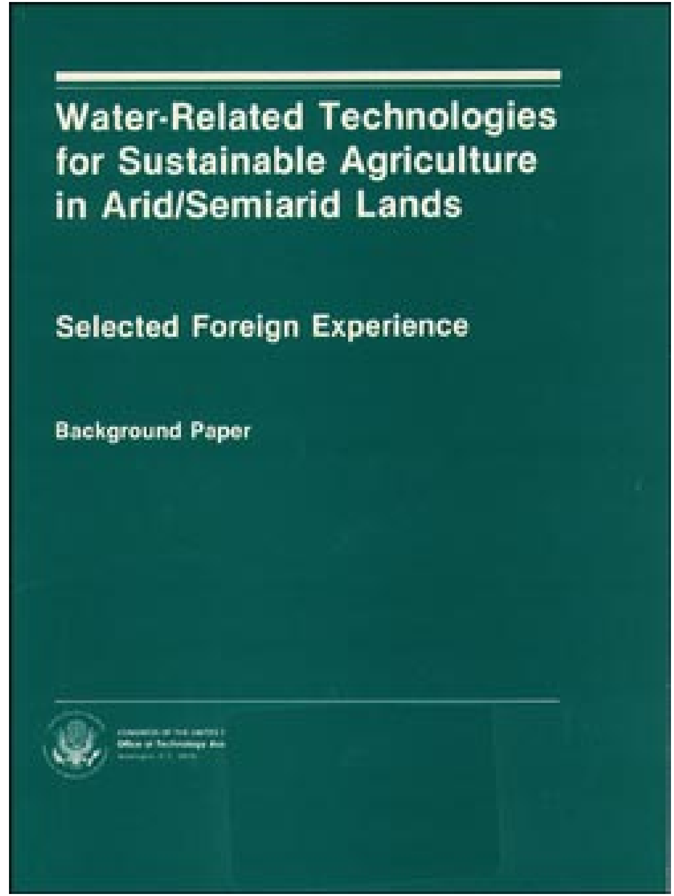
Water-Related Technologies for Sustainable Agriculture in Arid/Semiarid Lands: Selected Foreign Experience

May 1983

NTIS order #PB84-102912



Library of Congress Catalog Card Number 83-600535

For sale by the Superintendent of Documents,
U.S. Government Printing Office, Washington, D.C. 20402

Preface

This report complements the forthcoming OTA assessment on water and agriculture in U.S. arid/semiarid lands. The full assessment focuses on U.S. experience. Foreign experience is also important, however, particularly as U.S. agricultural, economic, and foreign aid interests are increasingly linked with those of other countries. The global significance of agricultural research and development on arid/semiarid lands is underscored by the fact that as much as 20 percent of the Earth's surface is arid and semiarid, containing nearly 16 percent of the world's population.

Described are selected foreign experiences using technology to develop and sustain agriculture in arid lands. The selection of examples was based on three broad considerations: I) availability of current reliable information, 2) variety of examples both in land use and technology type, and 3) projects of potential interest and relevance to the United States. The examples include breeding crops for drought resistance, game ranching, improving irrigation management, developing rubber production from arid/semiarid plants, and adopting technology-intensive water programs and policies. U.S. cooperative efforts with some of these experiments and technology transfer considerations for U.S. arid/semiarid agriculture are also discussed.

This paper was prepared by OTA Project Director Barbara Lausche based on extensive contractor research and with the assistance of OTA Food and Renewable Resources Program staff listed in this paper. OTA wishes to thank and acknowledge the Water and Arid/Semiarid Agriculture Advisory Panel and other contributors noted in the footnotes to this document who provided helpful materials and reviews to the OTA staff.

Water-Related Technologies for Sustainable Agriculture in Arid/Semiarid Lands Advisory Panel

James B. Kendrick, Jr., ***Chairman***
Vice President, Agriculture and University Services, University of California, Berkeley

Alton A. Adams, Jr,
Adams & Associates
Virgin Islands

Thomas G. Bahr (resigned May 1982)*
Director, Water Resources Research Institute
New Mexico

Wilbert H, Blackburn
Department of Range Science
Texas A&M University

William T. Dishman
Farmer/Rancher
Idaho

Harold E. Dregne, Professor
Department of Plant and Soil Science
Texas Tech University, Lubbock

Chester E. Evans
(Retired, USDA Research Director)
Colorado

Larry J. Gordon, Director**
Albuquerque Environmental Health Department

Robert M. Hagan, Professor
Department of Land, Air, and Water Resources
University of California, Davis

David E. Herrick (Retired, USFS)
Western Agricultural Research Committee
Colorado

Helen Ingram, Professor
Department of Government
University of Arizona, Tucson

Cyrus McKell
Director of Research
Plant Resources Institute
Utah

Michael F. McNulty
Director
Tucson Active Management Area
Arizona Department of Water Resources

Milton E. Mekelburg
president
National Association of Soil Conservation Districts
Colorado

Clifford J. Murino
president
Desert Research Institute
Nevada

Alice Parker
Farmer/Rancher
Washington

Cynthia Reed
Rancher
South Dakota

Luis Torres
Program Director
American Friends Service Committee
New Mexico

Casey E. Westell, Jr.
Director of Industrial Ecology
Tenneco, Inc.
Texas

Norman K. Whittlesey
Professor
Department of Agricultural Economics
Washington State University, Pullman

*Resigned to head the Office of Water Policy, U.S. Department of the Interior.
**Until August 1982 Deputy Secretary of New Mexico Health and Environment Department.

OTA Water-Related Technologies for Sustainable Agriculture in Arid/Semiarid Lands Project Staff

H. David Banta, *Assistant Director, OTA*
Health and Life Sciences Division

Walter E. Parham, *Program Manager*
Food and Renewable Resources Program

Barbara Lausche, *Project Director*

Phyllis Windle, *Analyst*

Rita Dallavalle, *Research Analyst*

John Willems, *Research Assistant*

Administrative Staff

Phyllis Balan, *Administrative Assistant*

Nellie Hammond Carolyn Swarm

Contractors

Daniel W. Gottlieb, *Researcher*
Grace I. Krumwiede, *Editor*

OTA Publishing Staff

John C. Holmes, *Publishing Officer*

John Bergling Kathie S. Boss Debra M. Datcher Doreen Foster
Joe Henson Linda Leahy Donna Young

Contents

Tables

Figures

Chapter I

Introduction

The Shaded Countries Are Highlighted in This Paper

Chapter I

Introduction

This background paper focuses on foreign and cooperative examples of what other countries are doing in arid and semiarid agriculture to cope with problems of aridity. The full assessment report, of which this is a part, focuses principally on U.S. efforts domestically.

This paper is designed to assist Congress in several ways. First, it provides information relevant to legislative activities on such broad topics as agricultural research, arid / semiarid land resource productivity, and water management schemes. Second, it illustrates approaches taken by foreign leaders on technology and policy issues affecting agricultural water use in arid / semiarid lands. Third, several examples illustrate the collaborative role of U.S. agricultural and scientific experts in international development and the mutual benefits to be derived by all parties. Finally, by providing examples of how other countries are coping with and using their arid / semiarid environments for productive agriculture, this paper contributes to the continuing congressional debate on ways to sustain agriculture in U.S. arid / semiarid lands.

This paper touches on only a few of the many examples of foreign and cooperative efforts in arid / semiarid agriculture. Numerous opportunities exist through these efforts for information exchange and scientific advancement in methods for making arid and semiarid lands productive.

Approximately 20 percent of all potentially arable land in the world is in arid and semiarid climatic zones, with Africa and Asia accounting for slightly under 10 percent and the United States about 3 percent (fig. 1).[1] About *16* percent of the world's population lives on these arid and semiarid lands (table 1), and about 90 percent of them live outside the Western Hemisphere. Research and development in semiarid and arid agriculture has global significance in light of these statistics. *

The maintenance of some land productivity in these fragile environments is a particular concern for countries that have a major portion of their population engaged in farming or livestock production. It is also of concern to countries with more diversified economies, such as the United States and the Soviet Union, since populations and economies may also depend on the productivity of such lands. A number of countries are trying to cope with aridity and agricultural production. Israel has a deliberate policy of settling its deserts and a system for managing water. The Soviet Union, with about one-fifth of its people living on semiarid and arid lands, has under consideration a partial diversion of north-flowing rivers to desert areas in the south.[2] In the United States, with about one-third of its land area (excluding Alaska) being arid and semiarid, water availability and degradation are topics of growing concern.

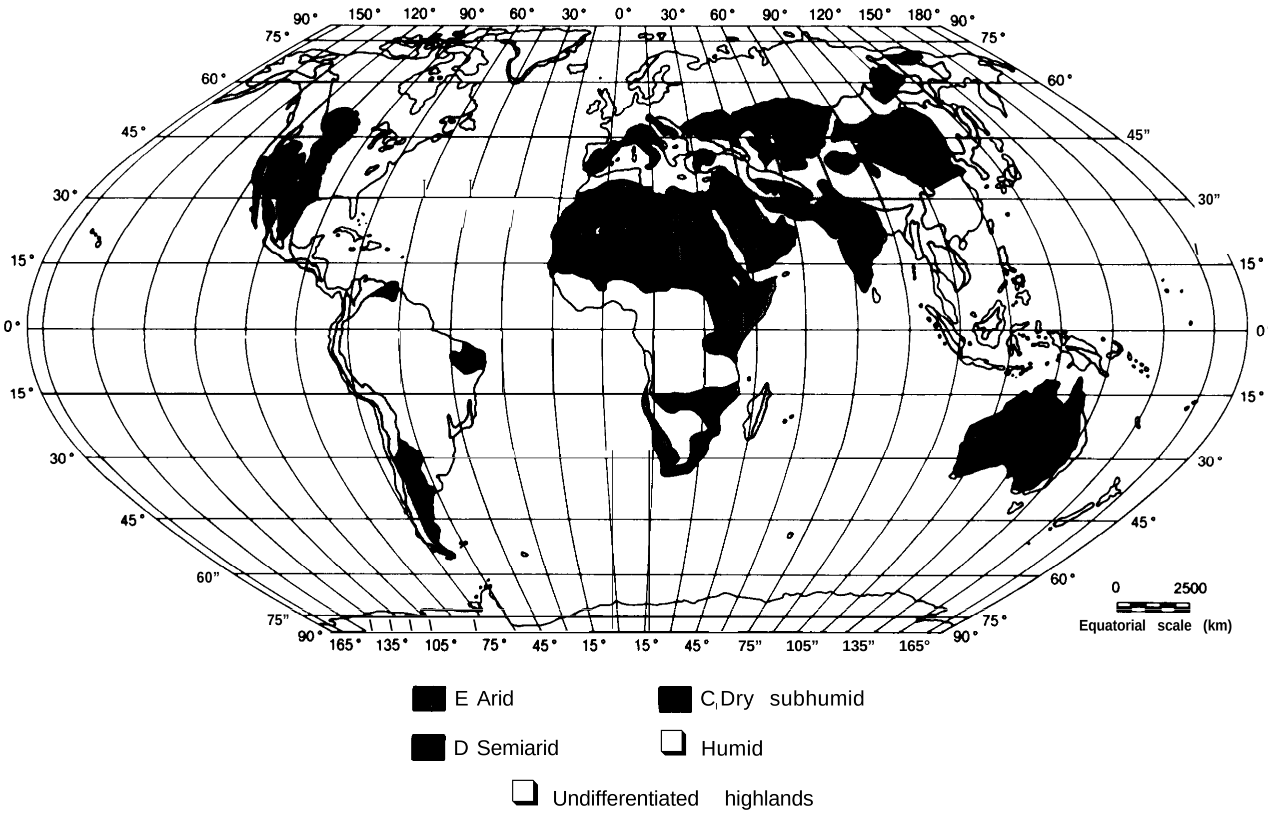
Ancient civilizations in arid and semiarid lands—whether located in the Southwestern United States, along the banks of the Nile, in the Tibesti massif of the Sahara, in the Negev Desert, within the Persian Empire, or on the banks of the Yellow River in China–all practiced agriculture through some form of irrigation. In some cases, great rivers, such as the Nile or the Euphrates, provided an inexhaustible source of fresh surface water. Systems of canals were constructed with ditches and sluices and animal- or human-powered devices for lifting water to higher ground.

[1]H. Dregne (cd.), *Arid Lands in Transition* (Washington, D. C.: American Association for the Advancement of Science, *1970),* pp. *32-33.*

*Arid and semiarid lands have been defined in a number of different ways. Their main characteristic is a low average precipitation or moisture, a condition which is directly affected by other variable elements of the climate, such as temperature, sunshine, wind, and moisture conditions.

‘M. Biswas, "United Nations Conference on Desertification in Retrospect" (Laxenburg, Austria: International Institute for Applied Systems Analysis, September *1978).*

Figure 1.—Dry Climates of the World (highland areas [light tone] have not been analyzed)



SOURCE: H. P. Bailey, "Semi-Arid Climates: Their Definition and Distribution," p. 78, in Hall, et al., *Agriculture in Semiarid* Environment, 1979.

