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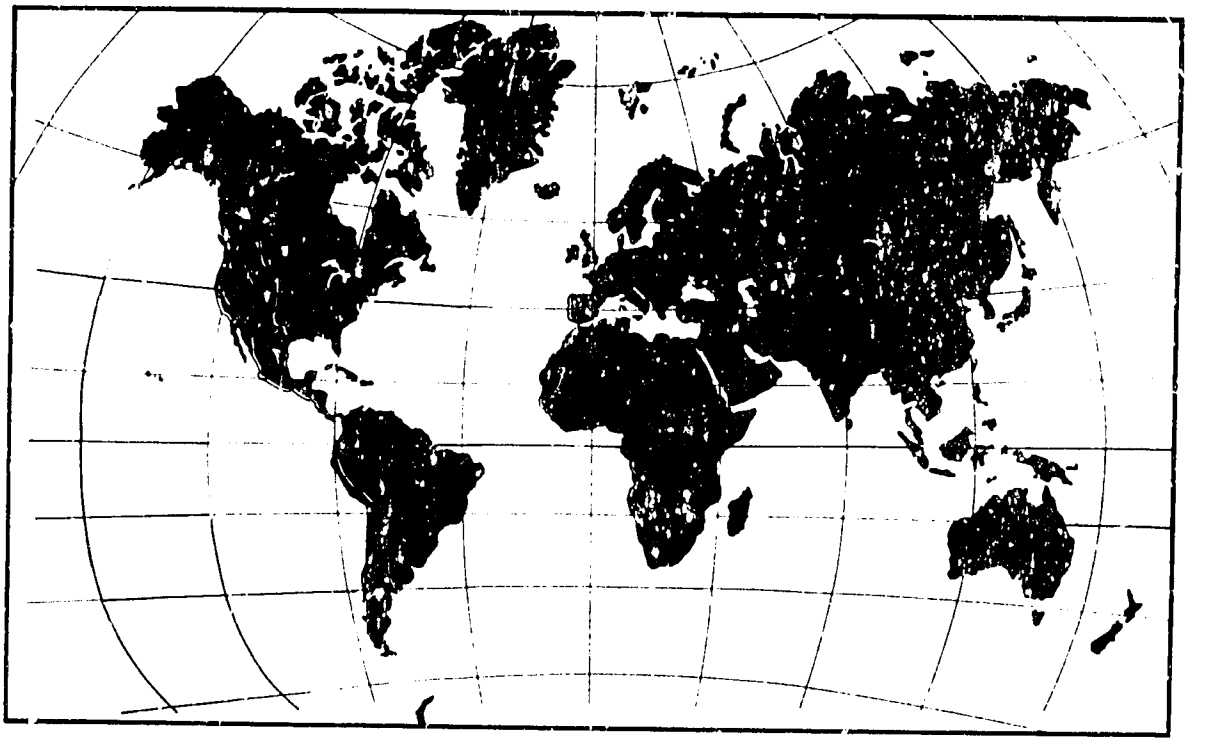
International Conference on Dryland Farming

Amarillo/Bushland, Texas U.S.A.
August 15-19, 1988



Executive Summary

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Preface

An International Conference on Dryland Farming was held in Amarillo/Bushland, Texas, U.S.A., August 15-19, 1988. There were 460 registered participants from 52 countries and 36 states of the United States. The Conference was organized to help commemorate 50 years of service to the agricultural community by the U.S.D.A., Agricultural Research Service, and the Texas Agricultural Experiment Station at their research facilities at Bushland, Texas. The purpose of the Conference was to evaluate past progress in dryland farming, identify constraints, propose methods and technologies needed to alleviate those constraints, propose policies and programs for more effective technology transfer, and identify research needs and priorities for dryland farming.

During recent years, the focus on increasing food production throughout much of the world has been on irrigated agriculture. Since 1950, the amount of irrigated land has increased from about 94 million hectares to about 220 million hectares. During the 80's, however, the rate of irrigation development has dropped materially and is presently less than 1 percent per year. World population is increasing at the rate of about 1.7 percent annually and exceeds 3 percent in many parts of Africa. Irrigated land accounts for approximately 18 percent of the cultivated land, but produces 33 percent of the food. The cost of irrigation and drainage development of new systems averages over $5,000 per hectare and can be as high as $10,000. While irrigated agriculture will continue to expand and produce a significant portion of the world food supply, it appears certain that much of the additional food production needed in future years must come from the 80 percent of the cultivated land which is not irrigated.

