establishment of improved pastures, cattle production has become a viable enterprise in parts of the Cerrados in Brazil and Llanos in Colombia and Venezuela. Moreover, with improved agronomic practices, including the use of lime, and complex fertilizer involving nitrogen, phosphorus, potassium, minor elements and sometimes sulphur, combined with the use of varieties with tolerance to soluble aluminum, soybean has become an important crop within the last five years, in the Cerrado of Brazil. In all probability, within the next decade, with the development of varieties of sorghum and maize with tolerance to aluminum toxicity, they too will become important commercial crops in parts of the Cerrado. The same may become feasible for rice, triticale and possibly also wheat.

Establishing human settlements in Central Africa
It would appear that with the technology now being developed, or which is likely to be forthcoming during the next two to three decades, that a vast area in Central Africa can also be opened to human settlement. In order to achieve this objective, it will be necessary to bring under control trypanosomiasis and theileriosis which have, up to the present, devastated domestic livestock, whenever attempts have been made to introduce them in this vast area. Moreover, in order to make human settlement possible, there will have to be parallel developments which will bring under control both malaria and trypanosomiasis (sleeping sickness), as well as the widespread use of yellow fever vaccine, which is available.

The International Laboratory for Research on Animal Diseases (ILRAD) has been working on these two devastating livestock parasitic diseases (trypanosomiasis and theileriosis) since its establishment in 1973. As Dr. A. R. Gray has indicated in his presentation, this is a very complex problem. A great deal has been
learned about these complex parasitic diseases during recent years by employing modern biotechnological methods, but no practical commercial control is yet available. Nevertheless, the employment of new biotechnological methods, involving the use of hybridomas to produce monoclonal antibodies, may eventually lead to the development of effective vaccines which will help, when combined with other approaches, to bring these complex devastating animal diseases under control.

Concurrent parallel development to bring under control the human diseases — malaria, trypanosomiasis (sleeping sickness) and yellow fever — are essential to permit human settlement. The two former diseases are under accelerated study by various international and national health research organizations employing hybridomas to produce monoclonal antibodies and, hopefully, eventually effective vaccines. Some scientists have predicted that an effective vaccine for malaria may be developed within the next decade.

A second approach would also appear to be justified, namely to attempt to solve the trypanosomiasis cattle diseases problem, in part at least, through breeding of a tolerant race of cattle. It has been known for a long time, that the West African breed known as N’Dama is considered to be trypano-tolerant when grown in West Africa, but becomes susceptible when moved to other areas, where apparently other strains of the trypanosomes are prevalent. This indicates that there is probably a good possibility of pyramiding genes for resistance to different strains of this disease, if the problem is attacked with a large and vigorous cattle breeding program employing modern biotechnology.

Modern techniques which have become available in the last decade could greatly facilitate the establishment of an accelerated breeding program with some hope for a breakthrough in increasing and broadening the resistance trypanosomes and consequently the adaptation of the N’Dama to other areas of Central Africa. Among the techniques now available that can be used to accelerate the breeding program are the use of hormones to stimulate ovulation and production of multiple ova, recovery of the ova followed by in vitro artificial fertilization and, subsequently, embryo transplant to surrogate mothers that are carrying the basic resistance of the N’Dama. Subsequently, the calves would be challenged with infection by trypanosomes and the most tolerant utilized for the next cycle of breeding. These techniques, when properly exploited, have the potential to increase the number of embryos per year produced by one cow from 1 to 50 or 60 calves in a single year and, thereby, tremendously accelerate a breeding program.

The third possibility, even further removed from the conventional, but which, from my point of view, merits serious consideration, is the domestication of wild species of antelope, such as the large eland, which is reported to have meat of excellent quality. The eland lives and flourishes in the tse-tse fly Glossina-Trypanosoma infested environment and is reported to be either tolerant/resistant/or immune.

All of the domesticated animals on which man depend were domesticated by Neolithic women long before anything was known about imprinting. It seems to me that a research effort should be made to collect several hundreds new-born eland calves, imprint them, and in subsequent weeks and months, select those which have the genes for greatest docility, which is probably inherited as a
polygenic recessive. Once a number of partially docile calves are identified, a breeding program could be launched employing hormone to stimulate multiple ovulation to produce many ova, followed by recovery of the ova, fertilization in vitro, and transplant to the most docile surrogate eland mothers. Through this three-pronged approach, it would seem reasonable that through one or another avenue, or in combination, progress can be made to make Central Africa habitable for human settlement in the next three or four decades.

Human settlements in the “forbidden” Amazon rainforest
The tropical rain forest of the Amazon covers a vast area. Over the past decade, there have been many emotional articles published saying that the tropical rain forest ecosystem must be preserved at all cost. I wish this were possible! But drawing on my forestry and agricultural experience, I know that this is an over-optimistic and unattainable wish.

As human population pressures build, the volume and rate of “slash and burn” migratory agriculture will advance into the Amazon tropical rain forest. It will bring with it destruction of the ecosystem, accompanied by continued propagation of human misery and ignorance, since such deforestation and migratory agriculture, as everywhere in the past, will not be accompanied by the development of public services, e.g., schools, medical care, housing, transportation, etc. The alternative, which seems to me to be a more promising one, is to learn to manage part of this ecosystem for the production of goods and services useful to society, without destroying the system and, at the same time, provide improved standards of living for those who are engaged in such undertakings. I personally was very impressed with the JARI (Ludwig) Forestry Project in the Amazon Basin. The JARI Forestry Project, although often criticized by environmentalists, appeared to me to be a big step in the right direction toward learning how to produce valuable goods for mankind, without destroying the ecosystem. Under the skilled management of trained foresters and engineers, *Gemelina arborea*, *Pinus caribea*, and several species of *Eucalyptus* were being grown successfully in plantations for the production of pulpwood. This was being done by the establishment of well planned and well managed plantations wherein the employees had access to the benefits of schools, medical care and housing, unlike the situation with the “slash and burn” migratory agriculture.

The plantation approach, involving the use of several tree species, as executed at JARI, did not provoke serious erosion and did not destroy the environment and was producing economic yields of pulp. Eventually it would also have produced timber for saw logs. Experimental plantings indicated that African oil palm and perhaps other native palms, e.g., Babassu (*Orbignya speciosa*) and *Curyocar* sp., could have been grown successfully under proper plantation management in this ecosystem.

With the development of a strong, dynamic, breeding program to incorporate resistance to leaf blight (*Dothidella ulei*) into high latex-yielding populations of the native Brazilian rubber tree, *Hevea brasiliensis*, this tree species could be brought under successful intensive economic plantation management in its homeland in the Amazon drainage.

I am convinced that the best way to utilize the tropical rain forest of the Amazon
without disastrous destruction of the ecosystem will be through the development of sound systems of plantations based on three species that are needed for industry such as for paper and pulp, and for production of edible and non-edible oils, nuts, coffee and cacao.