Table 1 .—Estimates of Drylands Population by Region and Livelihood Group[a]

Region	Total drylands		Livelihood populations in drylands					
	Population (thousands)	Urban based (thousands)	Percentage of total	Cropping based (thousands)	Percentage of total	Animal based (thousands)	Percentage of total
Mediterranean Basin	106,600	42,000	39%	60,000	57%	4,200	4 %
Sub-Sahara Africa	75,500	11,700	15	46,800'	62	17,000	23
Asia and the Pacific	378,000	106,800	28	260,400	69	10,300	3
Americas	68,000	33,700	50	29,300	43	5,100	7
Total	628,400	194,200	31%	397,100	63%	37,100	60/0

[a]Meigs classification (1953) including extremely arid, arid, and semiarid area. Secretariat of the United Nations Conference on Desertification, 1977. Sums are not exact due to rounding.

SOURCE: M. Biswas, United Nations Conference on Desertification in Retrospect (Laxenburg, Austria: International Institute for Applied Systems Analysis, September 1978).

Archeological evidence also suggests that since the beginning of recorded history ground water has been used to grow crops. The qanats of Iran, built some 3,000 years ago, were underground gravity flow channels for distributing water for distances up to 20 miles. They are still in use and supply 35 percent of Iran's freshwater. Their apparent durability is a result of a simple technology that used gravity for energy and kept withdrawals balanced with recharge.

Dryland farming, using runoff water collection and runoff waterspreading systems, also was well known in antiquity. These techniques are still practiced in some arid and semiarid lands of the world. For example, Israeli researchers have reconstructed a number of runoff systems from that period. These systems work on the principle of collecting or diverting precipitation that is not immediately absorbed by the ground. One method has been to build a dam in a riverbed during the dry season. When heavy rains came, flood waters were collected and diverted to irrigate surrounding cultivated land, Runoff systems required large topographically suitable areas not under cultivation to collect rain that would not be immediately absorbed. This water would be carefully managed to meet surrounding agricultural needs,

Water runoff from slopes was enhanced by removing stones from surface canals to release the runoff to different fields. This system of water management flourished some 1,500 years ago. In evaluating such ancient practices one writer states, "for all their antiquity, these methods can form not only a basis for survival and income for many communities in developing countries, but a source of additional income to communities living in the deserts of developed countries."[3]

Ancient societies coped with their arid and semiarid environments through technologies which they tried to adapt to suit their natural environments. Similarly, societies and technologies today in such environments also must live within and respect certain natural limits, including the vagaries of climate. This report highlights a few examples of how some other countries are attempting to maintain or increase agricultural productivity on their arid and semiarid lands. For example, Israel has undertaken a national program of total water resource management (ch. VI). Several countries in Africa are experimenting with game ranching (ch. III). Senegal and international researchers are investigating the potential for greater bean and cowpea production in arid lands (ch. II).

In many instances, foreign projects in arid/semiarid agriculture are being aided by U.S. funds and researchers. The United States, through the Agency for International Development (AID), for example, has been working on irrigation water management in Pakistan (ch. IV). New South Wales, Australia, has received assistance for its research program on developing natural rubber from the guayule shrub from the U.S. Department of Agriculture (USDA) (ch. V). The Office of Technology Assessment's publication *An Assessment of the United States Food and Agricultural Research System,* in chapter VIII, "International Dimensions of Research, " provides a historical overview of the agricultural programs of these agencies.

At the start of the 1980's, USDA alone was involved in more than 300 international cooperative research projects. The Office of International Cooperation and Development, USDA, initiates and administers these projects abroad. Some of the countries with which the United States has cooperative research or scientific exchange agreements are Australia, Canada, Great Britain, Japan, Israel, the Netherlands, and Spain.[4]

Besides bilateral agreements, the emerging international agricultural research network offers further opportunities to share in the world's agricultural expertise and knowledge. Since 1960, 10 international agricultural research centers with budgets of nearly ***$140*** million in 1981 have been established. The Consultative Group on International Agricultural Research (CGIAR) sponsors them as well as three other related programs. The United States, through AID, is a charter member and provides about 25 percent of their total funding. Two of them—the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India and the International Center for Agricultural Research in the Dry Areas (ICARDA) in Lebanon–specialize in problems of aridity and agriculture. See table 2 for a list of these centers and programs,

[3] A. Issar, "The Reclamation of a Desert by the Combination of Ancient and Modern Water Systems, " *Outlook on Agriculture,* vol. 10, No. *8*, 1981, p. 393.

[4] U.S. Department of Agriculture, Office of International Cooperation and Development, *Foreign Development, USDA Role* (Washington, D. C.: U.S. Government Printing Office, January 1981), p. 12.

Table 2.—CGIAR-Sponsored International Agricultural Research Centers and Programs

	Location	Year established	Core funding, 1980[a] (in millions)
Centers			
1. International Rice Research Institute (IRRI)	Philippines	1960	$15,032
2. International Maize and Wheat Improvement Center (CIMMYT)	Mexico	1988	16,056
3. International Institute of Tropical Agriculture (IITA)	Nigeria	1988	14,038
4. International Center for Tropical Agriculture (CIAT)	Colombia	1988	14,275
5. International Potato Center (CIP)	Peru	1972	7,100
6. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	India	1972	10,375
7. International Laboratory for Research on Animal Diseases (ILRAD)	Kenya	1974	10,031
8. International Livestock Center for Africa (ILCA)	Ethiopia	1974	8,954
9. International Center for Agricultural Research in the Dry Areas (ICARDA)	Syria, Lebanon	1975	11,292
10. International Food Policy Research Institute (IFPRI)	United States	1975	2,305
Programs			
11. West African Rice Development Association (WARDA)	Liberia	1968	2,562
12. International Board for Plant Genetic Resources (IBPGR)	Italy	1973	2,925
13. International Service for National Agricultural Research (ISNAR)	Netherlands	1979	1,095

[a]Does not include special projects. Some contributions remained to be allocated to individual centers/programs.

SOURCE: U.S. Agency for International Development, 1981.

Collaborative agricultural research and information exchange is an increasingly important requirement for countries concerned about maintaining the productivity of their arid lands in order to meet the needs of their economies and people. U.S. attention to foreign experience and commitment to cooperative exchange of research and knowledge in arid/semiarid agriculture have several ongoing and long-term benefits, including:

- avoiding costly duplication by building on the experience and research of other countries and of U.S.-funded international agricultural research centers;
- assuring that the results of U.S. foreign assistance activities in agriculture are made available to U.S. citizens, adapted to the fullest extent possible to U.S. lands, and analyzed for relevance with future foreign assistance;
- providing ideas for U.S. farmers who are interested in direct field experimentation or adaptation of foreign examples to make their operations more economical as water and energy costs rise; and
- building good will and channels of international communication of benefit beyond the agricultural sector.

Over the long term, diversification, rather than duplication, of research and development can help to strengthen economies. Development of productive agricultural systems that can be sustained on arid/semiarid lands can help meet growing worldwide demand for food and fiber.

Chapter II

Breeding Beans and Cowpeas for Drought Resistance and Heat Tolerance

Chapter II

Breeding Beans and Cowpeas for Drought Resistance and Heat Tolerance

SUMMARY

This international cooperative experience with plant breeding provides insights for expanding food production in U.S. semiarid lands. In particular:

- beans and cowpeas are dryland staples in many developing countries and, in the future, they may provide an alternative dryland crop for U.S. semiarid lands;
- collaborative plant breeding programs are expected to increase the productivity of these crops under conditions of drought and heat stress by combining native varieties of Central American and African plants with high-yielding Californian strains; and
- this international research has benefited foreign farmers and U.S. researchers and shows potential for directly benefiting American farmers and consumers.

INTRODUCTION

Traditionally, plant breeding and testing have focused more on improving yield, quality, and resistance to disease and less on adapting plants to natural environmental stresses. Recently, however, problems associated with environmental stresses such as heat, drought, and salinity have attracted more attention. About four-fifths of the gap between average and record crop yields in the United States results from such stresses. The factors that make plants do better or worse under stress are not well understood. One path to such understanding is through crossbreeding of high-yield strains with those that have survived under harsher climates and conditions.[1]

Some crops grown in the United States under rainfall or irrigation have the potential for being grown with less water and producing higher and more stable yields. Beans (common beans that are grown to produce dry beans) and cowpeas are two semiarid crops with such characteristics. Both are legumes and have long been grown overseas under dryland farming regimes that have produced hardy strains. In Senegal, for instance, the local cowpea is so hardy it has been called "the crop of security." The cowpea and bean have been dependable crops, producing food in arid and semiarid regions when sorghum and pearl millet crops failed.'

For many developing countries, beans and cowpeas are dietary staples. In Mexico, for example, where 40 percent of the bean production comes from semiarid lands, beans are a staples These legumes provide a major source of high-quality and affordable protein and carbohydrate. In addition, they are an important source of the B complex vitamins.[4] For this rea-

[1]B. Hiatt, "To Increase Survival, " Mosaic (Washington, D. C.: National Science Foundation, May-June 1982), p. 27.

[2]A. E. Hall, "International Cooperation in Agricultural Research to Develop Improved Cowpea Cultivars for Semiarid Regions of Africa and the United States, " Office of Technology Assessment commissioned paper, April 1982. Supplemented by telephone interview with Dr. Hall, University of California (Riverside), April 1982.

[3]M. Wayne Adams, Michigan State University, former director of the Bean/Cowpea CRSP, April 1982, telephone interview.

[4]*Annual Report of the Bean/Cowpea Collaborative Research Support Program (CRSP)* 1981, Bean/Cowpea CRSP Management Office Staff, Michigan State University (East Lansing, Mich.: December 1981).

98-353 r - 83 - 3

son, U.S. technical assistance programs have focused on these legumes as a possible means of improving food and nutrition abroad, particularly for subsistence and low-income peoples.

COLLABORATIVE RESEARCH SUPPORT PROGRAM

In September 1980, the Bean / Cowpea Collaborative Research Support Program (CRSP) was established through funds from the U.S. Agency for International Development (AID) under Title XII of the Foreign Assistance Act of 1975.[5] The purpose of the program has been to help eradicate hunger and malnutrition in Africa and Latin America. The program's research focus is on the production and use of dry beans *(Phaseolus vulgaris* L.) and cowpeas or black-eyed peas *(Vigna unguiculata* (L.) Walp.). Research on environmental stress on these plants is a major component.[6]

[5] The Bean/Cowpea CRSP is one of several programs funded by AID. CRSPs generally involve U.S. universities, research institutions in developing countries, and international agricultural research centers. All contribute resources to the projects. Their main purpose is to assist development of research capacities abroad, but they are also designed to benefit U.S. agriculture. The description of CRSP is from Bean/Cowpea CRSP Annual Report and An *Assessment of U.S. Food and Agricultural Research* (Washington, D. C.: Office of Technology Assessment, U.S. Congress, 1981), p. 164.

[6] *Annual Report,* op. cit.

The Bean / Cowpea CRSP is managed by Michigan State University. Nine other universities also participate. The collaborating countries include Brazil, Cameroon, the Dominican Republic, Ecuador, Guatemala, Honduras, Kenya, Malawi, Mexico, Nigeria, Senegal, and Tanzania. The total fiscal year 1981 contributions by all parties are shown in table 3. About 25 percent of the total U.S. contribution comes from private and public U.S. institutions, reflecting some sense that potential benefits might accrue to U.S. agricultural research interests, especially the private sector. A description of the CRSP bean projects in Guatemala and Mexico and the cowpea project in Senegal follows, to illustrate the kinds of activities and benefits coming from the Bean / Cowpea CRSP.

Bean CRSP--Guatemala[7]

Cornell University and the Instituto de Ciencia y Technologiá Agrícolas (ICTA) of Guate-

[7] *Annual Report,* op. cit., app. D.

Table 3.—Fiscal Year 1981 U.S. Financial Commitments to Bean/Cowpea CRSP Projects

Country/institution	Plant	U.S. AID contribution	U.S. institution contribution	Percent of total project contribution from U.S. institution
INCAP,[a] Central America/Washington State	Dry bean	$159,700	$73,130	31'!0
Honduras/Puerto Rico	Bean	50,500	20,075	28
Guatemala/Cornell	Bean	89,250	27,871	24
Brazil/Wisconsin	Bean	83,900	11,617	12
Brazil/Wisconsin	Bean	83,900	26,809	24
Brazil/Boyce Thompson Institute	Cowpea	83,900	29,704	26
Dominican Republic/Puerto Rico	Bean	92,350	31,168	25
Dominican Republic/Nebraska	Bean	92,350	48,320	34
Senegal/UC-Riverside	Cowpea	140,000	48,830	26
Cameroon/Georgia	Cowpea	126,000	31,546	20
Nigeria/Michigan State	Cowpea	67,200	31,542	32
Nigeria/Georgia	Cowpea	67,200	21,333	24
Kenya/UC-Davis	Bean	134,400	44,840	25
Tanzania/Washington State	Bean	117,460	63,682	35
Malawi/Michigan State	Bean	92,482	12,928	12
Total		$1,480,592	$523,395	260/o

[a] Institute for Nutrition in Central America and Panama.

SOURCE: *The Annual Report of the Bean/Cowpea Collaborative Research Support Program (CRSP), 1981,* Bean/Cowpea CRSP, Management Office Staff, Michigan State University, December 1981.

mala are collaborating on bean research to determine, on a worldwide basis, how variations in day length and temperature affect plant development, maturity, and adaptation. These plant characteristics, in turn, affect how much water a crop requires. Cornell University scientists have found, for instance, that the time it takes the bean plant to grow to the flowering stage is important in determining its yield. The time factor, in turn, is influenced by length of daylight and day/night temperature differences.