During the past 50 years, much has been learned about dryland farming. The principles learned and the technology developed need to be used to decrease risks and increase overall productivity everywhere that dryland farming is practiced. Large areas of the land that must be farmed to meet the current and future food needs of the world occur in high risk areas that have limited and erratic rainfall. These lands are also highly subject to wind and water erosion. Therefore, it is essential that the technology that has been developed and will be developed in the future be spread and used as quickly and as widely as possible.

It was with this background that the Conference was developed. Also, the location of Amarillo/Bushland, Texas, seemed particularly appropriate because it is located in the southern Great Plains of the United States where 50 years ago the area was in the midst of a severe drought, resulting in the most severe erosion ever witnessed on the continent. The area became known as the "Dustbowl," and many forecasters thought the area had no future. However, new policies and technologies were developed for both dryland and irrigated systems and the area developed into a highly important and productive area. Therefore, the location seemed to provide a natural setting where scientists, conservationists, farmers, and others could meet to share experiences and ideas about dryland agriculture.

To allow Conference participants to get a broad view of the agricultural systems in the region, Pre- and Post-Conference Tours were developed. Seventy-four participants from 31 countries took part in the Pre-Conference Tour where they visited farmers' fields and experiment stations at Temple, San Angelo, Big Spring, and Lubbock, Texas. The Post-Conference Tour featured three of the original U.S.D.A. dryland field stations established in 1914 (Woodward, Oklahoma; Garden City, Kansas; and Akron, Colorado) as well as stops in Tribune, Kansas, and Greeley, Colorado. Seventy-five individuals from 29 countries participated in the Post-Conference Tour.

A Conference Proceedings will be forthcoming which will contain the 259 papers presented. This Executive Summary contains a list of recommendations for actions, a brief summary of the technical sessions, an overview of what was learned during the Conference, and a list of participants.

Recommendations of the Conference

The final half-day session of the Conference was devoted to summarizing what had been presented and identifying priorities for further action. Based on those discussions, as well as the written reports by the rapporteurs, the following list of recommendations was formulated.

1. Dryland agriculture must play an increasingly important role in future production of food and fiber. It is well documented that the drylands have received a disproportionately low share of resources devoted to increasing agricultural production. It will be necessary for both governments and researchers to devote more attention and resources to dryland farming problems than has been done historically.

2. An international commission, or committee, on dryland farming should be formed. The World Bank, in its role as Secretariat for the Consultative Group on International Agricultural Research (CGIAR), should take the lead in establishing a task force, or committee, to form such a commission. The purpose of the commission would be to promote a continuing international dialogue on dryland farming and to develop mechanisms for establishing networks among institutions for coordinating research and technology transfer activities.

3. The resource base must be protected. Consequently, it is essential that land resource management policies be strengthened, particularly as they relate to lands frequently taken in and out of crop production systems. Policies of international organizations and governments need modification to encourage research and better management of dryland resources so that the resource base will be sustained and present and future food and fiber needs can be met.

4. Resource inventories required to develop data bases for good planning include soil characteristics, topography, climate, biota and socioeconomic factors. These data are essential to achieve appropriate land use and management. More effort should be devoted to development of resource inventories in dryland areas. Special and urgent attention should be given to climate and soil data bases.

5. Cropping systems for dryland farming must be developed and used. Site-specific research is needed, but results must be used in concert with biologically- and physically-based models and sound data bases to permit extrapolation of results to other locations.

6. More effort by scientists in developed and developing countries should be directed to forming management systems that permit sustained use of fragile lands. Attention of scientific teams must be focused on fragile lands that are being farmed and new lands being brought under cultivation for the first time.

7. Infrastructure and socioeconomic conditions required for the development and sustainability of dryland areas must be identified and developed.

8. Attention should be given to the development and implementation of policies for reducing human and livestock population pressures on deteriorating lands so that desertification can be prevented.

Summary of Rapporteurs' Reports

Marvin E. Jensen

The purpose of the closing session was to evaluate the Conference findings and assess what they mean. We asked a rapporteur for each session to provide feedback to the Conference organizers relating to the Conference objectives of: 1) Evaluating past progress; 2) Identifying constraints; 3) Identifying methods and technologies for alleviating constraints; 4) Identifying policies and programs for more effective technology transfer; and 5) Identifying research needs and priorities. Additional information requested included 1) Points of agreement; 2) Points of disagreement; 3) Issues not covered; and 4) New, promising problem-solving approaches.

This summary presents highlights of keynote and plenary presentations and a summary of the information provided by rapporteurs. Many rapporteurs reported similar items, but with different points of view. Because of the voluminous material collected, only selected items are included in this summary. Additional details can be found in the rapporteur reports contained in the Conference Proceedings.