Even though the JARI Forestry Project has been disposed of by Ludwig, I sincerely hope that the Brazilian Consortium, which has taken over the management of the JARI Forestry Project, will continue to develop it with sound forestry management skills and, thereby, open the way to successful management and rational exploitation of this ecosystem. I firmly believe that controlled and scientific management is the only viable alternative to the disastrous ravages that will result from uncontrolled “slash and burn” migratory agriculture, as population pressures evolve.

INCREASING YIELDS AND CROPPING INTENSITY

In order to comply with world food production needs during the next five decades, per hectare crop yields must be greatly increased in the developing nations, especially the densely populated Third World nations. Today, there is frequently a five- to seven-fold yield difference between yields of many crops in the developing countries and the developed countries. Hence, the opportunity for dramatic improvement in yield and production in many countries is great if we are to be successful in accelerating agricultural production in the developing world. Let me highlight some of the major problem areas and factors which must be considered.

Soil Infertility
Without a doubt, the single most important factor limiting crop yield on a worldwide basis is soil infertility (after moisture over which man has only limited control). The lack of one or more of the essential plant nutrients is the result of the joint effect of natural weathering followed by leaching and combined with extractive farming practices. Phosphorus and potassium and other nutrients have been gradually leached from the soil during geologic time to a level where, with subsequent continuous extractive farming, they soon limit crop yield. Virtually all traditional farming systems are highly extractive. They are essentially “mining” operations whereby each year crops are harvested and little or none of the crop residue or animal wastes, which would partially restore soil fertility, are returned to the soil. The exceptions are the Chinese, Japanese and Koreans, who have done an excellent job of maintaining a moderate level of fertility by the use of organic wastes. Soil fertility can only be restored by the application of the right kind, organic and/or chemical, and proper amounts of fertilizer which will vary with soil type, climate and crop. It can only be determined by research. Until soil fertility is restored, improvement in crop cultural practices and varieties will improve yield only marginally.

Among the three major plant nutrient deficiencies that most often limit crop yields worldwide, nitrogen deficiency is the most widespread, although phosphorus (availability to plants) and potassium deficiencies are also widespread. Crop yields in certain soils may also be limited by deficiency of the secondary
nutrients — sulphur, calcium or magnesium. Deficiencies of minor elements, such as boron, chlorine, cobalt, copper, iron, manganese, molybdenum and zinc, are also depressing yields in some areas.

If the world’s food needs are to be met during the next several decades, it will be absolutely necessary to increase greatly the production and use of chemical fertilizers. Large increases in the use of fertilizer will be essential to increase crop yields on the nutrient-depleted and infertile soils of the developing nations.

Prior to 1950, many agriculturists believe that soil nitrogen could be maintained at levels capable of producing high grain yields by employing legumes in rotations with cereals, supplemented by the use of animal manure. This situation has changed drastically during the past three decades because of two factors, namely:

1) The shrinking of the per capita arable land base in food-deficit, densely populated nations which has made it almost impossible to leave land out of food crop cultivation for the production of a green manure crop. Moreover, there is an increasing shortage of animal manure available to restore soil fertility, since more and more of it is being used as a home fuel.

2) The availability of relatively low-priced nitrogenous fertilizers increased dramatically during the 1950s, 1960s and early 1970s as a result of a revolution in fertilizer production technology resulting from the introduction of large centrifugal compressors and improved catalysts which greatly cut production costs.

As a result of these two factors, there has been a rapid increase in nitrogenous fertilizer consumption which, in turn, has greatly contributed to increased food production. Annual nitrogen fertilizer use in the USA increased from 900,000 to 10 million nutrient tons per year from 1950 to 1980 and in India from 250,000 to 3.96 million nutrient tons from 1960 to 1982. These increases in fertilizer use correlate closely with the increases in crop yields and production in these two countries, as is evidenced in Tables 1 and 2.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area (thousands of hectares)</th>
<th>Yield (tons per hectare)</th>
<th>Production (thousands of tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1938 to 1940</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>36,014</td>
<td>1.80</td>
<td>64,104</td>
</tr>
<tr>
<td>Wheat</td>
<td>23,635</td>
<td>0.96</td>
<td>22,453</td>
</tr>
<tr>
<td>17 major crops*</td>
<td>128,820</td>
<td></td>
<td>252,033</td>
</tr>
<tr>
<td><strong>1958 to 1960</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>29,714</td>
<td>3.36</td>
<td>99,891</td>
</tr>
<tr>
<td>Wheat</td>
<td>21,419</td>
<td>1.67</td>
<td>35,883</td>
</tr>
<tr>
<td>17 major crops*</td>
<td>127,436</td>
<td></td>
<td>391,388</td>
</tr>
<tr>
<td><strong>1978 to 1980</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>29,338</td>
<td>6.32</td>
<td>185,208</td>
</tr>
<tr>
<td>Wheat</td>
<td>25,614</td>
<td>2.22</td>
<td>57,016</td>
</tr>
<tr>
<td>17 major crops*</td>
<td>132,544</td>
<td></td>
<td>610,293</td>
</tr>
</tbody>
</table>

*Corn, wheat, rice, barley, sorghum, oats, rye, cotton, soybeans, peanuts, beans, flaxseed, potatoes, sugar beets, hay, corn silage, tobacco.
Table 2. Wheat production in India before and after the wheat revolution. (Data from the Indian national wheat program. Format adapted from that of B.A. Krantz.)

<table>
<thead>
<tr>
<th>Years</th>
<th>Wheat production (millions of tons)</th>
<th>Gross value of increase* (millions of dollars)</th>
<th>Number of adults provided with carbohydrate needs by increase (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966 to 1967</td>
<td>11.39</td>
<td>88</td>
<td>3</td>
</tr>
<tr>
<td>1968 to 1969</td>
<td>18.65</td>
<td>1540</td>
<td>50</td>
</tr>
<tr>
<td>1970 to 1971</td>
<td>23.83</td>
<td>2576</td>
<td>94</td>
</tr>
<tr>
<td>1972 to 1973</td>
<td>24.74</td>
<td>2758</td>
<td>101</td>
</tr>
<tr>
<td>1974 to 1975</td>
<td>24.10</td>
<td>2630</td>
<td>96</td>
</tr>
<tr>
<td>1976 to 1977</td>
<td>29.08</td>
<td>3626</td>
<td>133</td>
</tr>
<tr>
<td>1978 to 1979</td>
<td>35.51</td>
<td>4912</td>
<td>180</td>
</tr>
<tr>
<td>1980 to 1981</td>
<td>36.50</td>
<td>5110</td>
<td>186</td>
</tr>
<tr>
<td>1981 to 1982</td>
<td>37.80</td>
<td>5370</td>
<td>196</td>
</tr>
</tbody>
</table>

*The wheat value used in $200 per ton, similar to the landed value imported wheat in India in 1981. Calculations are based on the provision of 65 percent of the carbohydrate portion of a diet containing 2350 kilocalories per day, or 375 grams of wheat per person per day.