A number of factors make U.S.-Guatemalan cooperation in this research beneficial. Plant geneticists who work on breeding to produce a particular characteristic, such as optimum time from planting to flowering, need a variety of beans with that characteristic from which to draw genetic material. Guatemala, one of the areas in Central America where the bean originated, offers a greater diversity of bean plants than does the United States, since the plant has had a comparatively longer time to develop there. Guatemala also has both high and moderate altitude locations in close proximity. This provides a greater variety of day/night temperature ranges in which to field-test new strains.

Bean CRSP--Mexico[8]

Collaborative bean research began in 1982 between the Instituto Nacional de Investigaciones Agrícolas (INIA) in Durango, Mexico, and U.S. universities. Two initial considerations make Mexico a natural partner for bean research. First, the bean originated in the highlands of Mexico as well as Guatemala. Thus, the genetic material available in Mexico also is rich in diversity. Second, Mexico is the second largest bean-producing nation in the world.

The United States and Mexico have collaborated on research in two specific areas. Mexican researchers have made some progress developing bean varieties that are drought resistant. U.S. researchers have worked on improving the process by which beans convert atmospheric nitrogen to a usable form, allowing production without the need for supplemental nitrogen fertilizer. If drought resistance and greater biological nitrogen fixation can be merged, bean farmers in both countries may be able to get along with less fertilizer and water, Drought resistance in bean production may not seem immediately critical to U.S. agriculture. However, beans already are grown in some semiarid U.S. areas, and nationally the bean is a major crop. As world food demand increases, production of drought-resistant beans on U.S. water-limited lands may become increasingly important to make optimal use of those lands and help meet world food needs.

The second area that the joint Mexico/U.S. bean research has been pursuing is the further development of strains with a structural adaptation that deters water loss through transpiration. Such bean plants turn their leaves in dry periods so that the surface through which water is lost is pointed away from the Sun. Five of the top yielding strains of beans being researched through this program at Michigan State University have this capability.

Cowpea CRSP--Senegal[9]

The Cowpea CRSP is especially active between the University of California at Riverside and the Senegalese Institute for Agricultural Research, This program began 6 years ago as a small component of an AID-funded effort by UC/Riverside to assist with rural development in semiarid Africa with emphasis on the Sahel. The principal reasons that Senegal was so attractive for this collaborative research were that: 1) the cowpea probably originated in Africa, and 2) Senegalese plant breeders had begun using the available diverse cowpea genetic stock to develop cowpeas specifically adapted for semiarid zones.

The objectives of the cowpea research program include: 1) developing improved cowpea varieties and management methods for subsistence farmers in the semiarid zone of Senegal, and 2) developing cowpea varieties with im-

‘3 Adams interview, op. cit.

[9]Ibid.

proved drought adaptation, heat tolerance, and yield stability for use in semiarid zones throughout the world, including the United States.[10] During the first 2 years (1980-82) of the project, a number of significant findings were made by the joint efforts of U. S., Senegalese, and other researchers. The major findings follow.

Improving Drought Adaptation

Field screening techniques are being used in California to select cowpeas with: 1) roots more able to extract water from the soil, 2) earlier flowering, and 3) greater proportions of total carbohydrate in the pods. For example, some of the material produced will mature in 60 days, the length of the short rainy season in parts of Africa. Cowpeas with these improved characteristics are being crossed to produce superior progeny. About 30 of the advanced cowpea lines originating from crosses between Senegalese and Californian cowpeas have been evaluated for drought resistance and yield stability in cooperative tests in Senegal and California.

Screening for Heat Tolerance

Hot weather in both Africa and the United States causes flowers to drop and therefore pods never form. This reduces cowpea yields. Research by a Sudanese student at UC/Riverside has established a connection between excessive flower drop and high night temperatures just before flowering. Cowpeas from throughout the world have been grown during hot weather in the Imperial Valley, Calif., to search for strains with tolerance to heat. Two African strains were discovered that have greater heat tolerance than both the local varieties grown by farmers in Senegal and the blackeye pea types grown in California.

The challenge in research is to overcome the problems caused by the harsh environments in semiarid zones by breeding into the high-yielding California varieties the heat tolerance and drought adaptation characteristics identified in the more hardy Senegalese and other African cowpeas. According to one UC/Riverside scientist on the project, "the cooperative yield tests have demonstrated that some of the advanced cowpea lines are adapted to California and have improved drought resistance, whereas other lines are extremely early and require only 60 days from sowing to harvest in African conditions. During extreme droughts, with a short rainy season, these early lines have the potential to produce substantial yields while most cowpeas would fail to produce seed."[11]

[10] Hall, op. cit., pp. 1-2.

[11] Ibid., pp. 3-4.

TECHNOLOGY TRANSFER CONSIDERATIONS

The bean/cowpea collaborative research projects are relatively new and have not yet been implemented directly in commercial agriculture. Initial signs indicate, however, significant potential for improved bean and cowpea yields and water use efficiency through this collaborative plant breeding research. Cowpea varieties developed by this program with improved drought-resistance and heat-tolerance characteristics could increase the productivity and profitability of dryland and irrigated agriculture in semiarid regions of both developed and developing countries.

Agricultural productivity of arid and semiarid lands will become increasingly important to help meet growing food demands. Crops such as the cowpea may not now be of major importance to U.S. diets, but they could become an important export crop in the years ahead. This could become a factor in helping maintain a favorable U.S. balance of payments as well as providing a means of foreign assistance. Such foodstuffs would be particularly important for feeding children and pregnant women in countries where protein shortages develop.[12]

Promotion of this collaborative research and its potential benefits depends almost entirely on efforts of the involved scientists. In the views of some United States scientists participating in this international research, general U.S. interest in and use of the knowledge generated so far is insignificant. The matter has been given little attention by the U.S. Government.[13] In contrast, both Canada and Australia have specific organizations and programs designed to encourage international agricultural collaboration for use in foreign assistance as well as in their own agriculture.[14] The benefits to U.S. agriculture from the brief collaboration to date in the Bean/Cowpea CRSPs suggest that more U.S. participation in this kind of international research could provide important future benefits for U.S. farmers in arid and semiarid agriculture,

[12] Hall interview, op. cit.

[13] *An Assessment of U.S. Food and Agricultural Research, op. cit.*, pp. 151-169 (see footnote 5).

[14] Donald Plucknett, Science Advisor to the CGIAR Secretariat, World Bank, May 1982, telephone interview.

Chapter III

Game Ranching in Africa

Chapter III

Game Ranching in Africa

SUMMARY

This use of dry grasslands in Africa provides a striking contrast to most uses of U.S. rangelands. In particular, this chapter illustrates:

- attempts to make productive use of degraded grasslands and to prevent their further deterioration by relying on native animal species,
- analogous efforts in the United States which relate to and draw on the African experience, and
- difficulties inherent in developing animal agriculture tailored to long-term resource sustainability.

INTRODUCTION

In years past, the low rainfall grassland plains of Africa, with their immensely rich and varied wild animal populations, formed a major natural resource of the continent. Today these once beautiful and productive areas are in varying degrees of degradation.

Both climatic factors and human exploitation have influenced the condition of these lands. In many instances, wild animal populations have been eliminated or threatened as the land has become degraded and moved increasingly toward arid and semiarid conditions.

Human activity has played a large role in destroying the delicate natural balance between vegetation and wild animals.[1] Desert shrubs have been stripped from the land for use as firewood to the extent that local supplies have virtually disappeared, and charcoal must now be shipped 100 to 200 miles for use in some cities. Such woody ground cover normally served to hinder erosive water runoff and enhance retention of water in the soil. Overgrazing and compaction of the soil by domestic animals, in a region where land is considered common property by stock owners, also has contributed to the degradation.[2]

Commercial production of imported domesticated livestock (primarily cattle, sheep, and goats) continues in the African savanna in spite of the impact on the land. The animals are maintained in African countries with the assistance of much livestock research and social expenditure, in part because they have become an integral part of the local social and economic systems. Owning a large herd is a mark of prestige; it also ensures a constant milk supply despite the low productivity of milking cows and the shortness of their milking period. A herd provides insurance for survival through its meat, dairy, and other products should a calamity such as an outbreak of disease or drought occur. Sheep are retained because mutton is the preferred meat of the region. The consumption of goat meat is generally restricted to the poor. Nevertheless, goat is of particular value in arid lands because it survives when sheep and cattle perish, thus providing a more secure supply of milk, meat, and skins in emergencies.[3] These multiple social benefits have tended to override the fact that the quality of beef is often inferior to that of beef produced in a more favorable climate. Moreover, seasonal variations in water and forage availability are not conducive to the rapid growth of cattle, sheep, or goats.

---

[1] Southwest Research Laboratories, "The Establishment of Wildlife Ranches in Developing Countries" (Los Alamitos, Calif.: November 1981), p. 1.

[2] L. Chatterton and B. Chatterton, "Combating Desertification in Winter Rainfall Regions of North Africa and the Middle East," *Outlook on Agriculture, vol. 10, No. 8,* p. 397,

[3] *Smithsonian* magazine, vol. 10, No, 5, August 1979, p. 38.

98-953 0 - 83 - 4

In contrast, indigenous animals have naturally adapted to the arid and semiarid environment of the African savanna. In one important aspect they are particularly adapted: they require little water. If fresh grass is available, camels, for example, require virtually no water. Even when water is available in such areas as central Sudan, camels are often not given water more than once every couple of months. The Sudan exports tens of thousands of camels to upper Egypt for meat each year. Because of their adaptability, camels in the Sudan are valued more highly for their milk and for transportation than for their meat.[4]

Antelopes, gazelle, oryx, and other game species also are well adapted to life in arid regions. (See table 4 for scientific names of common African game species.) The eland, for example, can endure fairly large variations in body temperature without sweating, so they can reduce water loss. The ostrich can survive a 25 percent loss of body weight, much of which is water that can be replaced in a single drinks Game animals also have potential as an excellent source of high-quality meat. With its higher proportion of protein to fat, some game meat may be nutritionally superior to domestic meats. And if allowed to grow naturally on the range, game meat may contain lower levels of the kinds of chemicals, including growth hormones, commonly used in modern ranching.[6]

[4]J. L. Cloudsley-Thompson, "Animal Utilization," *Arid Lands in Transition,* Harold E. Dregne (cd,) (Washington, D. C.: American Association for the Advancement of Science, 1970), p. 67.
[5]Ibid., p. 68.
[6]Ibid., p. 58.

Table 4.—Common and Scientific Names of Animals Cited in Text

Since much information about animals is classified by scientific names, this list is provided to help readers locate additional data. There may be cases where disputes in synonomy or regional variation are not reflected.

Domestic and wild cattle and their relatives:	
Domestic cattle	*Bos taurus*
Domestic goats	*Capra hircus*
Domestic sheep	*Ovis aries*
African buffalo	*Syncerus caffer*
American bison (buff ale)	*Bison bison*
Antelopes and their relatives:	
Dik-dik	*Madoqua* spp.
Duiker	*Sylvicapra* spp., *Cephalophus* spp.
Eland	*Taurotragus* spp.
Gerenuk	*Litocranius walleri*
Grant's gazelle	*Gazella granti*
Hartebeest	*Alcelaphus buselaphus*
Kudu	*Tragelaphus* spp.
Impala	*Aepyceros melampus*
oryx	*oryx* spp.
Springbok	*Antidorcus marsupials*
Steenbok	*Raphicerus campestris*
Thomson's gazelle	*Gazella thomsoni*
Wildebeest	*Connochaetes* spp.
Deer and their relatives:	
Axis deer	*Cervus axis*
North American elk	*Cervus canadensis*
White-tailed deer	*Oedicoileus virginiana*
Other animals:	
African camel	*Came/us dromedaries*
Giraffe	*Giraffa camelopardalis*
Zebra	*Equus* spp.
Birds:	
Ostrich	*Struthio came/us*
Ring-necked pheasant	*Phasianus colchicus*

SOURCE: Office of Technology Assessment.

EXPERIMENTS IN GAME RANCHING

A growing awareness of the serious impacts domesticated cattle, sheep, and goats are having on the African savanna has spurred interest in game ranching of native species. In the IWO's a number of ranches in Africa began experimenting with a mixture of domestic and game animals to counter growing land degradation and to boost the economic value of indigenous wildlife species in order to help preserve them.

The feasibility of game farms in several African countries is an area of ongoing research in the more productive use of arid and semiarid lands. On both experimental and commercial ranches, workers are testing the hypotheses that indigenous species are better adapted to the savanna environment and thus more easily and profitably raised than common domestic animals. For these reasons, game ranching has been called the use and enhancement of "nature's technology.'" The basic concept is to take economic advantage of the natural balance between vegetation and wild animals.