Keynote Highlights

Dr. Neville Clarke, Texas Agricultural Experiment Station, opened the Conference stating that dryland farming is extensive rather than intensive agriculture. Effective technologies are needed to sustain dryland agriculture. The primary socioeconomic concern is that dryland agriculture is a high-risk enterprise. A systems approach and risk management are key issues.

Dr. Nyle Brady, USAID, indicated that dryland agriculture will be growing in importance. Need for innovative dryland technologies is especially important in parts of Africa where population growth rates are about 3 percent per year. Current USAID concerns involve; 1) conservation of natural resources (water, soil and, plants); 2) socioeconomic issues such as government planning programs, womens' roles, credit, land tenure, and micro-enterprises; and 3) communications within the dryland community or developing a dryland technology network.

Dr. Edward Schuh, University of Minnesota and formerly of The World Bank, indicated that investments in agricultural research are among the highest payoffs. In view of this fact, he questioned why governments discriminate against agriculture and rural education and training and why rural infrastructure is neglected. Complex socioeconomic aspects of dryland farming were reviewed in detail, especially international trade issues. He stressed that a global food and agricultural system is emerging and that national economic systems are susceptible to international economic forces and trade.

Dr. Malcolm Hall, FAO, discussed similar issues and highlighted approaches and problems affecting technology transfer. He emphasized the differences between local and institutional knowledge. Local knowledge changes more slowly than institutional knowledge. Risk factors are of great local concern but are often overlooked by institutional programs. Intervention frequently fails because of insufficient knowledge and erroneous perceptions. Systems approaches to agricultural development with adequate training at the level of the populace are needed, especially in dealing with household and community problems.

Dr. Gerald Thomas, New Mexico State University, emphasized the need to consider environmental issues relative to sustainability of dryland agriculture. Verbal commitments have been made by The World Bank, USAID, and others but the impact of this new emphasis on programs is yet to be determined. Adding the environmental dimension will require more time to carry out programs. We must improve measures of progress, and we must apply economic values to our resource base. He stressed that every development project should have a conservation objective. If agriculturalists do not consider environmental issues, environmentalists will write the agenda.

Dr. M. Yudelman, World Resources Institute, indicated that investment in dryland agriculture is becoming more attractive relative to irrigation. Investments in dryland farming during the 1970s were relatively small and had little impact on raising agricultural productivity and returns on these investments were low relative to investments in irrigation. Only two of the international research centers, ICRISAT and ICARDA, are developing technologies that target large numbers of dryland farmers. Dr. Yudelman asked "Why have we neglected dryland agricultural resources?" Typically, small dryland farmers represent a major poverty problem that cannot be ignored, but solving this problem will be a long-term and difficult process.

Past Progress

Lessons have been learned, but we sometimes have difficulty relating current problems to these lessons. The same mistakes are frequently repeated without learning and adding to the knowledge base. Expanding food requirements caused by increasing populations are forcing tradeoffs between current production and sustainability of dryland agricultural systems. The long-term negative effects of some of these tradeoffs may be irreversible.

Both irrigated and dryland farming are production systems, but they operate on opposite ends of the production continuum. However, the knowledge base from which information can be drawn involves both irrigated and dryland farming systems. We have made a lot of progress in quantifying dryland farming environments, but we need less empirical methods for transferring the relationships to other locations.

Many examples of research progress were presented. These included water conservation and fallow technology; conservation tillage including no-till and residue management; cropping systems including cultural practices, plant geometry, and flexible cropping sequence; control of wind and water erosion; windbreaks; erosion models; pest management; fertilizer practices including principles of nutrient availability and mobility; crop cultivar development for drought tolerance and improved root systems; and risk management. Extensive research has produced information necessary for developing yield-water relationships and simulation models for dryland farming systems.

An important factor in dryland farming systems in developed versus developing countries involves the alternative and competing uses of crop residues. In the USA and other countries with similar conditions, crop residues are used as mulches to increase the retention of precipitation and to control wind and water erosion. In developing countries, however, there are alternative and competing uses for residues such as animal feed, fuel, fiber, and use as raw material for manufacturing. Use of dryland crop residues for livestock feed may have negative impacts on soil productivity, but dryland crop residue production is generally less variable than grain yields.

Many authors described integrated livestock-crops, agroforestry, and intercropping systems involving tree and food crops which may provide more stable production in fragile environments. Others related the importance of technologies such as improved micrometeorological and recording instrumentation and data management systems. Much progress also has been made in human resource development, but some participants indicated resource-environmental issues have been under-emphasized. Land use values have been increased in some areas by intercropping compared with monocropping.

Interdisciplinary approaches and teams were frequently mentioned as a requirement for solving multidisciplinary problems. Many examples of successful technology transfer techniques were summarized.