The euphoria for increased nitrogen fertilizer production and consumption was disrupted by the explosive increase in petroleum (and gas) prices following the OPEC oil embargo of 1974-74. The large increase in petroleum price, combined with panic buying and build-up of inventories, resulted in doubling — and in some cases tripling — the price of nitrogenous fertilizers. Since the Haber-Bosch process used to produce ammonia is energy intensive — requiring both high temperature and pressure — any increase in the cost of energy is strongly reflected in the production costs of ammonia and other nitrogenous fertilizer derivatives.

It is highly unlikely that another spectacular change in nitrogen fertilizer production technology will again soon come to the rescue to reduce production costs and thereby compensate for the large increases that have occurred in gas, petroleum and coal prices. Nevertheless, despite these increasing costs, the installation of new nitrogen production capacity has kept pace and even exceeded market demand over the past few years.

For the long-term, however, we must make commitments by expanding research to assure the availability of nitrogenous fertilizer (as well as other fertilizers) to farmers at reasonable costs. Without an assured and expanding supply of fertilizer supplies, it will not be possible to double food production during the time period of the next doubling of world population. I agree wholeheartedly with the views expressed by Drs. R. Scott Russell and G. W. Cooke who emphasize the need for greatly expanding basic chemical and engineering research to find less energy-intensive processes than the Haber-Bosch process for fixing atmospheric nitrogen.

Within the past decade, as a result of the increase in cost of ammonia production, there has been a resurgence in research on biological nitrogen fixation. This is commendable. This effort is not only desirable, but deserves further funding to explore the whole array of approaches, including gene splicing, cell fusion and DNA transfer, that potentially could increase the nutrient nitrogen...
supply including attempts to improve biological nitrogen fixation by *Rhizobium* spp., *Azospirillum* sp., *azolla-anabaena* complex, blue-green algae, mycorrhiza, and actinomyces.

On the industrial front, better management of fertilizer production factories, especially in developing nations where many factories are producing at only 65-75 percent of rated factory capacity, is urgently needed. On another industrial research front, the International Fertilizer Development Center (IFDC) is attempting to modify conventional nitrogen fertilizers, such as urea, so as to produce slow release formulations which will improve nutrient uptake efficiency. More of this type of research is needed.

Moreover, a large research effort is needed to reduce losses of nitrogen from the soil after it has been applied. At present, in some cases only about one-third of the applied nitrogen is utilized by the crop. These losses both add to the cost of fertilizing crops and add to the pollution problem.

**Soil toxicities**

Certain soil toxicity problems, such as acidity with high levels of soluble aluminum, can be corrected by liming. However, in certain highly leached soils like the oxisols and ultisols, where the entire soil profile is acid with toxic levels of aluminum, liming only corrects the toxicities in the surface layers. Within the past decade, varieties of both wheat and rice have been selected that can produce economic yields of grain on aluminum toxic soils where the former varieties that were susceptible to soluble aluminum could not.

Although the breeding of crop varieties for resistance or tolerance to soil toxicity problems is in its infancy, I am optimistic that varieties of other crops with tolerance to various soil toxicities can be developed during the next decade.

**Improved crop varieties**

Average yields are the composite effect of the interaction of the genetic yield potential of the variety, moisture, temperature, light, plant nutrients, and the negative effects of weeds, diseases and insects. Since world record crop yields are 4 to 9 times greater than the average crop yields even in the most productive farming areas, such as the USA, it is evident that there is a very large unexploited genetic yield potential yet to be utilized in the varieties of our major crop species now available. The continuation and development of aggressive breeding programs to transfer the maximum genetic yield potential (or as much of it as is possible) to improved varieties, adapted to the different environments where the crop is to be grown, are essential to realizing this unexploited genetic potential.

**Agronomic practices**

In a traditional agriculture, where lack of plant nutrients limits yield, agronomic practices generally receive little attention. The traditional farmer has learned from experience that he can do little to increase crop yields by manipulating agronomic practices. When soil fertility is restored, the use of an improved set of agronomic practices becomes imperative for exploiting opportunities for a big increase in yields. These practices must be based on extensive research conducted on farms
throughout the area where the crop is grown. Also needed to achieve high yields are good seedbed preparation, proper seed rates and the correct dates of sowing for each of the improved varieties, proper conservation and management of soil moisture, and proper control of weeds.

**Control of diseases and insects**

In low-yield traditional agriculture, it is only in unusual years that ecological conditions are sufficiently favorable for diseases and insects to reach ravaging proportions. When these conditions do occur, however, the losses are severe, for there are no organized disease or insect control programs to advise and assist the farmer. In most years, however, the pathogens and insect pest species, like the host plants, are all struggling for survival under difficult unfavorable environmental conditions. The situation in high-yield intensive agricultural systems changes this equilibrium dramatically; fertilized soils and improved agronomic practices result in the development of thick lush stands of crops. The ecology within these fields then becomes very favorable for weeds, pathogens and insect pests. Weeds become aggressive and unless controlled will greatly reduce yield. Disease- and insect-resistant varieties must be used to minimize the risks of crop losses. Moreover, an integrated control program must be adopted insofar as possible, including crop rotation, proper dates of planting, biological control, and the regular monitoring of the pest population combined with the timely application of pesticides when necessary, in order to reduce crop losses to acceptable economic levels.

**Availability of production inputs**

In most western advanced agricultural nations the distribution of production inputs such as improved seeds, feeds, fertilizer, herbicides, insecticides, fungicides, equipment and machinery is largely provided to farmers by an efficient highly competitive private agro-business sector. By contrast, in most developing nations, the private sector supply systems is either weak or non-existent and these services are assumed by government.

In many developing countries, production inputs are either unavailable or are available only in a few large cities far removed from agriculture production areas where they are needed. It is necessary to establish an effective network to distribute these inputs down to the village level if production is to be improved. The timeliness of distribution and appropriateness of the products being distributed are of primary importance, but all too often they are hopelessly entangled in a web of bureaucratic inertia which adversely affects production.

**Government economic policies affecting agriculture**

Whenever an attempt is made to provide change in a primitive agriculture, an effective technological package of improved crop varieties and agronomic practices must be developed, based on research, to overcome the inherent defects and weaknesses in the traditional agricultural system. The improved technology must be checked for validity and demonstrated widely on hundreds of farms. Once improved production practices have been developed and widely demonstrated with positive results, they must be married to sound government policy that will
encourage improved technology adoption and thus result in increased production. Governments must assure the availability of proper kinds and amounts of inputs at reasonable prices at the village level, and they must make credit available for purchase of these inputs, especially for the small farmers, so that they can participate in the use of the new technology. Finally, government policy must assure the farmer a reasonable price for his products at time of harvest. Floor prices for grain of the important crops must be announced before time of planting. They should be established at prices similar to those for the commodity on the international market, plus freight from the point of supply to port of importation. If prices in the free market at harvest fall below the announced floor level, the government must enter the market to assure the announced price level. The grain purchased by the government to stabilize prices at harvest can be fed into the market later to stabilize grain prices for the consumers.