Major projects at the following ranches were started in the 1970's: Ubizana and Theunis in Natal, South Africa; Doddieburn and Mkwasine in Zimbabwe; Kruger in South Africa; and Athi River in Kenya. The limited data reported on these ranches to date indicate that the most significant costs of game ranching are in capturing and stocking animals, erecting a perimeter fence, and, when necessary, building processing facilities. Stocking costs have ranged from $50,000 at the Ubizana Game Ranch to $146,000 over 3 years at the Theunis Game Ranch in South Africa. Fencing costs were estimated at $1,044 per kilometer in South Africa in the early 1970's. The Mkwasine Game Ranch in Zimbabwe spent over $56,600 to fence 59,304 acres (24,000 hectares). Processing facilities that comply with veterinary and health standards have been found also to be costly. A canning and drying facility in the Kruger National Park in South Africa, for example, cost the equivalent of $1.5 million. However, that facility returned the investment within 3 years. A smaller, less sophisticated facility on the Theunis Game Ranch, which prepared fresh cuts and sausage, cost about $146,000.[8]

One of the largest experimental game ranches in Africa is the Athi River, Kenya ranch, established in the mid-1960's by David Hopcraft. This experiment has attracted interest from both developed and developing countries and is the focus of a major portion of the remainder of this chapter.

[7]David Hopcraft, "Nature's Technology," 19, *Technological Forecasting and Social Change (1980).*

[8]S. Mossman and A. Mossman, "Wildlife Utilization and Game Ranching," IUCN Occasional Paper No. 17 (Merges, Switzerland: International Union for Conservation of Nature and Natural Resources, 1976).

THE HOPCRAFT PROJECT[9]

Athi River, Kenya Demonstration Wildlife Ranch is located about 25 miles from Nairobi. It contains 20,000 acres, some of which are used for cattle ranching. Hopcraft began his project with the help of a 1966 U.S. National Science Foundation research grant for a 3-year comparison of the land effects and the meat and hide yields of cattle and game raised on Kenya grasslands. In the study, he fenced off and halved a uniform 300-acre plot of land. One side was stocked with cattle, the other with gazelle.

Hopcraft found the physical effects of the two species on the land to be substantially different. The cattle significantly reduced grass cover and other types of stable vegetation, created serious tracking problems, and trampled the vegetation on their daily trek to the water hole, compacting the soil. In contrast, according to Hopcraft reports, the gazelle left an area that retained 32 percent more grass cover and 100 percent more self-perpetuating species. The gazelle area did not show either tracking problems or land devastation around the water hole.

Economically, Hopcraft found the gazelle carcass to be more profitable than the cattle carcass. His figures indicated that 47 percent of the gazelle was lean meat, compared to 32 percent in cattle; the cattle in this experiment yielded 7.9 pounds per acre per year, the gazelle produced 14.6 pounds per acre. Cattle raised under traditional stock raising methods, according to Hopcraft, would yield much less lean meat than those on his farm.

[9]David Hopcraft, op. cit.

Income from the gazelle substantially exceeded that from cattle because of the gazelle's higher market price, almost double that of domestic meat, and production of 50 to 100 percent more meat per acre. Hide sales favored the game species as well, the gazelle hides returning a price roughly 25 percent higher than that received for cattle hides. Approximately 10 acres per head and 3 years were needed to produce one cowhide, while Hopcraft estimated that 1 acre could produce eight gazelle hides in only 1 year.

Hopcraft interpreted his findings to indicate that adaptation to the environment is a very important factor. "An indigenous animal spends far less energy than an imported beast in overcoming the harsh environmental conditions such as disease, weather, and vegetation. Thus, more energy becomes available for growth. " The advantage is augmented, he maintains, by the negligible costs of herd maintenance. Gazelle, for example, require no pesticide dippings, inoculations, or night enclosures. Hopcraft estimated that expenses on a cattle ranch consume about 66 percent of income, compared to only 20 percent on a game ranch.

In 1976, Hopcraft received a grant from the Lilly Endowment of Indianapolis for the large-scale application of his findings. This grant was increased in 1977. The funding covered construction of an 8%-foot-high fence around the 31-mile perimeter of his ranch, a project requiring 15 months to complete. This fence enclosed more than 5,000 indigenous animals of 20 different species–giraffes, eland, wildebeest, dik-diks, impala, zebra, hartebeest, and others. About half were from the gazelle family.

According to Hopcraft, this variety of game has helped maximize the productivity of the vegetation. The treetops are forage for the giraffe; the higher bushes are eaten by the eland, kudu, and gerenuk; the lower bushes by the gazelle and impala; and the grasses by buffalo, zebra, wildebeest, and hartebeest. Smaller shoots and leaves serve the duiker, steinbuck, and dik-dik. The seeds are eaten by the ostrich and other game birds. There is some overlap in browsing, but according to one report this

Photo credit: *Agency for International Development*

The eland of East Africa is the largest of the plains animals that graze across the vast savannas

Photo credit: *Agency for International Development*

Herds of zebra and wildebeest roam across the grass fields inside Ngorongoro Crater in Tanzania

arrangement is conducive to helping the vegetation remain in natural balance.[10]

Erecting the perimeter fence was a major endeavor in the large-scale project. Once operational, the project faced a second hurdle and one of its greatest impediments: securing the Kenyan Government's permission to market the game meat. Hopcraft lobbied for 7 years before obtaining an exemption from gaming and food laws. Cropping game on the Hopcraft ranch began early in 1981. Plans are to crop about one-quarter to one-third of the game population annually. * Now, the ranch's game

[10]Southwest Research Laboratories, op. *cit.*, p. 8.

*Gabriel Von Latham, April 1982, telephone interview. Von Latham and Hopcraft have formed a French-based firm, Wild Indigenous Livestock Development (WILD), to export game ranching to other countries.

meat is sold in hotels and restaurants in Nairobi as a luxury item, and outlets are being sought outside Kenya.

Some of Hopcraft's preliminary findings are:

1. it is possible to live within the natural balance of land and animals in this part of Africa and to use extremely profitably the natural increase of animals for production of meat and hides;
2. ranching indigenous animals requires little input and little imported energy; and
3. far greater production of meat is attained per acre, gaining profits of nearly five times those of traditional livestock rearing, in a sustained multicultural environment.[11]

[11]Southwest Research Laboratories, op. cit., p. 9.

DISCUSSION OF FINDINGS

Some controversy exists over Hopcraft's findings and extrapolation of results obtained on his relatively small plot of land. The advisability of game ranching as an approach to increased economic productivity is under question because of the high capital outlay needed to establish and outfit a fenced range of adequate size.

In general, substantial costs are involved with game ranching where the project must acquire land, construct perimeter fences, stock and harvest the animals, and construct slaughterhouse facilities. Hopcraft was able to avoid many of these costs. Local circumstances, for example, helped Hopcraft minimize stocking costs. In fencing the ranch, several thousand animals were trapped within, saving the time, money, and effort of capturing and transporting them from outside. The weaving of the fencing material onsite from local materials further reduced operating costs. Hopcraft also was able to purchase inexpensively a mobile slaughterhouse from the United Nations Food and Agriculture Organization.

Similar economizing may be possible in other game ranching developments in the African savanna and elsewhere if indigenous species are used. Certain other experiments, however, which must trap and transport game from outside, may find their initial costs much higher. Many game ranchers may have to construct slaughterhouses because of the distance of their operations from commercial facilities.

A group of Cornell University researchers visited Hopcraft's ranch several times to conduct research and to report their findings to the Lilly Endowment. * They have gathered data on range ecology and the digestibility of various plant species by game animals. Co-director Daniel G. Sisler has concentrated his study of the project on the economics of meat production, handling, and marketing. Dr. Sisler raises a number of points about the economics of game ranching:

1. Costs of establishing and operating a game ranch. Although Hopcraft has shown that game meat sales will cover variable operating costs, according to Dr. Sisler, he has not shown that their sales will cover all the fixed costs associated with setting up a ranch. If the fence, slaughterhouse, cooling facilities, vehicle, capture of animals, and labor were all included, the net income might be well below that of a well-managed cattle ranch. The costs of establishing a cattle ranch would have to be compared with those of establishing a game ranch, or the assumption would have to be made that both kinds of ranches are operational at the time of the comparison.

*This section discussing the controversy over Hopcraft's results is based on information from Daniel Sisler and Robert McDowell, Professors of Agricultural Economics, and Robert P. Bauer, graduate student, Cornell University, April 1982, and with McDowell again in August 1982.

Cropping, handling, and marketing game meat are distinctly different from similar operations associated with domestic animals. Table 5 shows some of the characteristics of cropped game animals to consider in handling and marketing. The initial investment in slaughterhouse and refrigeration facilities and their operating expenses may be substantial. The services of a veterinarian maybe needed to meet inspection requirements. These costs are in contrast to cattle ranching, where animals are typically sold live, with slaughter and inspection taking place at a publicly owned slaughterhouse.

In contrast, harvesting at the Hopcraft facility was labor intensive and unusual. Cropping of all animals took place at night, with a crew of three men shooting the animals from a Land Rover. Cropping was reasonably efficient, and dead animals were at the slaughterhouse within 1 hour. During the first year of operation, the game meat was found to be of high quality and accepted by customers. Fat content was low. Statistics relative to cropping indicated that there was no significant seasonal variation in carcass weight of game animals.

Sisler estimates that the establishment costs are roughly equal to those in establishing a cattle ranch. Net operating income may be about equal if the price received for game meat is approximately twice that for cattle (the price ratio in the first year of the Kenya ranch operation).

2. **Game ranch management.** A well-managed game ranch requires highly sophisticated technical knowledge as to rates of growth for each game species, plant food preferred, degree of predation by other species, fawning rates, growth rates, sex composition, compatibility of species, gestation period, and age of sexual maturity of differing species. The availability of this expertise adds cost to the project.

3. **Use of energy.** Although the energy used for a game ranch is less than that for cattle ranching, Sisler estimates imported energy for a game ranch is approximately 40 percent of that required for a comparable cattle ranch. Vehicles use diesel fuel, as does the operation of the slaughterhouse and chilling facilities.

4. **Development of markets.** A ready market existed for all game meat produced from the Hopcraft ranch during 1981 operations. This does not mean that there would necessarily be a consistently adequate market for game meat within Kenya. The absolute quantity of game meat marketed is a small proportion of total red meat consumption in Nairobi. It seems probable that any sizable increase in game meat production could cause prices to decline. The most serious obstacle facing continued efficient marketing of game meat in Kenya is assuring a strong market for all would-be producers. Hopcraft was successful as the only producer operating on a small scale in the capital city of Nairobi.

The majority of Hopcraft's clients were restaurants, although one butchery was a steady client. The meat was sold at 25 shillings per kilo, approximately twice the price of quality beef. The clientele of these restaurants and butcheries has been more than 90 percent expatriate, and wholesale purchasers knew that the high price could be passed onto their customers. When surveyed, clients stated that game meat constituted about 5 percent of total sales. Restauranteurs estimated that the cost of preparing a game meat meal was 20 to 30

Table 5.—Characteristics of Cropped Game Animals

				Percent total weight dressed	
Species	Body length (cm)	Shoulder height (cm)	Dressed weight (kg)	Annual range	Average
Thomson's gazelle	78	67	13	53-55	54
Grant's gazelle	108	91	33	52-61	55
Kongoni	121	119	69	49-52	52
Wildebeest.	135	132	125	49-60	53

SOURCE: "An Economic Analysis of Harvesting Techniques, Game Meat Characteristics and Marketing Prospects," tables 1, 2, and 3, paper by Daniel Sisler, Professor of Agricultural Economics, Cornell University, preliminary draft, October 1982.

percent more than that of a beef, poultry, or pork meal. Retail price per plate, however, is usually about the same for game and traditional meats. Table 6 shows the monthly average of kilos of game meat delivered to four or five clients each week and the corresponding revenue from each delivery.

Limited quantities of sausage have been produced from the game meat. The market appears to be strong for this high-value product, which could be marketed at a lower expense than chilled meat. However, equipment for sausage manufacturing is costly, as are some ingredients, notably fat. While sausage production shows signs of profitability, more effort is needed on marketing and promotion of this specialty item.

According to Sisler, game meat will continue to be a high-priced specialty meat if game meat production is to be profitable. Because of its cost, it seems likely that in the foreseeable future game meat will not be a source of low cost animal protein for native peoples.

5. **Price of hides when sold in quantity.** Sisler found hide sales extremely difficult to calculate. If they can be sold at a favorable price, this would be an added source of revenue for game ranching. The development of a market for specialty hides, however, was difficult for Hopcraft's 1981 operations.

6. **Water use.** Theoretically, the expense of drilling wells or installing dams and watering facilities can be considerably less than what is required for cattle. However, a perimeter fence may prevent migration of animals to natural watering points and better range. So any area would need to be large enough to take care of this requirement.

7. **Stocking ranches.** The financial break-even point for game ranches of Hopcraft's size, calculated by Cornell University reviewers, is roughly 2,000 animals-about twice the current level of Hopcraft's harvest. This figure represents about 40 percent of the 5,000 game that Hopcraft estimated in his 1980 report. More recent estimates from Cornell indicate that the game animals on the ranch number about 2,500 to 2,800. The costs of establishing a similar ranch elsewhere would be extremely high. Also the cost of importing animals would be high. In the first year of operation, only four species of adult males—Thomson's gazelle, Grant's gazelle, wildebeest, and kongonis were harvested. It is unclear what will happen to the ecology when all cattle are removed and game animals expanded.