Constraints

The rapid rate of population growth in many countries has resulted in conflict between maintaining a sustainable production system and meeting increasing food requirements. Loss of topsoil is for all practical purposes an irreversible process and can quickly lead to desertification. Sustainable dryland agriculture requires conservation of the natural resource base.

Insufficient and highly variable rainfall are major constraints in dryland farming. Water supply for crop use is often the most limiting production variable. Dryland farming areas typically are high wind areas, which results in susceptibility to wind erosion and crop damage. Low residue production limits potential control of both wind and water erosion and evaporation suppression, and particularly so when there are competing uses for residues.

Dr. John Monteith, ICRISAT, stated that truth proceeds faster from error than from confusion. We potentially can learn more from mistakes than from successes. The learning curve is slow in agricultural systems. It is especially slow for dryland farming systems because many years may be required to establish needed relationships and basic data under local conditions. Even more important, the returns often do not provide sufficient incentives for farmers to adopt new, risky technologies.

Lack of biologically- and physically-based relationships between available water and crop yields, soils and economic data, reliable rainfall data, solar radiation and temperature data from common sources were frequently cited as major constraints in developing or adapting new technology. Limited alternative crops and compatible crops for dryland systems also limit the adoption of more productive cropping systems. Lack of market alternatives for crops produced in dryland areas further limits the selections.

Soil constraints include degradation, low organic matter, poor structure, low fertility, lack of profile information and taxonomy, and, in some areas, soil acidity problems. Removal of surface vegetative cover through excessive tillage and over-grazing decreases infiltration rates, increases runoff, and reduces resistance to erosion. Energy and equipment available to small farmers in developing countries severely limit land shaping and surface modifications by tillage that can enhance rainfall retention. Several authors indicated they were not able to provide optimal fertilizer recommendations based on weather probabilities because of inadequate models and data. Inadequate equipment available to small farmers also limits optimal placement of fertilizers.

Government policies have resulted in inadequate long-term investments in dryland production systems including trained professional staffs for research and extension. Many existing programs are based on short-term time frames driven by economics. Typically, in research and technology development, farmers are not involved in planning approaches and programs. As a result, they are not always receptive to proposed new practices, or new practices are not compatible with current practices. Economic constraints include limited analyses of dryland systems, limited diversity and flexibility, low inputs and low profits, high interest rates, and lack of production incentives. Analysis of social impacts of investments and development is also often lacking.

Limited adoption of new technologies, for whatever reasons, hinders development of more productive dryland systems in developing countries. Effective strategies are lacking. Extension programs are generally understaffed and frequently the staff is not adequately trained to facilitate technology transfer.

Methods to Alleviate Constraints

Greater investments are needed in developing dryland cropping systems that result in more efficient use of rainfall, plant, and soil resources and reduce subsistence farmers' risks. Programs and policies are needed to develop an adequate agricultural support infrastructure for dryland areas.

In developed countries like the USA, the current public and farmer perception is that development of agriculture in developing countries increases competition for farm products in the world markets. This perception limits

support for international agricultural development programs. However, studies have shown that development of agriculture in developing countries increases their buying power and demands for more specialized agricultural products. More assessments and dissemination of these interrelations are needed.

Effective government programs frequently are not funded and implemented because agricultural entities cannot agree on priorities. Government programs can influence both public and private investments long-term funding, production incentives, fertilizer policies, and research funding. Adequate infrastructure for agricultural support and production incentives can enable many subsistence dryland farmers to become production oriented. Many participants felt that international organizations like The World Bank should play a greater role in shaping government programs and policies for dryland areas.

Better basic understanding of the crop-soil-environment system is needed. Research results should describe basic relationships to enable more direct transfer of information to other regions. Dr. Monteith proposed an improved technique for characterizing water-limiting environments which involves normalizing rainfall using the vapor saturation deficit and linking this parameter with interception of solar radiation. Characterizing climates in this less empirical manner would enable transferring relationships to other areas. Guidelines for measuring and reporting basic environmental data are needed to enable extrapolating experimental results to areas where limited studies have been conducted.

A critical mass of scientists is often lacking at research locations in developing countries which limits effective technology transfer and development of new knowledge. The interdisciplinary interaction of scientists, technicians, and farmers can result in the whole being greater than the sum of the parts relative to development and transfer of dryland technology. Getting scientists of different disciplines to work together can be difficult, but experience has shown that greater use of interdisciplinary teams in research enhances the development of improved technology. Greater efforts are needed to establish teams involving economists, environmentalists, sociologists, and various physical and biological scientists. Administrators should be encouraged to give rewards to teams effective in research and extension.