Research and extension programs
Agricultural research and extension programs in most developing nations are weak. They are handicapped by a shortage of trained people, inadequate budgets, and the low prestige associated with agriculture. In reality, even though 50 to 85 percent of the total population in most developing nations is involved in agriculture, this profession often occupies the lowest rung on the socio-economic ladder. Consequently, many of the most talented young people with a rural background want to forget about the hard work and low income of agriculture. They seek careers in medicine, dentistry, law, engineering or business.

It is impossible to transform a traditional agriculture into a modern agriculture without the assistance of a large group of motivated and trained scientists and technicians. My experience in a number of countries, where research and training programs were initiated when few trained people were available, indicates that it takes 20 to 25 years to identify, train and provide research experience for enough young scientists and technicians that a national research institute can be organized and staffed effectively.

Maintaining creativity and viability in research organizations, once effectively staffed and launched, is equally frustrating and complex. Research organizations in developing nations — even more than in developed nations — are vulnerable to the disruptiveness of political winds, inadequate funding, corruption and the insidious viruses of bureaucratization and scientific fossilization.

Multiple cropping
Within the past decade multiple cropping — growing two or sometimes three different crops on the same land within a year — has become commonplace in some semi-tropical and tropical areas. Multiple cropping, which increases both food production and farm income, was neither agronomically or economically feasible before the introduction of the use of chemical fertilizers combined with the use of high yielding early maturing semi-dwarf wheat and rice varieties. During the next two decades, an expansion and intensification in multiple cropping can add greatly to world food production. Increased fertilizer availability must be assured if this potential is to become reality.
NEW AGRICULTURAL RESEARCH DEVELOPMENTS

Due in considerable part to the creation of the internationally funded network of 13 international agricultural research centers working on food research problems of the developing world, a growing number of new agricultural research achievements stand to benefit future food producers and consumers, especially in the developing world. Let me highlight two new research achievements associated with CIMMYT, the international center with which I am most familiar.

**Nutritionally superior maize**

The grain of all the major cereal crop species is deficient in one or more of the essential amino acids. These deficiencies limit their nutritional value as food for direct human consumption, and also, indirectly, for utilization as feed for the production of high nutritive value animal products, which in turn are used to improve human diets.

Twenty years ago at Purdue University, a poor unimproved maize variety carrying the Opaque-2 gene (which many years previously had been used in maize chromosome mapping studies) was found to have nearly double the levels of lysine and tryptophan of normal maize. Feeding studies with monogastric animals, including children, established that Opaque-2 maize was far superior nutritionally to normal maize. This discovery triggered enormous enthusiasm and research activity in many universities, hybrid seed companies and in international research institutes, directed toward the breeding of high-yielding maize varieties with the additional benefit of high nutritional value. The euphoria associated with the discovery of the Opaque-2 gene in maize — similar to what has occurred in the past decade with the advent of the so-called new biotechnology, genetic engineering, recombinant DNA, cell fusion, etc — soon led to the initiation of similar research on other cereals, including barley, sorghum, wheat and rice.

Despite a large breeding effort, especially by hybrid corn seed companies in the USA, extending over a decade, the defects associated with the Opaque-2 gene, were not overcome. The best Opaque-2 hybrids and varieties yielded 15 to 20 percent less grain, by weight, than the normal counterpart, largely because of reduced endosperm (kernel) density associated with the Opaque-2 gene, and in addition, had grain of softer texture which was also more susceptible to ear rot and insect damage. As a result, by the mid-1970s, the breeding efforts of virtually all of the USA hybrid maize seed companies and universities were discontinued.

The CIMMYT’s breeding program under the direction of Dr. Ernest Sprague, and led by Dr. Surinder Vasal, a breeder, and Dr. Evangelina Villegas, a biochemist, however, was continued with effort unabated. As a result of the close cooperation between breeder and chemist (involving the analysis of many thousands of grain samples for lysine and tryptophan content during each generation over the past 14 cycles of recurrent selection), success has been attained. In the recurrent selection process, a large number of genes which modify endosperm (kernel) density, texture and indirectly affected grain yield, and which also influence resistance to ear rot and to insect damage, have been accumulated, while the high lysine and tryptophan content of grain of the Opaque-2 parent, has
been maintained. It took 15 years of continuous research effort to achieve this goal. Currently, several of the broadly adapted, high yielding, high nutritive value maize varieties in both dent and flint grain types, are in various stages of multiplication and distribution. The hard endosperm quality protein maize (QPM), Tuxpeño 1 variety, typifies the new QPM varieties. It is high yielding, has good agronomic type, and is broadly adapted to the coastal areas (up to an elevation of 1,000 meters) of Central America, Mexico, several countries of the west coast of Africa, and to two southern-most provinces of China. A large number of other high nutritive quality populations and varieties are well advanced in the breeding program and destined for use in areas from the equator to 30° latitudes and elevational zone of 1000-2000 meters. Materials suitable for use at high elevations are also under development, but still years away from reaching commercial exploitation.

The development of high-yielding, broadly adapted high nutritive maize varieties is of particular significance to the large number of subsistence farmers who grow and consume maize as a basic food, and can thereby improve their diet nutritionally at no added cost. It will also be of great significance to those who use maize as a feed for livestock, for it can reduce the cost of feed rations, especially for monogastric animals.

The implications of the development of the high yield, high nutritive quality maize varieties is of additional significance in that maize has the highest maximum genetic yield potential of all the cereals. Moreover, it has tremendous genetic variation which permits it to be grown in a wide range of environments across latitudes and elevations. Maize now ranks second worldwide in production, after wheat (if rice tonnage is measured as dehulled rice rather than paddy). However, maize is destined, I believe, to become number one in world cereal production within the next decade.

**Triticale — Scientific Man’s First Cereal Crop Species**

Despite many advances in genetics, cytology, plant and animal breeding over the past 60 years, mankind still depends for his food supply on the same species of plants and animals that were domesticated 6,000-12,000 years ago by Neolithic women. This truth has been perplexing, frustrating and demoralizing to at least five to eight generations of scientists. It now appears that after nearly 100 years of struggle, scientists are on the verge of adding triticale as a new, economically important, cereal crop to our array of food production resources.