Other questions remain. What will happen to the off-take rate of game animals when younger animals and a part of the females of each species are harvested? Will the price of game meat be less when it is sold in larger quantities? At present, cropping is completed in accord with what can be sold rather than in a manner to regulate or sustain species composition and number. Achieving a balance between meat production and the natural sustainability of the animals in their local environment will be one of the most critical facets of ranching.

Table 6.—Monthly Deliveries to Nairobi and Revenues (game meat only)

Month	Number of deliveries per month	Total monthly delivery (kg)	Mean weekly delivery (kg)	Monthly revenue Kenyan shillings	U.S. dollars
January	4	954	239.6	23,962	$2,188
February	4	769	192.3	19,227	1,756
March	4	1,008	252.0	25,200	2,301
April	4	857	214.3	21,430	1,957
May	5	1,469	293.8	36,725	3,354
June	4	1,614	403.5	40,345	3,685
July	5	1,481	296.2	37,025	3,381
August	4	1,276	319.0	31,898	2,913

SOURCE: "An Economic Analysis of Harvesting Techniques, Game Meat Characteristics and Marketing Prospects," paper by Daniel Sisler, Professor of Agricultural Economics, Cornell University, preliminary draft, October 1982.

TECHNOLOGY TRANSFER CONSIDERATIONS

Data are not available to make definitive statements about the economic feasibility of expanding game ranching to other parts of Africa. However, because of the optimism for Hopcraft's efforts, the U.S. Agency for International Development (AID) has funded a game ranching feasibility study by Hopcraft for the Department of Wildlife in Botswana. Hopcraft is looking at the possibility of establishing two demonstrations similar to the Kenya ranch, one in a communal area and the other on a private ranch in Botswana. The communal area would involve some 20 farm families living on 5,000 acres, who would be trained to manage the animals. *

Developing international markets for game meat would help assure game ranching profits and increase the desirability of starting such operations. Hopcraft has proposed that Rhodesian and Botswanan game be shipped to Europe through South African ports and airports. The development of widespread markets for these high-priced specialty meats will take a major effort, although some researchers believe that a market is there.[12] Game meats are still an insignificant factor in world food production and world trade. According to U.S. Department of Commerce figures, the United States imported less than $1 million of game meats in 1981. Both the United States and Europe (especially West Germany, Switzerland, and England) could prove to have substantial potential as markets if a reasonably priced, secure supply became available.

Some research on game ranching, parallel to that in Africa, is under way in the Western United States assessing the advisability of a partial shift to native or imported stock. As much as 85 percent of agricultural land in the American West is used as range, and a growing awareness of the problems of overgrazing, reduced water availability, and lower economic return from ranching operations has influenced American ranchers to look into alternative ranching systems. Experimentation with native American bison is under way, and the adaptation of imported African species as a U.S. cash crop is being considered. In light of this American interest in importation, the objectives pursued and results identified by game ranchers in African countries may provide insight for U.S. consideration.

Two types of operations in the United States are similar to the wildlife management schemes in Africa: 1) game ranches that permit hunting of wildlife, and 2) native game farming or herd management of a single indigenous species such as buffalo or elk to produce meat, hides, and other products.

Game Ranches

The Texas Parks and Wildlife Department reports more than 800 game ranches in that State. The Exotic Wildlife Association, a group of game ranches, has 200 members. The State's boom in game ranches has been encouraged, in part, by the promotional efforts of energy companies that provide their top executives with trips to such ranches.[13]

Many ranches have game indigenous to the United States, as well as imported animals. The 50,000-acre Y. O. Ranch in Mountain Home, Tex., for instance, has 10,000 game animals. Half are drawn from native species. The balance are animals culled from 35 African and Asian species. These include antelopes, axis deer, zebras, ostriches, and giraffes.[14]

Game ranches in the United States are almost exclusively focused on sport. They might become more profitable if excess animals could be slaughtered and marketed. A major factor in marketing game meat is Federal and State legislation that bars such sale except under very restrictive conditions. For example, leg-

*Reservations expressed by AID officials in telephone interviews in August 1982 are strongest regarding the economic feasibility of game ranching without a major export market.

[12]Fred Wagner, Associate Dean, College of Natural Resources, Utah State University, June 1982, telephone interview.

[13]Charles Schreiner IV, manager and co-owner of Y. O. Ranch, Mountain Home, Tex., April 1982, telephone interview.

[14]Ibid.

islation requires inspection of wild animals before they are slaughtered for public consumption. Federal laws also require slaughterhouse facilities for game that are separate from those for domestic meat. If game animals have to be first captured and then transported to a specific slaughterhouse for inspection before being killed, the process may make the final product cost prohibitive.[15]

Native Herd Management

One of the principal wild species being managed for commercial exploitation in the Western United States is the American bison (buffalo). Some herds are being raised on semiarid rangeland, particularly on those lands where precipitation for forage production for cattle is inadequate. The National Buffalo Association has some 800 members, of whom approximately 500 have herds. Ironically, the demand for buffalo meat from some supermarkets and restaurants exceeds the available supply, mainly because of the lack of both a centralized marketing system and uniform health inspection regulations.[16]

Experts on game ranching abroad are divided on the feasibility and advisability of introducing foreign (exotic) species to U.S. domestic ranges or expanding native species. Raymond Dasmann, who helped set up one of the pioneering game ranches in Rhodesia, believes that wild ungulates (hoofed mammals), in some settings, are capable of producing more meat than domestic animals.[17] Certain areas of scrub vegetation in California, he estimates, could yield up to 550 kilograms of meat per square kilometer, or more than seven times the average yield from domestic livestock. While the evidence is far from conclusive about the efficiencies of wild ungulates versus cattle in converting biomass to meat, advocates suggest it is sufficient to justify more research on managing ungulates for meat production. Raised in proximity with domestic cattle, they do not necessarily compete with the latter for vegetation but instead actually may assist in maintaining a better balance of forage for both.

To help develop a U.S. market for game meat, Texas Tech University is evaluating mixed ground meats comprised of venison, pork, and beef for palatability and nutrition .18 Generally, landowners with large stocks of wildlife are not yet investing much capital and other resources into its management. They are turning instead to more intensive production of livestock and other primary activities.[19]

Other experts state that imported animals would bring little, if any, ecological benefit. They suggest that such animals usually compete with the range of domestic or native species already competing for forage and may carry parasites that can be transmitted to animals or humans. One expert who holds this view suggested five ecological principles to consider in determining the efficacy of introducing an exotic animal to a new environment:[20]

- **Every habitat tends to be full.** Nature abhors a vacuum and there are few vacant spaces in natural communities. Physical space alone does not constitute a vacancy in the animal community. Sufficient vegetation, preferably not that favored by existing animals, must exist to support new animals.
- **Each species has a specific set of tolerances and must be placed in an environment to which it can adapt.** Ecological homologs are the best candidates for introduction to new lands. These are animals with identical counterparts, frequently found on another continent. They are often look-alikes, have identical habits, and

[15]Ibid.

[16]Judi Hebbring, Executive Director of the National Buffalo Association, July 1982, telephone interview.

[17]R. Dasmann, "Biomass, Yield, and Economic Value of Wild and Domestic Ungulates, " *Transactions of the 6th International Union of Game Biologists* (London: Nature Conservancy), pp. 227-233.

[18]Robert Warren, Assistant Professor, Department of Range and Wildlife Management, Texas Tech University, April 1982, telephone interview.

[19]G. Burger and J. Teer, "Economic and Socioeconomic Issues Influencing Wildlife Management on Private Land" (unpublished paper).

[20]James G. Teer, "Introduction of Exotic Animals, " *Wildlife Conservation Principles* (Washington, D.C.: Wildlife Society, 1979), pp. 173-175.

98-953 0 - 83 - 5

occupy similar habitats. The axis deer, for instance, is a homolog to the white-tailed deer.

- **Plastic species have higher probabilities of succeeding.** A plastic species is one that is able to adapt to varying conditions. Such a species often has large variations in its appearance as indicated by large numbers of races. North American ring-necked pheasants, for example, have subtle differences in coloration and other attributes which reflect the underlying genetic variation that makes them successful in a variety of locations.
- **Introduced species in direct competition for resources with closely related animals will fail.** Although dislocations of native species can occur, they usually have the advantage because they evolved in place.
- **Transplanting animals from complex communities, such as their natural habitat, to relatively simple communities, such as farms or game ranches, has been successful.** The significantly decreased presence of other types of life may give exotics an advantage in their new environment.

This same expert suggests that the Sonoran and Chihuahua deserts of the southwestern United States and northwestern Mexico might be suitable for oryx, gazelle, or springbok. But such marginal lands are few in North America, and good rangeland is almost fully used by domestic animals.[21]

Advocates of game ranching believe that the technological and ecological aspects of game ranching are favorable. They believe institutional factors such as encroachment of wildlife on neighboring lands, lack of marketing mechanisms, and health regulations are the main barriers to future development.[22] The long-term potential of game ranching, whether in the United States, Africa, or elsewhere, will depend on economic, social, and ecological conditions of the area.

If the potential exists for eventually marketing low-cost game meat in quantity, game meat could provide a more significant source of protein than now exists. With more secure markets, game ranching operations that fit into the ecology of the area in their use of the water, land, and vegetation also could provide one more means of economic productivity from arid and semiarid lands. As human exploitation destroys the natural habitats of wild animals, their existence as a wild species is threatened. This technology may have the added benefit of helping to preserve them for future generations.

[21] James G. Teer, Director, Welder Wildlife Foundation, April 1982, telephone interview.
[22] Raymond F, Dassman, Professor of Ecology, University of California, Santa Cruz, August 1982, telephone interview.

Chapter IV

Managing Water on Farms in Pakistan

Chapter IV

Managing Water on Farms in Pakistan

SUMMARY

This foreign irrigation experience with on-farm water management provides insights for problem analyses and technology adoption relevant to irrigated agriculture in the United States, in particular:

- use of a multidisciplinary team approach to problem analyses, data collection and evaluation, and design of the most appropriate technology package for effective on-farm water management;
- maximum farmer participation in development and adoption of technology solutions, including farmer involvement in water-use planning, design of the technologies and irrigation practices, and training in maintenance requirements for such technologies; and
- information synthesis and dissemination of project results and water management knowledge and techniques so that other projects can analyze the experience for possible relevance to their own agricultural water-use needs.

INTRODUCTION

Meeting future needs for increased food production will depend heavily on improving existing agricultural schemes that manage water. One study, for instance, projects that about one-third of the increased food production from 1975 to 1990 in Asia on irrigated lands would come from improvements to existing systems.[1] To what extent these increases can be achieved depends, in the opinion of many development experts, on successful water management and other practices at the farm level. As one U.S. Agency for International Development (AID) paper stated:

> The present drama in irrigation is not one of simply more large dams and reservoirs, but the improvement of water management for the total system with a special focus at the farm level to help farmers make more efficient use of water for increased crop production.[2]

Modern agricultural irrigation systems have involved billions of dollars in dams, reservoirs, and water conveyance works. At the same time, there is growing recognition that little emphasis has been placed on water allocation and application on farms.[3] Instead, irrigation planners often have assumed that delivering more water to farmers would improve crop yields without the need to consider actual farmer practices and participation. Yet an obstacle to increased agricultural production in many countries is poor on-farm management of water supplies.[4] A recent World Bank paper[5] proposing the establishment of an International Irrigation Management Institute identified the following problems with current irrigation schemes:

1. uneven distribution of water to farms along the canals, with lower productivity

[1] International Food Policy Research Institute, *Investment and Input Requirements for Accelerating Food Production in Low Income Countries by 1990* [Washington, D. C.: IFPRI, September 1979), p. 26.

[2] Agency for International Development, ''Planning Concepts for a Flexible Irrigation Water Management Strategy in Asia, " Asia Bureau memorandum, Jan. 25, 1982, p. 4.

[3] Ibid.

[4] Colorado State University, "Evaluation of the On-Farm Water Management Research Project, Colorado State University, " report to the Agency for International Development, September *1979*, p. *6*.

[5] Proposal by the Technical Advisory Committee to the Consultative Group on International Agricultural Research for the establishment of an International Irrigation Management Institute, April 1982.

at the plots farthest from the diversion point in the canal;
2. low crop yields caused by water loss in transmission;
3. unreliable and untimely water deliveries; and
4. waterlogging (the condition in which the water table rises to near the surface of the soil) and salinity.

Methods exist to improve on-farm water management, but implementing these methods has been difficult for a number of reasons. Close cooperation among farmers and between farmers and irrigation technologists is required. However, institutional mechanisms for involving farmers generally have developed piecemeal and without regard to deriving lessons that may have general application for future projects. Lack of systematic documentation of methods or results has constrained transfer of successful experiences from one country to another. An analysis by AID states that "the flow of scientific knowledge in irrigation is slow, erratic, and piecemeal" and that "seldom does one country know what works under what conditions at what costs in a neighboring country."[6]

A recent AID project in Pakistan was an attempt to address these problems by improving on-farm water management.

[6]Agency for International Development, Asia Bureau memorandum, op. cit., p. 11.

AID PROJECT IN PAKISTAN*

In 1968, AID contracted with Colorado State University (CSU) to help Pakistan address its problems of low water-use efficiency** on farms and low food production. A unique aspect of the contract was the requirement that CSU analyze and report the processes developed during the project, so that AID might draw from these experiences for use in other developing countries. CSU also was asked to develop information and training materials for use in graduate courses on water management.