Use of crop residues for erosion control and maintaining soil productivity is basic to dryland farming systems in the USA. Additional economic assessments of the long-term value of residues are needed where crop residues may generate greater short-term values when used as animal feed by subsistence farmers. Investments in alternative sources of fuel for heating and cooking may be required to enable developing countries to adapt conservation techniques that are based on crop residues.

Control of wind and water erosion and resulting crop damage can be accomplished by such methods as: adoption of no-till practices; use of grass buffer strips and other wind breaks; effective residue management; rough tillage and tied furrows; a total systems approach; and water harvesting. Where renewable water resources exist, supplemental irrigation can be particularly effective in cropping-livestock systems because feed produced on irrigated land can maintain the livestock base in droughts.

Better plants also are needed with more effective root systems for dryland farming. Improved criteria and parameters are required to enable plant breeders to improve and develop alternative cultivars.

Improved management practices and management models are needed. These models should enable improved predictions of plant nutrient requirements and soil fertility management, manure use, and soil organic matter dynamics.

Effective Technology Transfer Programs and Policies

Networks which can facilitate developing and adapting dryland farming technologies can be achieved by linking national and international organizations devoted to these problems. The exchange of scientists, exchange of scientific and technical information, and appropriate training are needed to adapt or transfer new technology. Expert systems for dryland management coupled with computer assisted video training systems could enhance technician training and technology transfer. Farmers also require training. Arrangements are seldom made that enable innovative farmers to see first hand how improved technology is being used. Use of video tapes can greatly enhance transfer of technology to farmers.

Increased emphasis is required on sustainability in all agricultural research and development activities. Conference participants generally agreed that comprehensive management models would improve predictions of crop and animal performance and social impacts. However, model predictions must be validated by site specific data bases. Systems for disseminating real-time predictions of climate effects on crop growth for farmer use in decision-making are essential.

The mandate of single commodity research centers may limit their ability to address flexible cropping system problems. Single commodity programs are needed, but investments in single commodity programs should be balanced with investments in integrated production systems. Additional emphasis on training in basic science and in planning, evaluating, and conducting research is required to increase the return on research investments. National and international agricultural development centers can facilitate this training as well as develop needed climate and soils data bases and conduct field evaluations.

Governmental policies and programs should be linked to integrated production system technologies rather than to single dryland and resource conservation practices. Rainfed and irrigated agricultural production programs must be planned and implemented as an integrated, complimentary system. Associated government policies that can directly affect dryland agriculture include energy, low-cost loans, equipment loans, power, prices, marketing, land reform commitments, wind breaks, and subsidies.

Research Needs and Priorities

The purpose of dryland farming research in developing countries should be to close knowledge gaps and to adapt known technologies to local conditions, or adaptive research. Knowledge and data gaps include: 1) economics of alternative uses of crop residues for erosion control and water conservation, livestock feed, domestic fuel, and miscellaneous uses; 2) plant nutrient requirements and soil water extraction, plant water stress, and disease relationships under intercropping systems; 3) environmental impacts and society benefits of agricultural policies; 4) weed control technology in conservation production systems; 5) real-time and historical meteorological data bases with real-time management models; 6) guidelines for predicting the suitability of no-till production systems on various soils; 7) better understanding of biological activity in soils including nutrient-organic matter interactions, buffering capacities, and chelation complexes in tropical regions; 8) stability of integrated forage-livestock farming systems; and 9) guidelines for cropping systems involving integrated practices, system evaluations, intercropping, and agroforestry. Other identified research needs were better measurement technology, management systems, modeling physical and biological systems and model validation, land use policies, and risk analysis. Participants generally expressed the need for research on all of the constraints previously mentioned.

Points of Agreement

There was general agreement that there will be increasing dependence on dryland agriculture for meeting future food and fiber demands. Also, there was agreement that there will be more emphasis on overcoming the effects of drought while maintaining the sustainability of the production system.

Points of Disagreement

There was some disagreement about the suitability of soils on which no-till systems could be used. Everyone did not agree that there was inadequate data concisely describing the climate in experiments. Also, not everyone agreed on the role of fallow in dryland farming systems.

Differences were recognized among participants about the value of data from models and modeling efforts because of site-specific characteristics. Differences were also acknowledged about the merits of intercropping versus monocropping systems.

Issues Not Covered

Many important issues were not covered and they are too numerous to include in this brief summary. Several issues not adequately covered, although mentioned by some participants, include: alley-tree cropping systems; training needs; plant response to grazing; storage; and environmental and socioeconomic issues.

Promising New Problem-Solving Approaches

Most of the promising, new, problem-solving approaches have already been mentioned. Additional areas include processing and storage technology for dryland crops and better descriptions of agro-climatic zones to enable more rapid transfer of applicable technology.