Triticale is an allopolyploid cereal species that is formed by crossing ryes by wheat. The first natural occurring triticale was observed and reported by Wilson in Scotland in 1875. Rimpau in 1890 succeeded in crossing wheat and rye and, apparently through automatic self-doubling of the chromosomes, obtained a partially fertile triticale. However, two principal obstacles to the breeding and development of triticales as a crop persisted for more than fifty years. These were: 1) lack of a satisfactory technique for doubling the chromosomes in the F₁ seedlings which would result in partial fertility and set of seed, and 2) endosperm incompatibility in the hybrid seed which resulted in shrivelled grain, poor germination and weak seedlings, most of which died.
The solution to the former problem was achieved in 1937 when it was found that the proper application of colchicine to the apical meristematic tissues of F1 triticale seedlings disrupted cell wall division but not chromosome division, thus resulting in doubling of both the wheat and rye chromosomes and giving rise to partially fertile F1 plants which produced a few seeds. The solution to the second obstacle was made in the 1940s when effective techniques were developed to extract the embryos a few days after fertilization and grow them in the laboratory on artificial cultural media.

Several European scientists, including Drs. A. Muntzing (Sweden), Sanchez Monge (Spain), and N. V. Tsitsin (USSR), spent most of their professional lifetime unsuccessfully attempting to develop commercially acceptable varieties of triticale. Dr. L. M. Shebeski (as he has indicated at this conference) launched the first triticale breeding program in the Americas at the University of Manitoba in 1954. CIMMYT began a small breeding program on triticale in the spring of 1964. In December of that year, CIMMYT entered into a cooperative agreement with the University of Manitoba to establish an expanded and accelerated triticale breeding program. Seed from the best individual plants from early segregating generations harvested in the winter nursery in CIANO (Mexico) was divided and shuttled to Winnipeg, Canada, and Toluca, Mexico, for planting in summer nurseries. Selections made in these two summer nurseries were again shuttled to the CIANO (Mexico) for planting in November and the process repeated over a number of years.

When the cooperative program was initiated, in 1964-65, it was confronted with a number of factors that seriously negated high grain yield and also affected yield stability. Among these were: 1) partial to nearly complete sterility, 2) grain endosperm shrivelling and low grain test weight, 3) extreme day-length sensitivity resulting in very late maturity under short Mexican days, and 4) extreme plant height which resulted in lodging.

In the mid-1960s the yield of the best triticales was only about 40 percent (2.6 metric tons/hectare) of the best Mexican bread wheats (6.0 metric tons), under Sonora conditions. Moreover, the seed was so badly shrivelled, that it would have been unacceptable for either feed or as a good grain. In addition, all of the triticales were late maturing, tall growing and lodged badly.

In 1968, the Prince of Serendip smiled and blessed the CIMMYT triticale program. Several completely fertile semi-dwarf, early-maturing triticale plants (later named Armadillo) were found in the complex Canadian-CIMMYT Cross (population) X308 subsequently. This was obviously the result of a partially sterile, permissive triticale plant in the X308 population being surreptitiously pollinated by a CIMMYT early-maturing dwarf bread wheat plant. With this unexpected “assistance” from Mother Nature, the problem of infertility was solved. It soon became evident that this high degree of fertility could be transferred with ease, by crossing, to other triticales. Seed of the highly fertile armadillo triticale lines were distributed to triticale scientists in many countries.

Overcoming the sterility problem also resulted in a substantial increase in grain yield, but the program continued to be frustrated by shrivelled grain, lodging and susceptibility to a number of diseases. A large crossing program, employing a
diverse group of ryes and wheats as parents, was initiated to overcome these problems. By 1977-78 the best new triticale varieties were yielding as much as the best Mexican semi-dwarf wheats under Sonora conditions.

In recent years, there has been a gradual improvement in grain plumpness and test weight. Earlier-maturing lines, that show promise for use in marginal rainfed areas in high elevation, are also being developed. Lodging, however, continues to be a problem when triticales are grown under irrigation on soils of high fertility or where heavily fertilized.

Triticales are beginning to find a market both as a food grain and as a feed grain. They also show promise for use in malting. As a food grain, with proper modifications in milling, fermentation, and baking procedures, triticale can be used to produce acceptable baked products such as bread, tortillas, chapatis, cookies, and pastries. As a feed grain, triticale is far superior to rye and substantially better than wheat for use in rations for monogastric animals such as swine and poultry. Triticales are also being grown primarily for winter forage production in several countries.

Spring growth-habit triticales — the type being developed by CIMMYT — are now being grown on small but an increasing commercial area in Mexico, Argentina, Australia, Brazil, Canada, Ecuador, Kenya, Portugal, Spain, Tunisia, and the USA. Winter-habit triticales developed by the USSR and Poland are being grown on more than a million hectares in the USSR and eastern European countries. Triticale is especially promising as a new crop in Poland for replacing rye, which provokes metabolic and nutritional problems when used in rations for swine and poultry.

It now appears that triticale is well on the way toward being established as a new commercial cereal crop and will likely be grown on a rapidly increasing commercial scale — especially in problem soils — during the next decade. It has taken the collective effort of many scientists from many countries nearly 50 years to “create” this new commercial cereal crop — the first new important cereal crop “species” that has been added to our food resource base since the domestication of our other cereals thousands of years ago.

The potential role of “new” genetic engineering

In some scientific circles, today, there is expectation that major production benefits will soon be forthcoming from the use of genetic engineering. The new techniques in gene splicing and DNA transfer, in cell fusion, tissue culture, hybridomas and monoclonal antibodies, all open new horizons to solving some of nature’s most frustrating problems of animal and plant health and plant and animal nutrition, and provide another avenue for further increasing the genetic yield potential of animals and food crops.

Great progress has already been made by employing new genetic engineering techniques with bacteria and yeasts to produce insulin, interferon sp, and growth hormones. The use of hybridomas and monoclonal antibodies for use in diagnostic purposes is well advanced, and will undoubtedly lead to the production of both safer and more effective vaccines for many human and animal bacteria and viruses. There is now also hope that these new techniques will, in the next decade or two,
lead to the development of effective vaccines against some of the complex vector borne parasitic diseases such as trypanosomiasis and malaria. There are those that believe that the use of these techniques will also usher in a new era in increasing the breadth, level and stability of disease and insect resistance in higher plants, and thereby greatly decrease the need for chemical fungicides and insecticides.

It appears to me that it is a mistake to assume that the transfer into crop species of disease and insect resistance-genes, through genetic engineering, will result in substantially more durable resistance in varieties than what has been achieved with conventional hybridization techniques to date. It is well established that when pathogens and insects are faced with extinction, they are saved from this fate by mutations and the formation of new races. In all probability, it will be many years before genetic engineering techniques can successfully be used alone to breed superior crop varieties, especially in complex polyploid crop species such as wheat. Rather, such techniques will be used as adjuncts to conventional plant breeding methods.

There are, however, some of these techniques, such as cell and tissue culture, that are already being used commercially to multiply valuable new mutants in floricultural and ornamental species. Similarly, fast growing disease resistant superior trees are being propagated by meristematic tissue culture to speed multiplication.