The focus was the small farm. The pilot research area, the Mona Reclamation Experimental Project, covered 30 villages and more than 10,000 acres. Project work was later extended to other areas of Pakistan. The key participants were the CSU team, local Pakistani universities, farmers, and local and provincial governments.

*The description of this project is based on the evaluation report, other project reports, and telephone interviews in April and May 1982 with Max Lowdermilk, senior water management specialist consultant to AID, and Colorado State University project personnel, including Gaylord Skogerboe, project coordinator, 1974-80, and Thomas Trout, project agricultural engineer, 1976-78.

Water-use **efficiency refers to crop production per unit of water used, irrespective of water source, expressed in units of weight per unit of water depth applied to unit area.

Background

The broad objective of the AID-Pakistan water management project was to improve the effectiveness of water use through better control of irrigation water. This ultimately would help to increase economic returns to the farmer. Pakistan has about 25 million acres (10,125,000 hectares) of land under irrigation through the use of canals which divert water from the Indus River and its tributaries. This irrigation system is the largest contiguous system in the world. The river diversion process, large primary canals, and the distributional network of smaller canals are outstanding engineering achievements in diverting and conveying water. Yet little attention traditionally had been given to agricultural use of the water once it was delivered to the farm. The farmers were left to fend for themselves. Water distribution to the fields after release from the canals was poorly managed. Despite multibillion-dollar investments, crop yields remained low, and problems of waterlogging and salinity frequently were severe.[7] Salinity control and reclamation programs in the 1960's attempted to lower wa-

[7]Colorado State University evaluation op. cit., p. 7.

ter tables and provide additional water supplies, but they were not so effective as had been anticipated.[8] In 1976, as a result of research findings, Pakistan approved a $44 million matching loan agreement with AID for an on-farm water management pilot program to partially line and reconstruct 1,500 watercourses (out of more than 80,000 in the Indus River System). The research project continued under three successive contracts until AID activities ceased in 1980. The World Bank and the Pakistani Government are supporting many of the programs started during the AID/CSU project.

Collecting and Evaluating Data

One of the first tasks of the project was to measure watercourse losses that occur between the time water is diverted from canal turnouts to when it reaches the farmers' fields. Instead of 10- to 15-percent seepage losses as had been assumed by planners in Pakistan, real losses were found to be 40 to 60 percent.

Once the extent of watercourse losses was determined, the CSU team and farmers discussed various technologies and practices that could reduce those losses. They concluded that most of the losses could be prevented by rehabilitating earthen watercourses, lining critical reaches, and installing manufactured turnouts (devices to allow water to flow from the watercourse into the field).

The findings about losses of water in delivery to the fields also led to recommending less emphasis on large water supply works (such as dams) and more emphasis on water conservation and management.

Project Actions

Major project efforts were in technology adaptation, farmer participation, training, and information transfer.

[8]Ibid.

Adapting Technology To Meet Local Needs

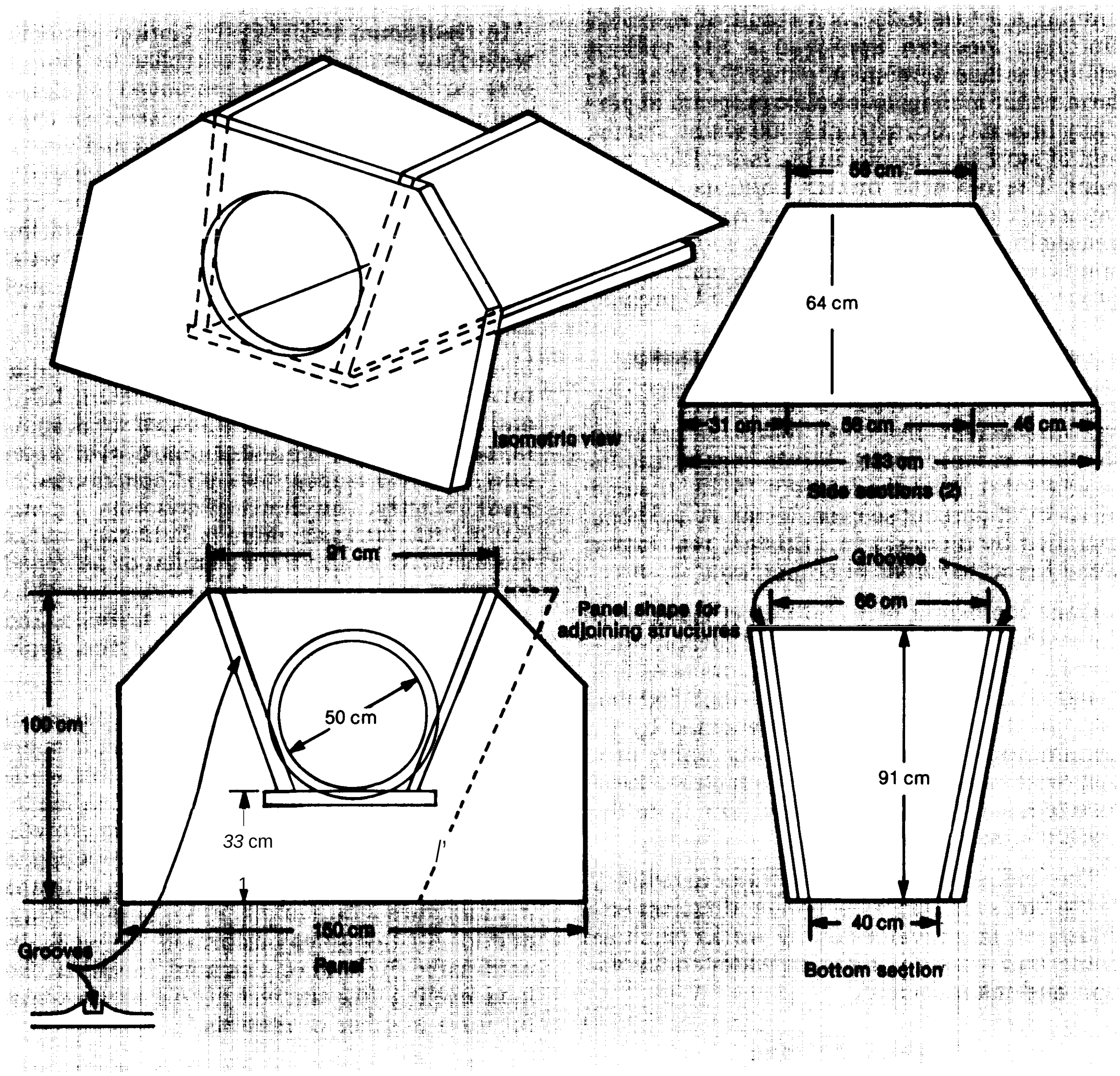
In traditional Pakistani irrigation systems, waterflow to the field is controlled by temporary earthen dams that are removed to release water and then rebuilt. This constant destruction and reconstruction has weakened watercourse walls, decreased efficiency of water delivery, and required considerable time and labor. Working with the farmers to find the most suitable system, the project staff went through several design phases of a new turnout device for controlling water flow to the fields. The final modified version was a simple, durable, locally built, and easy-to-install concrete turnout (see fig. 2). In addition to saving labor and water, the turnouts eliminated weak spots in the canal walls, improved control over water flow, reduced seepage loss, and contributed to local industry. The choice of concrete, a material of little intrinsic value in Pakistan, meant the turnouts would not be stolen or salvaged for other uses. Existing technology was thus adapted by the local artisans, the farmers, and the CSU team to solve a common local problem.

Uneven fields were another major factor in overirrigation. When a field is uneven, farmers overwater to cover the high areas; this leads to waterlogging of the lower areas, possible increased soil salinity, and uneven crop growth. To address this problem, the CSU team began a precision leveling program. Local artisans manufactured the equipment for land leveling, and local companies performed the work. In contrast to the concrete turnout, however, the land leveling program was not entirely successful for a number of reasons. *

1. It was less efficient, and thus more expensive, on small farms than on large.

*In spite of these problems, in 1973 the Pakistani Government embarked on a multimillion-rupee program of land leveling under an AID loan agreement.

Figure 2.—Precast Concrete Slab Installation for Panel Turnouts
(dimensions shown are for a 50-cm diameter turnout)



SOURCE: T. Trout, W. D. Kemper, and H. S. Hasan, *Circular Concrete Irrigation Turnout: Design and Construction, Handbook No. 1* (Denver, Colo.: Colorado State University, 1981), p. 49.

2. Leveling a typical small field in the Mona area required careful scheduling of equipment and nonuse of the field for a season. Most Mona area farmers, and in fact most of Asia, have small farms and cannot afford to take land out of production for a season.
3. Land leveling actually reduced yield for an additional season because topsoil was shifted. Most small-farm operators cannot sacrifice the yield necessary to have their fields leveled.
4. There may be additional environmental problems with erosion, since the soils will have been redistributed and infiltration to stabilize the soils may be reduced for the first season at least.

Farmer Participation

Social and economic constraints to effective water use and watercourse maintenance centered on the lack of: 1) effective local organization to mobilize labor and other resources, 2) knowledge among farmers regarding the magnitude of watercourse loss, and 3) technical knowledge among farmers for improving their watercourses.

Project workers recognized that, without farmer participation and cooperation on a long-term basis, technological solutions would have limited impact and any improvements made would be short-lived. The farmers were therefore involved in water use planning, designing experimental technologies and irrigation practices, and learning the maintenance requirements for such technologies.

The first step was enlisting farmers to assist in improving their watercourses. It was necessary to convince the farmers that if something needed to be done, the farmers would have to take the lead responsibility. Farmers were shown examples from other villages that had undertaken watercourse improvements with visibly beneficial results. They were encouraged by these demonstrations to reline and reconstruct their own local watercourses at sites where water loss had been greatest. The result was that water transport loss was greatly re-

Photo credit: Kay Muldoon for World Bank and IDA, December 1970

Using the traditional Pakistani method, a farmer opens his irrigation ditch to water his wheatfield on his 5-acre farm near the village of Bal

duced in the area and farmers gained a sense of responsibility for their own watercourse maintenance.

The next step was to setup water user organizations to help distribute the increased flow more equitably. Unfortunately, since water management in Pakistan is handled on a provincial basis, laws to assist the process had to be enacted one at a time. Nevertheless, far--reaching legislation was adopted in 1981 in a number of provinces to give legitimacy to the farmer organizations and provide them with legal status for bargaining purposes.[9]

Training and Information Transfer

The need for training local personnel became apparent early in the project. Pakistani research associates were brought to the university campus in Colorado for this purpose. This exchange proved valuable over the long term. According to one AID report, most of the train-

‘M. Lowdermilk, “State of the Art on Water User Associations for Improved Farm Water Management, ” paper for AID (undated].

98-353 0 - 83 - 6

ees who earned doctorates or masters degrees at Colorado "are involved in finding solutions to Pakistan's problems today." In addition, nearly 100 Pakistanis were trained in Pakistan for on-farm water management teams. The research and training functions also provided the opportunity for U.S. graduate students to study the problems firsthand in Pakistan.[10]

Perhaps the most significant result of the Pakistan project was the development and documentation of methodology for possible transfer to other settings. Project coordinators realized that in order to reap full benefits from the project, information would need to be circulated both within Pakistan and to other developing countries.

AID has published numerous manuals and technical reports explaining in detail the Pakistani process of onsite problem identification and the development of site-specific solutions and their implementation. It has produced handbooks describing the concrete-turnout design and manufacture, plans for encouraging farmer participation, and land leveling techniques. These handbooks are published in French, Spanish, and English. Within Pakistan, agricultural extension agents trained by the program continue their outreach work with farmers. A series of lectures has been videotaped for university instruction. (See app. B for a listing of AID-produced materials on irrigation water management.)

[10]Colorado State University evaluation, op. cit., p. 27.

Project Evaluation

Project evaluators identified several important factors that helped the project achieve some level of accomplishment:

- focus on a real world problem—i.e., "the poor management of existing irrigation systems;"
- use of an interdisciplinary approach, with a CSU team including a civil engineer, an agricultural engineer or agronomist, and a rural sociologist;
- CSU's collaboration with a number of Pakistani organizations responsible for varied aspects of on-farm water management;
- CSU's working relations with Pakistani colleagues (a large proportion of the project publications were of joint U.S.-Pakistani authorship); and
- CSU's contribution to the project design, made possible by AID's flexible management strategy.[11]

Broadly based data on crop yields as the result of this joint U.S.-Pakistan effort at improved water management are not available. On test plots, however, the project team found that good fertilizer responses and good yields were consistently obtained with irrigation levels as much as 40 percent below those previously considered to be optimum. CSU researchers have estimated that yields could be doubled if Pakistani farmers made some simple adjustments in their practices to reduce crop loss risk.[12]

[11]Ibid.
[12]Ibid., p. 23.

OTHER PROJECTS AS OUTGROWTH OF PAKISTAN PROJECT

Project in Egypt

Based on the successful efforts in Pakistan, AID embarked on a similar project in Egypt in 1978. Designed by many of the experts who worked in Pakistan, the Egyptian project also had as its goal improving the productivity of the small farm. The project components ineluded study of the economic effects of water distribution methods, fostering farmer organizations and better communications between farmers and the Ministry of Irrigation, and conducting research on techniques to increase agricultural productivity. This project is scheduled to continue until mid-1984.