There were perhaps two issues that permeated the Conference. First, the value of crop residues remaining on the soil surface for controlling wind and water erosion and evaporation suppression was clearly recognized. Second, simulation modeling in concert with a limited number of site-specific experiments for validating the models offers tremendous potential for improving the transfer of technology in dryland areas.

Summary and Conclusions

This Conference clearly demonstrated that a wealth of dryland farming knowledge exists, and that new knowledge and technologies are being developed and technologies are being transferred. The key question remaining before us is "Where do we go from here?" We do not need more bureaucracy, but we need more effective mechanisms to sustain the on-going efforts to enhance and promote the exchange of dryland production information and technology. These mechanisms should be globally oriented. Several possible alternatives are:

(1) Establishing an international non-governmental and non-political commission on dryland farming systems. Conferences like this, perhaps with a narrower focus, could be organized and held in different parts of the arid and semiarid world on a three- to five-year interval. Working groups and committees would meet annually.

(2) Establishing an effective mechanism for coordinating international dryland research and technology transfer linkages within an existing agricultural organization such as FAO or The World Bank if it does not already exist.

(3) Establishing formal linkages between existing international dryland research organizations like ICARDA and ICRISAT and research laboratories in developed countries for: real-time exchange of information; exchange of scientists; and establishing interdisciplinary working groups to address specific problems. International commodity research centers would be linked as needed, depending on cropping systems.

During the concluding open discussion, the Conference participants supported the continuation of effort that led to the development of this Conference.

The numerous expressions of concern about the need for new government policies and long-term support for dryland farming programs and research also reflects a deficiency in the agricultural community. Many recommendations made involve macroeconomics, but few participants admitted that they were negligent in interacting with macroeconomic decision makers. As agricultural researchers, we are addressing our concerns to co-workers rather than taking a more active role in macroeconomics that affect national policies.

What Have We Learned?

Peter Goldsworthy

We were privileged to participate in the celebration of the USDA Agricultural Research Service and the Texas Agricultural Experiment Station recognizing 50 years of research effort at Bushland, Texas, U.S.A. At the same time, we have participated in a truly International Conference.

There have been significant additions to our knowledge in all topics discussed at the Conference; the number and quality of the presentations are a measure of the large body of knowledge that is available. It is clear that there already is a great deal of interdisciplinary effort, but the diversity of the fields of study suggests that there are likely to be many productive opportunities for cooperation not yet explored. We need to ensure that efforts to extend this knowledge take full advantage of the complementary contributions that different disciplines can make. The key issue is "How do the many different fields of research fit together and what are the practical ways of applying the knowledge or technology to particular situations?" This issue was addressed right at the beginning of the Conference.

In the limited space available, I cannot attempt to identify all that was reported in the individual sessions, but rather try to capture the main thrusts of the Conference and the reader will need to see the Conference Proceedings for the detail and complete coverage. Also, the agricultural environments discussed during the Conference varied considerably, as well as the crops, cultural practices, and socio-economic conditions. The important thing to stress is that although the specific conditions vary greatly, the scientific basis for managing the environment apply everywhere.

The Task

Dryland farming occurs in environments where production depends largely or entirely on the water supply from current rainfall, plus water stored in the soil profile. The lack of water is a major limitation for crop production in dryland areas, so capture of rainfall and conservation of water are principal concerns.

Much of the world's agricultural activity is carried out in such environments. Where dryland farming is practiced, particularly in developing countries, it is common to find rural populations that are ecologically and economically disadvantaged. Drought is common in these environments and crop yields are highly variable, largely because weather conditions, especially the amount and distribution of rainfall, vary from year to year.

Whether our primary interest is agroclimatology, soils, cropping systems, or any of the other topics discussed at this Conference, our ultimate aim is to make life better for people who live in these environments. One way to help do this is to find ways to improve their agricultural production systems. New systems must be well adapted to the long term climate of the target region, and they must also be sufficiently robust and flexible to produce acceptable results in different individual years.

Drought

Studies of the consequences of the shortage of water within plants have received a great deal of attention over the past 20 years, and important papers relating to these topics were presented at this Conference. I intend to focus mainly on the ecological situations which lead to shortage of water in dryland agriculture, rather than on particular attributes of drought resistance in crop plants.

For at least part of their life, plants must obtain sufficient water to meet enough of the evaporative demand to permit growth and development. The amount of water required depends on two sets of factors:

—first, the length of period for which the water requirement must be more or less satisfied, which is determined by the life-cycle of the crop. The length of the life cycle will depend on the genetics, morphology, and management of the crop plants.