**CONCLUDING REMARKS**

I believe if proper emphasis is given to agriculture and if sound financial policies are established and implemented, that the line can be held on the food production front during the time of the next doubling of the world population. If this is to be achieved, it will require far fewer words and sensationalized reports and much more research action and production. Moreover, it must be remembered that producing more food and fiber and protecting the environment can, at best, be only a holding operation while the population monster is being tamed.

It could well be that the attitudes of scientists, political leaders, and the general public will be decisive in determining whether we reach or fail to reach the food production target needed to sustain our world civilization. If we fail in this endeavor, it will only prove the irrelevance and folly of whatever feats we accomplish in space and national and international defense.
CONCLUDING REMARKS

WORLD HUNGER: PROBLEMS AND OPPORTUNITIES

BRYANT W. ROSSITER

Someone asked a few moments ago my feelings, as Chairman, upon the successful completion of CHEMRAWN II. I have thought about this and I would say I feel like the young mother who just completed the arduous birth of her first child: had I known the task would be this difficult, I would not have undertaken it. Having seen the results, I am pleased that I did.

This is my second visit to the Philippines. On both occasions I have been impressed by the beauty, intelligence, and friendliness of the Filipino people. I asked a receptionist at the Philippine Plaza Hotel last Sunday why the people are so happy? She replied, “Life is sometimes difficult here, but we are happy because of our friends and strong, closeknit families.”

In the United States, we are concerned about the degradation of the family structure. Some people attribute this to the bad influence of television. There was a survey made among young children in which they were asked. “Which do you love more, your father or the television set?” Forty seven percent replied they loved the television set more. I was shocked by this finding and in the knowledge that I was an ideal father, I asked one of my young sons which he loved more, his father or the television set? This thoughtful young man looked at the ground, shuffled his feet, and then turned those big, beautiful, blue eyes toward me and asked “Do you mean the color TV or the old black-and-white down in the basement?”

So that we leave no doubt in the minds of our colleagues who have done so much to make this Conference successful, it is appropriate to acknowledge those responsible for the success of the Conference. We are grateful to expert speakers, poster presenters, and members of the Local Arrangements, Organizing, Program, and Future Actions Committees who have given so much of their time and talents. We are deeply appreciative of financial donors and exhibitors who have given

Director, Chemistry Division, Research Laboratories, Eastman Kodak Co., Rochester, New York, U.S.A.
generously at a time of worldwide economic stress. We are thankful for the many
forms of support we have received from our sponsoring and affiliate organizations.
All of these are listed in the formal literature of the Conference. I commend these
listings to your attention.

On behalf of all of you, I express appreciation to President Ferdinand E. Marcos
for his inspiring opening address and to Mr. James C. Ingram, Director of the
World Food Programme, for his instructive comments at the banquet on
Wednesday evening. We are grateful to the Philippine Government for the
luncheon on Monday and the reception-buffet Monday evening. Government
officials and workers have provided many kindnesses, hospitality, security, and
other services in support of this meeting.

We are delighted with the opportunity to have the Conference in the Philippine
International Convention Center which surely must be numbered among the
finest facilities of its type in the world. We are deeply indebted to the Barangay
Dance Troupe for the magnificent cultural presentation Monday evening. This
display of artistry, fun and friendship will long serve as a pleasant reminder of our
visit to this beautiful and friendly country. I also pay special tribute to the
members of the Local Arrangements Committee. Many individuals have worked
long hours over many months to ensure the success of the Conference. I wish there
were time to mention each by name and to thank them for their individual
contributions. Unfortunately, this is not possible.

It is appropriate to recognize the very special roles played by the International
Rice Research Institute, the Chemical Society of the Philippines, and the
American Chemical Society. Contributions by these organizations are substantial
and numerous. Without them, this Conference would not have been possible.

I am personally indebted to Dr. Marcos Vega, Dr. Joyce Torio, and
Mr. Gemelo Alvez and their staffs who have handled the Secretariats in Los
Baños, Washington, D.C., and here at the Convention Center in Manila. I express
appreciation to you, the audience. Many have come great distances, and at great
expense in terms of time and money, to contribute to the completion of the
objectives of this Conference.

Finally, I express sincere appreciation to Dr. Saburo Nagakura, Dr. Heini
Zollinger, and Dr. William G. Schneider. These distinguished scientists are
President, Past President, and President-Elect, respectively of the International
Union of Pure and Applied Chemistry. It has been their support and the
encouragement of the entire IUPAC organization that has allowed the
CHEMRAWN concept to grow and to develop into the significant international
activity that it is today.

Indeed, it was out of IUPAC that CHEMRAWN was born seven years ago in
Madrid, Spain. Delegates representing 43 nations gave unanimous support to the
program, which was intended to be worldwide in scope. This support, which
ultimately led to this Conference, was a recognition by chemical scientists
worldwide that their skills and expertise provide a unique opportunity to address
some of mankind’s most pressing problems . . . the alleviation of world hunger,
the acquisition of raw materials, the development of new energy sources, and the
elimination or mitigation of human disease. But more than that, CHEMRAWN’s
charter implies a responsibility by the scientific community to take active steps in meeting those problems. And so it was that CHEMRAWN was conceived out of a desire and determination to serve not only science, but all of humanity as well. For these same reasons, scientists and leaders from many disciplines have gathered here to come to grips with the awesome and complex problem faced by this Conference — world hunger.

CHEMRAWN’s vision springs from the optimistic view that those who are concerned with agriculture and with chemical resources and their transformation into the materials of life are in a unique position to make direct contributions to those very areas where mankind’s material needs are greatest. But CHEMRAWN also recognizes that science and technology alone cannot provide the answers. Global human problems, as Dr. Swaminathan reminded us, are multi-faceted and interdisciplinary, requiring that technical solutions be set in a holistic framework. Our perspective must also include socioeconomic, geopolitical, and environmental factors. It is this concern for the human system as a whole that I think makes the CHEMRAWN process unique. And it is in this context that the Conference activities proceeded.

Our primary objectives reflect this vision:
- First, to identify and prioritize research and development possibilities;
- Second, to strengthen the indigenous capacity of developing nations; and
- Third, to foster much needed cooperation among governments, industries, and academic institutions.

Will our mission be a success? Will we come close to meeting our goals?

Before these questions can be fully answered, the final recommendations of the Future Actions Committee must be formulated and disseminated widely to the world’s decision makers. And the results must be interpreted within the context of needs identified by individuals, countries, and institutions. Our hope from the outset has been to provide practical guidance and leadership which, in the words of one of our colleagues from Beijing, China, “works for us.”

Albert Einstein defined practical leadership in this way:

“The leader is one who, out of the clutter, brings simplicity . . . out of discord, harmony . . . and out of difficulty, opportunity.”