Water Management Synthesis Project*

Drawing on the Pakistani and Egyptian projects data, AID launched a Water Management Synthesis Project. Its purpose was to stimulate international exchange of irrigation water management knowledge and techniques. The project is managed by the Consortium for International Development, a group of universities with experience in providing technical assistance to developing countries. The effort involves both information transfer and technical assistance. Information on irrigation developments worldwide is regularly analyzed and systematically distributed to about 700 officials, researchers, and other individuals in some 30 countries. A few countries have requested assistance applying the Pakistani/Egyptian problem-solving process to their own agricultural water-use needs.

*This discussion is based on information received from a telephone interview with Wayne Clyma, Colorado State University, codirector of the Water Management Synthesis Project, in August 1982. Utah State University shared project responsibility.

TECHNOLOGY TRANSFER CONSIDERATIONS

There is some disagreement within the U.S. agricultural community about the degree to which the approach to problem analyses and technology adoption used in Pakistan is now used in U.S. irrigated agriculture. Nevertheless, with billions of dollars of new irrigation investments being planned by the United States and other bilateral and international lenders, many opportunities exist for validating and developing further some of the processes used in the Pakistani and Egyptian AID projects. Elements that have broad value for planning and implementing improved water management schemes include:

Interactive Field Research

In both projects, research teams worked closely with local officials, farmers, and researchers to identify the practical problems and those areas that appeared to have high potential for payoffs. This interaction also was important to obtain feedback as the new technologies and methods were tested. The projects demonstrated that when farmers perceive potential or actual benefits from improved water management, they become more active in contributing their ideas, labor, and capital.

Integration of Research Results With Government Policy

In Pakistan, the project findings of 40 to 60 percent water losses were received skeptically by many Government agencies and officials. The project team, in conjunction with Pakistan's Water and Power Development Authority's planning unit, persisted in its efforts to convince policy makers of the validity of the findings through individual discussions, seminars, publications, and the replication of the research on additional watercourses.[13] The result was a draft "Revised Action Programme for Irrigated Agriculture" calling for lining 24,000 watercourses and rehabilitating 48,000 more by 1990. In Egypt, the government has high expectations for the project, and both the Ministries of Irrigation and Agriculture already are looking to the project personnel for general guidance on the design of further programs that will increase agricultural production.[14]

[13] Colorado State University evaluation, Op. cit., p. 43.

[14] Mid-Project Evaluation Report of the Egypt Water Use and Management Project prepared for the Agency for International Development, November 1980, p. 19.

Multidisciplinary Approach

This was considered a significant factor by project participants and evaluators. The multidisciplinary approach brought together economics, institutional aspects, and sociology, along with the traditional disciplines of engineering and agronomy, in planning, implementation, and training. The multidisciplinary training of water management specialists is one of the major innovations required in the future. Demand for broad-based water specialists may exceed supply, given the scale of planned investments in existing and new irrigation schemes. The International Food Policy Research Institute (IFPRI) estimates, for instance, that in eight Asian developing nations alone, an additional 55,000 professionals, technicians, and extension personnel will be required annually until 1990 to manage and operate new irrigated areas. [15]

An outgrowth of CSU's work in Pakistan and other developing countries was a grant from the Ford Foundation for partial support of an intensive interdisciplinary course. * The course, offered in 1981, is noteworthy in its coverage of social, institutional, and technical aspects of improved irrigation water management. Most participants were from foreign countries.[16]

Information Dissemination

Worldwide

The Water Management Synthesis Project is a step toward creating an information system to meet irrigation management information needs. Such an organization would need to be: international in scope, cross-disciplinary, concerned with improving irrigation systems management, focused on developing countries and small farms, directly linked with action on research, able to identify and report on improved management practices, and backed by sufficient resources. No organization currently publishing and distributing information on irrigation combines all these features.[17]

United States

Irrigation technologies and the institutional arrangements for implementing them are generally site-specific. Nevertheless, U.S. project participants in the Pakistan and Egypt efforts maintain that the experience gained in those projects provides insights for solving irrigation problems in the arid lands of the American West. One of the Pakistan project participants, for instance, applied the problem analysis and techniques he developed abroad to work being conducted with Colorado farmers. The project involved organizing farmers to use water management technologies to reduce the salinity of discharge into the Colorado River from the Grand Valley .18 This demonstration project, funded by the U.S. Environmental Protection Agency (EPA), was later expanded with support from USDA's Soil Conservation Service.

Another example comes from the feedback of Pakistan's project and the development of CSU's interdisciplinary short course on water management. Although practically all of the attendees have been foreign students, administrators, and researchers, the course is open to U.S. citizens. The cofounder of the course, Everett Richardson, recognizes that the institutional setting for irrigation in the Western United States is different from that in Pakistan or many other developing countries. Nevertheless, he feels that "the principles of problem-solving and organization building are directly applicable to U.S. situations. " In addition, a number of potential applications of these foreign projects to the Colorado situation were identified. They include:

- the research development process;

[15]IFPRI, op. cit., p. *63*.

*The Ford Foundation also has considered support for an international center to conduct interdisciplinary research and training in the irrigation management field. This idea, which was viewed as having a high priority by the Consultative Group on International Agricultural Research, a multidonor-sponsored organization with headquarters in Washington, D. C., was rejected, however, for budgetary reasons.

16 David M. Freeman, Associate Professor of Sociology, Colorado State University, August 1982, telephone interview.

[17]Consultative Group on International Agricultural Research, op. cit., p. 28 (see footnote 5).

'e'' Modest Technologies," ***Mosaic*** (Washington, D. C.: National Science Foundation, January/February 1977), pp. 46-47.

- foliar spray techniques for applying nutrients, which are not used widely in Colorado but could be and which are being used in the Columbia Basin;
- an inexpensive canal outlet for water control and measurement;
- project publications covering such items as the design of buried pipelines and furrow irrigation systems; and
- improved surface methods and water management techniques that do not involve the costly investments for sprinkler, bubble, or drip irrigation systems which many Colorado farmers feel are the only means to increase water efficiency. *

*Mr. Richardson prepared an informal paper, "Egyptian Experiences Applied to Colorado, " for AID in 1982. He said in a telephone conversation in August 1982 that one or two Colorado farmers were interested in working with him to implement some of the methodology from the Egyptian project. Irrigation farms in Colorado face a fivefold increase in their water charges in 1983 because of assessments on irrigation districts for construction of new dam spillways. Before these assessments, Colorado farmers could afford to hold on to extra shares of water. Richardson believes the increase from $20 to $100 per share (each share equals 7 acre-feet) will make it more attractive to sell shares and to become more water efficient.

Chapter V

Developing Guayule (Natural Rubber) as a Commercial Crop

Chapter V

Developing Guayule (Natural Rubber) as a Commercial Crop

SUMMARY

This report of Australian and U.S. efforts to develop guayule suggests that new agricultural uses exist for arid lands. In particular:

- guayule is a water-conserving plant, native to the United States, which has important potential strategic and industrial uses;
- Australian research and development efforts have used and advanced those carried out earlier by the United States; and
- continued cooperation is expected to enhance U.S. commercialization of guayule production and to protect both countries from threats to other supplies of natural rubber.

INTRODUCTION

The United States depends on other nations for a number of industrial materials that are important to U.S. industry. Some are called strategic, meaning critical to our national defense, and must be acquired and stored in the United States to meet national defense needs. Study and research is taking place to determine the economic and political feasibility of producing some of these industrial materials from plants. (See table 7 for a list of selected potential domestic crops and the materials they could replace.)[1] One such strategic material, the subject of this chapter, is natural rubber. Because natural rubber is a strategic material, it is advantageous to have domestic control of supplies rather than importing and stockpiling them.

In 1981 the world's natural rubber supply fell short of demand by 110,000 metric tons.[2] The World Bank has estimated that world rubber needs will increase by 5 percent annually for the remainder of this decade; recent changes in the international economy may make that

[1] Howard C. Tankersley, Soil Conservation Service, USDA, and Richard Wheaton, Program Manager, Natural Rubber Program, USDA, "Strategic and Essential Industrial Materials From Plants—Thesis and Uncertainties," (OTA draft), November 1982.

[2] *Natural Rubber **(Guayule)** Research in the United States,* A Combined 1980 and 1981 Report on Implementation of the Native Latex Commercialization and Economic Development Act of 1978, Joint Commission on Guayule, U.S. Department of Agriculture, August 1982 (draft), pp. 2-3.

Table 7.—Potential Domestic Crops and Uses

Crop	To replace
Guayule *(Parthenium **argentatum*** A. Gray)	***Hevea*** natural rubber, resins
Crambe ***(Crambe*** *abyssinica* Hochst. ex R. E. Fries)	High erucic rape oil and petroleum feedstocks
Jojoba *(Simmondsia chinensis* (Link) C. Schneid)	Sperm whale oil and imported waxes
Lesquerella spp.	Castor oil
Vernonia spp.—Stokesia spp.	Epoxy oils
Kenaf *(Hibiscus cannabinus* L.)	Imported newsprint and paper
Assorted oilseeds	Petrochemicals for coatings

SOURCE: L. H. Princen, *Alternate Industrial Feedstocks From Agriculture* **(Peoria, Ill.: Northern Regional Research Center, 1980). Agricultural Research Service, US. Department of Agriculture in "Strategic and Essential Industrial Materials From Plants-Thesis and Uncertainties," OTA draft, November 1982**

estimate high. During this decade, however, natural rubber, as opposed to synthetic, is expected to retain its one-third share of the total rubber markets

As the largest single user of natural rubber, the United States greatly influences the world supply-demand formula and the price of natural rubber. Contributing to the rising demand for natural rubber is the boom in radial automobile tires, which require about 40 percent natural rubber, almost twice as much as that required in nonradial tires. While radials wear longer, their growing popularity creates additional demand for natural rubber. Moreover, synthetic rubber still lacks the elasticity, resilience, and resistance to heat buildup of natural rubber, indispensable factors for bus, truck, and airplane tires.[4] Consequently, radial tires have captured an increasing market share of the original auto equipment package in the United States. For example, radial tire sales expanded from 25 percent for the 1973 car models to 99.9 percent for the 1981 models.[5]

[3] National Academy of Sciences, *Guayule: An Alternative Source of Natural Rubber, 1977,* p. 54.

[4] Ibid., p. 2.

[5] Earl Kraher, Statistics Office, Motor Vehicle Manufacturers Association, July 23, 1982, interview.

SOURCES OF RUBBER

Most of the world's rubber comes from two sources: the hevea rubber tree (Hevea *brasiliensis* (wind. ex A. Juss.) (Muell.-Arg.) and synthetics made from petroleum feedstocks. A number of factors raise doubt about the reliability of *Hevea* as a secure and expanding source of natural rubber?

- *Hevea* only grows within a restricted area of the tropics.
- Brazil, a major natural rubber supplier, had its production wiped out by leaf blight early in the 20th century. Leaf blight has been a serious constraint to further production, although blight-resistant strains are being developed. Chemical control also may be a possible, but expensive, answer to controlling future blight.
- *Hevea* is one of the most labor-intensive crops in the world.
- Several of the primary producing countries, mindful of *Hevea's* production costs, are switching to less labor-intensive and more profitable crops.
- Southeast Asia, which accounts for about 90 percent of world production, has been subject to political instability.

Simultaneous with the uncertainty of an adequate future natural rubber supply, the production of synthetic rubber is being affected by rising costs of the petrochemical feedstocks from which it is produced. This relatively recent development reinforces the prediction in a National Academy of Sciences report that the demand for natural rubber will continue.[7]

These factors have contributed to a growing interest in guayule *(Parthenium argentatum* Gray) as a promising alternative source of natural rubber. Guayule is a shrub which grows wild in some semiarid regions of North America.

‘3 National Academy of Sciences, op. cit., pp. 2 and 60; and interview with Richard Wheaton, Program Manager, Domestic Rubber Program and Executive Secretary, Joint Guayule Commission, April 1982.

[7] National Academy of Sciences, op. cit., p. 2.

ADVANTAGES AND DISADVANTAGES OF DEVELOPING GUAYULE

Guayule has a number of properties that make it attractive as a source of commercial rubber:

- Its rubber has chemical and physical properties virtually identical to those of *Hevea*.
- It grows well under plantation conditions

and can be improved through crossbreeding.