—second, the time course of the evaporative demand during the life-cycle of the crop. Both components of total water requirement are strongly affected by temperature.

To design options (cultivars and ways to manage them) that are adapted to the main features of environments for which they are intended, and at the same time flexible enough to perform well in individual years, one must bear in mind how variations in the frequency and duration of dry periods affect the probability of a successful outcome in any one year, and over time (measures of risk).

Systems of Production

Dr. Nyle Brady, USAID, and Dr. Malcolm Hall, FAO, both reminded us during the opening session that part of the solution in designing new options in dryland regions lies in a knowledge of current practice and understanding the rationale of existing systems of production. During my tenure with the International Center for Agricultural Research in Dryland Areas (ICARDA), Allepo, Syria, we had to remember that in the drier parts of the Mediterranean region, the end product of the farming system is sheep and that other practices are done in support of the dominant livestock enterprise. Animals are mobile and can be moved to where grazing is available; they act as a combined bank account and reserve against hard times in a harsh environment; they provide income from the sale of milk, meat, and wool; and they make economic use of crop residues. Crops have to fit as secondary enterprises into a system of resource use in which animals come first.

Storage

Little was said at this Conference about storage and storage losses. Even with well adapted production systems, season to season variations in weather will give rise to years of good and of poor crop yields, and communities will continue to use a variety of means to minimize the risks and to ease the hardships in bad years. One of the most important provisions against the risk of drought is to store food. Therefore, an important part of the task of offsetting the effects of drought is to ensure that grain storage facilities are available and that storage losses are minimized.

Social, Economic, and Policy Issues

Dr. Nyle Brady, USAID, and Dr. Edward Schuh, University of Minnesota and formerly with The World Bank, pointed out that poverty is the principal cause of hunger in the poorest sector of the community and that by restricting the effective market for food, it also limits production. In poor countries or isolated regions, production occurs in self-contained subsistence systems. The household is then producer and consumer, with little or no cash and little incentive to produce more than it needs for its own use.

While most governments continually underinvest in agricultural research, education and training, and rural infrastructure needed for a healthy agriculture, Dr. M. Yudelman, World Resources Institute, spoke of the low returns to date on investment in dryland areas. So, what are the prospects for greater investment in dry areas?

New technology may eventually increase production and decrease unit costs of the products in marginal areas with subsistence agricultural systems, so that they give a better return and can compete in the market. There are excellent examples in North America, Australia, and in some of the developing countries as well, that food production can be increased significantly in dryland areas. However, producers in more favored rainfed environments are likely to continue to do better. Therefore, the tendency may remain on focusing investment where production can be improved more quickly, and to encourage people to move off drier marginal land to areas where there are opportunities to seek non-agricultural employment in towns and cities. In the meantime, there is a great need to do what is possible to lessen the poverty of very large numbers of rural people who will continue to live in these harsh environments. Also, as population increases, people are pushed more and more to the marginal lands so it will become necessary to utilize the dryland areas more effectively to meet the food and fiber needs of the people. Consequently, policy makers and governments need to recognize that much progress has been made in dryland farming systems and that dryland areas offer valuable resources worthy of development. Proper development will require a far greater proportion of resources than most governments have traditionally given to these less favored areas.

We were reminded that if farmers are to be persuaded to produce more, they must be given access to markets where they can sell surplus produce for cash and buy things they want, including fertilizer, seed, chemicals, and other inputs that may be needed before they can adopt new technology.

Transfer of Technology

The technical exchanges during the Conference showed that dryland farming is extremely diverse and individual countries within dryland regions differ from one another in environment, social organization, and economy. Consequently, though the scientific bases for managing the environment may be the same everywhere, important differences restrict transfer of technological practices from one environment to another. Technologies needed will often be locale specific so there are unlikely to be any universal technical prescriptions. The central problem is "How can the knowledge acquired in one situation be applied to another?"

Perhaps the best known examples of successful transfer of agricultural technology have been associated with the international plant breeding programs in wheat and rice. Their achievements were mainly the result of a plant breeding effort and agronomy played only a secondary role. The work focused on environments with an assured supply of water, where the initial impact on food production would be greatest. The procedures were based on multi-location trials and depended largely on the transfer of results from one location to another by analogy. As long as water was not a main limiting factor or source of variation, this procedure worked well. Most international crop improvement programs have continued to use the same procedure, but in more difficult, variable, dryland environments, it has been less successful. This is what we should have expected and it is important now to recognize that we need quite different approaches. One of the immediate challenges is to better evaluate and utilize more fully the large collections of germplasm material that have become available in recent years for a number of important food crops. For dryland areas, the need is to develop cultivars that will effectively exploit the advantages of specific adaptation to particular situations. Also, agronomy, which played a secondary role in the past, is much more important in the dryland areas because the genetic potential of crops cannot be realized unless agronomic practices are developed to conserve soil and water resources.