Those words might well serve as a charge to the Future Actions Committee as it completes the digest of the conference proceedings and formulates recommendations to assist institutions and governments in establishing research, policy, and funding priorities. And it can be a charge to all of us as we return to our respective nations to work on the goal we all share.

Speaking personally, I am greatly encouraged by what I’ve seen and heard during the past five days. Clearly, the time is ripe to develop on a broader, international scale, much stronger ties among the chemical, food, and agricultural scientists and to blend the leading edges of their skills and knowledge for the synergisms they will inevitably bring. The overriding message I’ve been getting is that there is great reason for hope and optimism. There is hope and optimism that, through technology available today and in the future, we can meet and subdue the world food crisis in spite of many uncertainties and a burgeoning world population. There is hope and optimism that research and development can be
strengthened very significantly in the developing countries. Great difficulty, as well as great opportunity, lies ahead in this particular area.

Today most of the problems of hunger and malnutrition reside in the developing world, yet nearly 95 percent of all research and development having the potential to solve these problems is done in the developed countries. Obviously, technology transfer in some form must occur. This does not imply, as some would suggest, however, that developing nations must be forever dependent upon imported technology. I would point out the experience of Thomas Jefferson, one of the United States’ founding fathers some 200 years ago. Jefferson was a man of great brilliance, supreme confidence and grand vision. Yet, when he considered the vast stretch of undeveloped land which now comprises the western U.S., he estimated it would take a thousand years or more to settle. Even this man of vision underestimated what free men under enlightened leadership can accomplish, given the opportunity to create for themselves.

Overcoming difficulty posed by limited R&D commitments, and thereby creating opportunity for future growth, requires that leaders from all countries select with skill and sureness — from the vast number of technological choices — those items that are most essential and appropriate for their economic and social well-being. We have hope and optimism that, through this Conference, directors of research and decision makers will be able to bring out of “technological clutter” a more simplified set of choices for research and development projects designed for highest impact and the greatest chance for success. And when this is done, we will have achieved our first Conference objective.

The key to the full development of this opportunity is our second objective: the strengthening of research, development, and an appropriate infrastructure within the developing countries. Here again, effective leadership is essential in order to provide fair and easy access to technology transfer under conditions that are equitable to all parties involved.

The third objective, that of accelerating the implementation of research priorities by fostering cooperation among governments, industries, and universities should be more than just the sharing of wealth and knowledge. It must be an exercise in human understanding designed, as Einstein stated, to “bring out of difficulty, opportunity.”

As a director of chemical research for a worldwide photographic company, I have experienced first-hand the realities of the competitive marketplace. Industries have an important role to play in the material supply and technology transfer process since they often possess the necessary technical, managerial, and capital resources required to bring practical, affordable, competitive products to the market. My experience also teaches that technological breakthroughs often result from trying new methods and approaches to scientific investigation. It is here that Sir Francis Bacon’s words ring true:

“It would be an unsound fancy and self-contradictory to expect that things which have never yet been done can be done except by methods which have never been tried.”

I agree with Dr. von Planta that the inclusion of the industrial point of view in a conference concerned with international development is appropriate and necessary.
for the solving of global food problems. As Sir Francis Bacon suggests, we need to explore new modes of communication and interaction. Happily, this process is already underway. In the past decade, important changes have taken place affecting the way industries and various countries do business. All parties are showing greater understanding, flexibility and pragmatism in their day-to-day dealings, and a greater appreciation for each other’s goals and needs. This trend should be accelerated and we should seek every opportunity to foster better communication and cooperation among governments, industries, and academia.

Finally, I wish to speak briefly of another element of the human system, not formally a part of this Conference. The story is told that young King Solomon was given the choice between wealth and wisdom. When he chose wisdom, God was so pleased that he gave Solomon not only wisdom but wealth as well. If we can cultivate the fields of human relationships and understanding in addition to the fields of agriculture and chemistry, we will find wealth in the form of more abundant food for all the world’s people and wisdom in the knowledge we have created a better life for mankind.

As we seek material advancement, we should see that the final purpose of science and technology is the universal and lasting establishment of peace. Indeed, as scientists, the advancement of this cause should be one of the major contributions of this Conference. Again, there is great difficulty, but great opportunity, in such an elusive goal. I marvel from time to time how technological success in pursuit of lofty human goals unifies mankind and brings forth a sense of pride that is universally admired and shared. The landing of the first man on the moon, the development of polio vaccines, and the eradication of smallpox are but a few examples of this.

Is it possible that the technology quest to eliminate hunger could also be one of our most effective tools for peace? If so, where will future leaders come from? Or as David Hopper asked on the opening day, “Where do we find the next Norman Borlaug?” You will agree that the world needs a few more! The answer to Dr. Hopper’s question is simple. Future leaders are to be found in the primary and secondary schools. Unfortunately, these leaders may never enter the food and agricultural sciences because they do not enjoy the prestige and glamor of the space, medical, and other fields. I believe we can and should enhance the image and rewards of those who work in the food and agricultural sciences. It is important that these fields not only be right but also popular. Perhaps part of this lack of popularity is our own fault through our failure to present more often, more clearly, and more forcefully, the great intrinsic worth and appeal of the scientific and technological work of those who feed the world.

There was a study made several years ago by a prominent publisher of English dictionaries to define the ten most beautiful words in the English language. These words were selected not so much for their melodious sound but for their ability to motivate the listeners to a greater sense of purpose, to elevate their lives, and to give them greater meaning and value. In this sense, the English words are not important because there are similar meanings and feelings in all languages around the world. That word which was selected as most beautiful was the word, “chime”. The quiet tinkling of a bell or chime which summons forth in the listener a sense of
peace, a sense of purpose, a sense of reverence, and a desire to do better, a willingness to serve God, and to serve one’s fellow men. The second most beautiful word was the word, “dawn”, as in the dawning of a new day. The dawn is that ever increasing light that takes one from darkness to brilliance; from dormancy into growth; from slumber into action; from despair into hope.

I believe these two words which have the power to inspire men and women to a greater cause, have as much meaning and significance for the fields of food and agriculture as for any other human endeavor. In the long history of mankind, what has struck in men greater reverence than the God-given soils, plants, and creatures from which we draw life? What endeavor is better able to take one from darkness into brilliance, from dormancy into growth, from slumber into action, from despair into hope, than to provide the basic nutritional needs of life, and from which flows all other possibilities? It seems to me, Mr. Chairman, that one of the major recommendations of the Future Actions Committee should be to set in motion those forces that will attract the better students to the noble work of those who feed a hungry world.