From the largely empirical approaches of the past, the science of agronomy is now much more analytical and predictive. The presentations by Dr. Calvin Rose, Brisbane University, Queensland, Australia, and Dr. John Monteith, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) demonstrated this admirably. They both developed theoretical arguments that help to reveal the processes involved, in soil erosion on the one hand, and in the relationships between plant and climate on the other.

Numerous other examples were presented at the Conference of new approaches to the study of soils and crops. Many, based on systems analysis and simulation methods, offer the means to couple environmental data more closely with what we know about the physical and biolog-

ical processes in the agricultural system. Models which simulate the major processes of energy, water, and carbon balance as well as crop growth, development, and yield are now available and others are being developed. Because the same key processes govern the function of most crop models, the models have tended to converge in form and function as they have evolved.

Though models may serve different purposes, the minimum data sets required are similar. Individual nations must provide the resources for the national soil survey and meteorological services which provide the required data. Special support will be needed if they are to continue their work of collecting data. One way to do this is to be sure governments are kept informed of the use that is to be made of the data, and of results that come from their use.

Crop models have an added value as self teaching tools. In their construction, they reveal to the investigators areas where assumptions have been made because of a lack of quantitative information about the process being modelled. It is akin to what Dr. Monteith said; The models may be imperfect, but they assist in clearing confusion, and to this extent they can help to guide research.

Compared with the introduction of a new variety or a management practice which involves but one component of the production system, the task of formulating options for whole or parts of production systems in regions with uncertain and unpredictable environments, is significantly more complex.

Models may be of assistance here, too; they can indicate how management systems might develop to make better use of the environment and resources. They can at the same time help breeders define the characteristics of the cultivars required to meet the producers' needs. An important aspect of simulation models is their ability, when employed with long term weather data (particularly rainfall), to provide probabilities of different outcomes (measures of risk), that cannot be obtained from field trials.

What Now?

We have been reminded that in adverse environments the task of generating new technology will be more difficult and the time taken for research to produce usable results will be longer than the 15 years often associated with less harsh circumstances. What we have seen at Bushland is the result of 50 years of investment and research effort. However, it serves as an excellent example that improved technologies can transform an area where erosion is rampant, as it was in that area in the 1930s, to a productive and sustainable area. In developing countries with fewer resources, the time taken for the results of research to spread and begin to have any significant impact, may well be of the order of 20 years or more. At the same time, we are faced with an urgency; while the average population growth rate is decreasing, it is still very high in many areas. The population of India will increase from almost 800 million now to about 1 billion in the next 15 years, with almost half of that increase in dryland areas. The population of the Sahel region in Africa will grow from 30 million to about 45 million in the same period, with all of the increase occurring in dryland areas.

We need to examine the yield gaps—potential yields, practical yields, and actual yields. One of the first tasks is to assemble and codify the scientific and technical knowledge from the substantial amounts of agricultural and environmental research that has been done in the past. This Conference has served as a valuable step towards that end.

We still need to learn a lot more about the agricultural environments of the developing countries; about the climates, weather, and soils; and about the existing land use and farming systems that have evolved to suit these environments, of the resources allocated to them, and of the constraints (including competition for resources) which restrict output. These studies will serve as a guide to the planning of research and can aid in the selection of representative locations at which research can be conducted. The same kind of information is needed to guide governments in the formulation of rural development programs.

If we wish to see new technology adopted, it must be founded on an understanding of the needs and the resources of the existing systems, rather than on scientific results alone; in other words, it must help to resolve the real problems that producers experience and must not call for resources that are not available. New technologies of this sort are only likely to emerge where the experience of local people has been incorporated in their development.

The work requires participation of interdisciplinary teams that contain both natural and human sciences. It will be very important to give support of this concept to national programs where there is no previous tradition of interdisciplinary cooperation. Dr. Schuh observed that we lack international institutions that can focus on interdisciplinary efforts. Until there are such institutions, we would do well to extend and strengthen linkages between the institutional structures that we have, along the lines of a dryland network described by Dr. Brady.

Much of the work done in dryland areas has been very empirical, and a lot of it still is. In the future, modern methods of agricultural science which are increasingly analytical, synthetic, and predictive must be employed in the developing countries and particularly so in the dryland areas. This will require a larger commitment by policy makers in allocating research resources to dryland areas. In the past, governments have consistently invested a smaller proportion of resources for agricultural research in the less favored environments. These policies require reexamination.

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