So our pursuit of peace through food must be global. Men and women everywhere seek the same comforts, desire the same opportunities, long for the same human dignity, and hope for a better world for their children and the generations to follow. In all respects, the things we hold dear and in common are greater than our differences. That should not be surprising. We are first of all brothers and sisters within the human family. Of course, the world does not require so much to be informed of this fact as it needs to be reminded of it. This membership in the human family implies world citizenship, a loyalty to the whole of mankind. Such loyalty need not conflict with traditional allegiances to family, to community, or to nation. It simply builds upon them and recognizes that traditional ties alone are not sufficient for the protection of interdependent peoples of the world.

Sixty-five wars since 1960 resulting in the death of over 10 million people in 49 countries, vast expenditures of human wealth and resources on military equipment, the everpresent threat of nuclear annihilation . . . all these suggest we ought to be concerned with the attitudes and the ideals of the family of man. If we pursue this wisdom, if we strive to sort through the clutter of opposing ideals, if we endeavor to rise above the discord and to see beyond the difficulties to the opportunities ahead, then not only can we feed a hungry world, we can help lead the way to a more peaceful unification of the entire human family.

Thank you, and I now declare this Conference adjourned.
## APPENDIX

### CHEMRAWN II COMMITTEE MEMBERS

<table>
<thead>
<tr>
<th>Role</th>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Chairman</td>
<td>Dr. Bryant W. Rossiter</td>
<td>Eastman Kodak Company, USA</td>
</tr>
<tr>
<td>Vice Chairman for Local Arrangements</td>
<td>Dr. Marcos R. Vega</td>
<td>International Rice Research Institute, Philippines</td>
</tr>
<tr>
<td>Vice Chairman for Finance</td>
<td>Dr. Richard L. Hall</td>
<td>McCormick and Company, Inc., USA</td>
</tr>
<tr>
<td>Secretary</td>
<td>Dr. Joyce C. Torio</td>
<td>International Food Policy Research Institute, USA</td>
</tr>
<tr>
<td>Developing Country Participation Chairman</td>
<td>Dr. Edward S. Ayensu</td>
<td>Smithsonian Institution, USA</td>
</tr>
<tr>
<td>Future Actions Committee Chairman</td>
<td>Dr. Cyril Ponnamperuma</td>
<td>University of Maryland, USA</td>
</tr>
<tr>
<td>International Union of Pure and Applied Chemistry (IUPAC)</td>
<td>Dr. S. Nagakura</td>
<td>IUPAC, President, Institute for Molecular Science, Japan</td>
</tr>
<tr>
<td></td>
<td>Dr. Heinrich Zollinger</td>
<td>IUPAC, Past President, Technische Hochschule Zurich, Switzerland</td>
</tr>
</tbody>
</table>
Poster Session Chairman
Dr. Ernesto del Rosario
University of the Philippines, Philippines

Program Committee
Chairmen
Dr. Norman E. Borlaug
Nobel Laureate, International Maize and Wheat Improvement Center, Mexico

Dr. Melvin Calvin
Nobel Laureate, University of California-Berkeley, USA

Mr. Peter A. Oram
International Food Policy Research Institute, USA

Scientific Editors
Dr. L. W. Shemilt
McMaster University, Canada

Dr. Gordon Bixler
American Chemical Society, USA

Publications Committee
Chairman
Dr. William G. Schneider
IUPAC, Vice President, Canada

Publicity Committee
Chairwoman
Ms. Carol L. Rogers
American Association for the Advancement of Science, USA

Treasurer
Mr. Francisco J. Marin-Price
American Chemical Society, USA

ORGANIZING COMMITTEE

Dr. Bryant W. Rossiter
Eastman Kodak Company, USA, Chairman

Dr. Adnan Al-Ageel
Kuwait Foundation for the Advancement of Sciences, Kuwait

Dr. Eduardo Alvarez-Luma
International Council for the Development of Underutilized Plants, Mexico

Dr. William O. Baker
Bell Laboratories, USA

Sir John G. Crawford
The Australian National University, Australia
Mr. Charles S. Dennison  
Council on Science and Technology for Development, USA  

Dr. Jacques Diouf  
Secretary of State for Scientific and Technical Research, Senegal  

Dr. Nicholi Emmanuel  
Academy of Sciences, USSR  

The Honorable He Kang  
Ministry of Agriculture, China  

Dr. Kenzo Hemmi  
University of Tokyo, Japan  

Dr. W. David Hopper  
The World Bank, USA  

Mr. Joseph H. Hulse  
International Development Research Centre, Canada  

Dr. Franklin A. Long  
Cornell University, USA  

Dr. Jamal T. Manassah  
City College of New York, USA  

Dr. William G. Padolina  
University of the Philippines at Los Baños, Philippines  

Dr. Bukar Shaib  
Special Advisor to the President, Nigeria  

Dr. M. S. Swaminathan  
The International Rice Research Institute, Philippines  

Dr. Werner Treitz  
Federal Ministry for Economic Cooperation, FRG  

Dr. Moriya Uchida  
TEIJIN Ltd., Japan  

PROGRAM COMMITTEE  

Dr. Norman E. Borlaug  
Nobel Laureate, International Maize and Wheat Improvement Center, Mexico,  
Chairman  

Dr. Melvin Calvin  
Nobel Laureate, University of California, Berkeley, USA, Chairman
Mr. Peter Oram
International Food Policy Research Institute, Washington, USA, Chairman

Dr. B. A. Abeywickrama
University of Ceylon, Sri Lanka

Dr. W. K. Agblé
Crops Research Institute, Ghana

Dr. C. C. Balch
University of Reading, England

Dr. Ricardo Bressani
Instituto de Nutricion de Centro Americana y Panama, Guatemala

Dr. George W. Cooke
Rothamsted Experimental Station, Harpenden, Herts., England

Dr. Masao Fujimaki
Ochanomizu University, Japan

Dr. Kurt F. Gander
Unilever Forschungsgesell-schaft MbH, FRG

Dr. Hans Geissbuhler
Ciba-Geigy Corporation, Switzerland

Dr. Ralph W. F. Hardy
E. I. du Pont de Nemours & Company, USA

Dr. Rogelio O. Juliano
University of the Philippines, Philippines

Dr. Mohammed El-Khash
The Center for the Studies of Arid Zones and Dry Lands, Syria

Dr. Mohammed Nour
International Center for Agricultural Research in Dry Areas, Lebanon

Dr. Thomas R. Odhiambo
The International Center of Insect Physiology and Ecology, Nairobi, Kenya

Sir Charles Pereira
Peartrees, Teston, Maidstone, Kent, England

Dr. David Pimentel
Cornell University, USA

Dr. R. Scott Russell
The Grange, East Hanney, Wantage, Oxon, England
Dr. Bernard S. Schweigert  
University of California-Davis, USA

Dr. Gerald G. Still  
U.S. Department of Agriculture, USA

Mr. R. V. K. M. Suryarau  
Coromandel Fertilizers Limited, India

Dr. Lee Kum Tatt  
Singapore Institute of Standards and Industrial Research, Singapore