- It appears to be only slightly affected by latitude or altitude and therefore may be of interest to nations lying outside the Tropics that cannot produce synthetics.[8]

Certain characteristics of guayule make it particularly suitable for semiarid land cultivation. These relate to temperature and drought tolerance, yield, and durability. Guayule grows well in temperatures ranging from 770 to 1040 F (250 to 40°C), and wild guayule can survive temperatures below 32° F (0° C). Most literature suggests 16 inches (40 millimeters [mm]) of rainfall is optimal for growth. U.S. plantings during World War II showed that 11 to 25 inches (280 to 640 mm) were needed for commercial production. Experience with the shrub also indicates that if precipitation falls below about 14 inches (350 mm), supplemental irrigation may be needed. Within this moisture range, however, rubber yield is only slightly affected as water is reduced toward the lower ranges of tolerance. Finally, the root system can penetrate to a 20-foot depth (6.5 meters), with plants living for 30 to 40 years in their native environment.[9]

Despite these apparent advantages, guayule faces many technical and economic barriers to commercial development. Much technical refinement is required to reduce the cost of producing guayule to a level that is economically attractive. Some of the major difficulties involve solving problems at the early stages of agriculture production, such as developing guayule strains that contain uniformly high quantities of rubber.[10] The rubber content of harvested shrubs, for example, can vary from 8 to 26 percent of dry weight (table 8). *Verticillium* and *Phytopthora* root rots are the major disease problems, both of which are aggravated by excessive soil moisture. In its native habitat, guayule is rarely affected by disease, but under cultivation its susceptibility increases. Another problem is providing a secure supply at a production level that could meet demands consistently. In addition, the economics of the international rubber market must shift if there is to be commercial guayule development. One estimate is that guayule will be competitive when *Hevea* reaches 90 cents per pound.[11] The average price of *Hevea* from January to June 1982 was only 46.6 cents per pound, even though it reached a peak of nearly 74 cents in 1980 (fig. 3). If the international economy revives, market prices might again rise, providing incentive for guayule investment.

In spite of these difficulties, one country with considerable arid and semiarid land, Australia, has begun to research the feasibility of the commercial production of guayule. The next section reviews some of the principal elements of the Australian experience as one example of the growing interest in the commercialization of guayule.

Table 8.—Components of Harvested Guayule Shrub

Moisture	45-60 percent
Rubber	8-26 percent[a]
Resins	5-15 percent[a]
Residue	50-55 percent[a]
Leaves	15-20 percent[a]
Cork	1-3 percent[a]
Water solubles	10-12 percent[a]
Dirt and rocks	Variable

[a]Dry weight basis.

SOURCE: National Academy of Sciences, *Guayule: An Alternative Source of Natural Rubber* (Washington, D. C.: NAS, 1977)

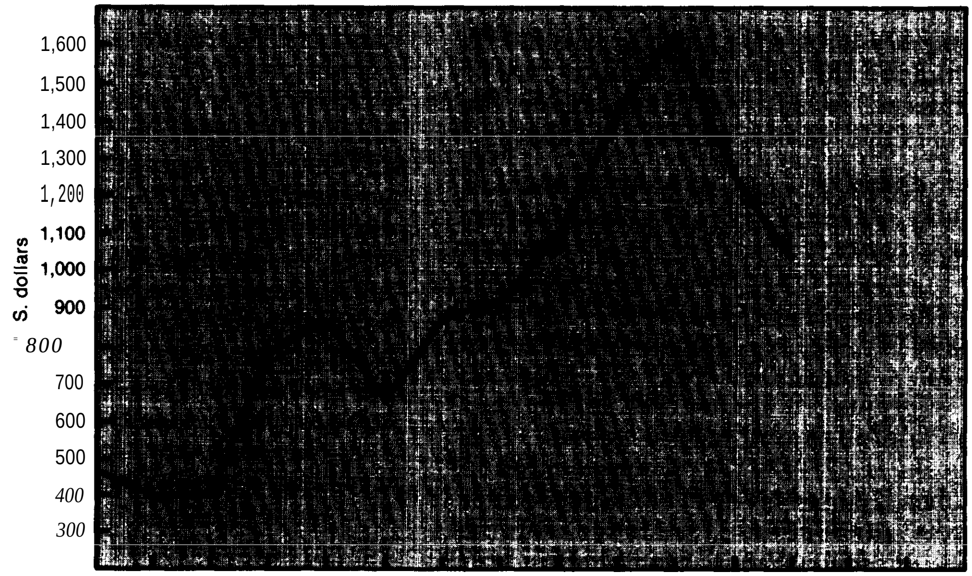
8 Ibid., pp. I-10.

9 For a more complete description of guayule's characteristics, see L. W. Owens, *Report on Guayule Potential and Research in South Australia,* February 1981, sec. 3 (unpaginated); and A. R. Bertrand, "A Review of Guayule Research: 1941 -1981," memo to Chairman of Joint Guayule Commission, in Joint Commission Report, appendix.

10 National Academy of Sciences, op. cit., p. 12; and E. G. Knox and A. A. Theison (eds.), 1981 *Feasibility of Introducing New Crops: Production-Marketing-Consumption (PMC) Systems,* ch. VI, Guayule, G. L. Laidig, pp. *100-I2o* (Emmaus, Pa.: Rodale Press].

II Wheaton interview (see footnote 6).

Figure 3.—Natural Rubber Prices per Metric Ton



	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Price per metric ton[a]	$462	$399	$402	$785	$868	$659	$872	$917	$1,108	$1,423	$1,625	$1,252	$1,027[b]			
Price per pound	21.0c	18.1c	18.2c	35.6c	39.3c	29.9c	39.6c	41.6c	50.3c	64.6c	73.7c	56.8c	46.6c			
% increase or decrease	+ 20%	– 13%	(level)	+ 95%	+ 10%	– 24%	+ 32%	+ 5%	+ 20%	+ 28%	+ 14%	– 23%	– 18%			

[a]New York price R.S.S. 1 Rubber [b]Jan.-June Average

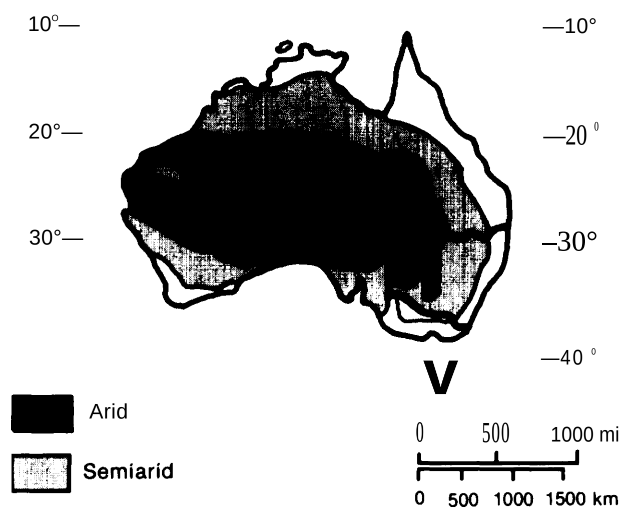
SOURCE: Joint Commission on Guayule, U.S. Department of Agriculture, *Natural Rubber (Guayule) Research in the United States,* A Combined 1960 and 1981 Report on Implementation of the Native Latex Commercialization and Economic Development Act of 1978, August 1982 (draft), P. 3.

RESEARCH ON GUAYULE IN AUSTRALIA

Background

Australia became interested in guayule in **1941**, when the Japanese takeover of Malaya (now Malaysia) cut off its natural rubber supplies. A guayule project was particularly attractive to Australia, a country where three-quarters of its land area—1.9 million square miles (490 million hectares)—was arid and not in any competing use at that time. As can be seen in figure 4, the entire interior of the country is a large arid basin, experiencing high temperatures and an evaporation rate of 100 to 120 inches (2.5 to 3 meters) per year.[12] Some of the area is favorable for guayule production. In July 1942, Australia began a wartime project to investigate alternative sources of natural rub-

Figure 4.—Australia



SOURCE: Distribution of Arid Homoclimates. Eastern Hemisphere. Western Hemisphere. U.N. Maps No. 392 and 393, Revision 1, by Peverill Meigs, UNESCO, Paris, 1960,

[12] R. O. Slayter and R. A. Perry (eds.), Arid *Lands of Australia* (Canberra: Australian National University Press, 1969), p, 56.

ber. A principal focus was guayule, a plant not native to Australia. The United States, which was conducting a similar experiment in the U.S. Southwest, provided Australia with seeds and technical information.[13]

This early Australian experiment made some progress in determining plant growth and rubber production potential. The project ceased, however, when the war situation improved for the Allies in 1943 and *Hevea* rubber became more plentiful. Limited guayule cultivation continued into the 1950's entirely as a research effort with no goal of commercialization, and was abandoned at the end of the war.

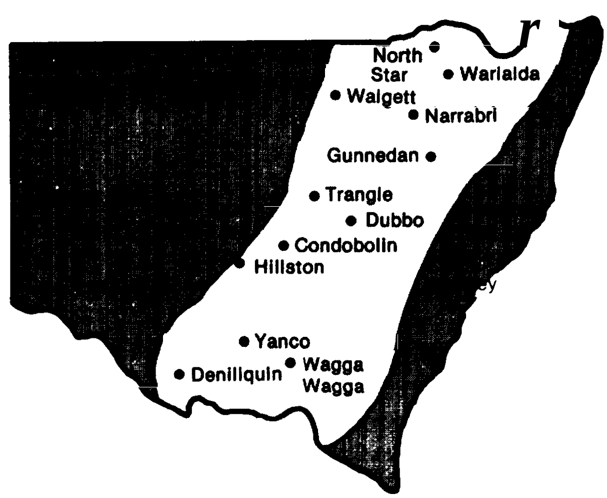
Current Research

In 1980, guayule research was resumed in Australia in New South Wales, a state in the eastern corner of the country. Figure 5 shows the shaded region considered potentially suitable for guayule development. This area consists of the western slopes and plains which fall along a north-south belt through the traditional cropping areas in New South Wales. Nine test plots in this region were planted with guayule –Condobolin, Yanco, Narrabri, Trangie, North Star, Warialda, Hillston, Wagga Wagga, and Deniliguin. The project was funded for 3 years. Its overall goal has been to determine the feasibility of guayule commercialization under dryland conditions in New South Wales. (See app. C for estimated costs of producing 1 acre of guayule in New South Wales.) The Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia is assisting with the research. In addition, the United States is exchanging research and development information through a joint agreement with the New South Wales Government. The priority research objectives of the project are:[14]

- *Developing techniques for direct seeding of guayule under dryland conditions.*— CSIRO anticipates that higher yields of rubber can be gained by spacing guayule plants in a manner similar to that used in growing cereal grains.
- *Understanding the physiology of guayule growth and rubber production.—Information* from test plots about the effects of solar radiation, temperature, and soil water on key plant parameters will be used to identify the most favorable environments for guayule production.
- *Developing guayule strains best suited to Australian dryland environments.—The* United States is providing some of its highest yielding rubber varieties for testing in Australia.[15]
- *Investigating alternative processing methods for guayule.*

Results of this Australian research already show a number of promising signs. First, there appears to be the potential for considerable savings in seedling costs, one of the more expensive aspects of guayule production. Consultants to CSIRO have projected eventual seedling

Figure 5.—Test Sites, Western Slopes, and Plains (shaded) of New South Wales



SOURCE: I. A. Siddiqui and P. Locktov, *A Feasibility Study on the Commercialization of Guayule in New* South Wales, Australia, December 1981, California Department of Food and Agriculture

[13] For an account of this early project see R. L. Crocker and H. C. Trimble, *Investigations of Guayule in South Australia* (Melbourne: Commonwealth of Australia, Council for Scientific and Industrial Research, Bulletin No. 192, 1945).

[14] G. Alan Stewart, Convenor, CSIRO Working Party on Guayule. Correspondence to Dr. B. T. England, May 17, 1982.

[15] I. A. Siddiqui and P. Locktov, *A Feasibility Study on the Commercialization of Guayule in New South Wales, Australia,* California Department of Food and Agriculture, Division of Plant Industry (Sacramento: December 1981), p. 12.

costs of $6 per 1,000. This is significantly below the price of $80 to $100 per 1,000 seedlings charged by two California nurseries in 1982, although such costs were affected by relatively low production volumes.[16]

Second, Australia is making progress in developing technology for processing the guayule. Table 7 from chapter III shows the components of a harvested guayule shrub. The method preferred by researchers at CSIRO to extract the rubber from the debris includes shrub deresination and solvent extraction of the rubber. This complicated chemical process involves parboiling and cleaning the shrub, hammermilling it through a fine-grade screen to extract the resin, and finally extracting the rubber by dissolving it in a solvent. With this separation process, up to 95 percent of the rubber can be recovered.[17] An alternative extraction method involves a pressure vessel to waterlog the debris accompanying the rubber, which in a subsequent slurry tank sinks, leaving the rubber afloat. But the water requirement for this alternative process is a major disadvantage in arid areas.[18]

Future Research

A report of U.S. scientists who visited Australia in 1982 indicates that the New South Wales project has already made progress. The trip was made under the Memorandum of Agreement between New South Wales and the U.S. Department of Agriculture for the interchange of research information, germ plasm, and scientists involved in guayule research. Extensive research data and information were exchanged, accompanied by discussions in reviewing the problems and potential areas of research in New South Wales. Sites visited included Narrabri, Trangie, Condobolin, and Hillston. The U.S. research team, which traveled some 700 miles (1,100 kilometers) by auto throughout the project site, obtained important information on the environmental conditions under which guayule would be grown in New South Wales. The report recommends priorities for future research in a number of areas, three of which have particular relevance for arid and semiarid lands:

- evaluation of existing varieties, both for resistance to drought and for high rubber yield;
- determination of water requirements under various plant spacings and with cultural practices which conserve or collect water; and
- evaluation of direct seeding in the field under irrigation versus using transplants from nurseries.[19]

In addition, the report recognizes the need for research in areas involving infrastructure for commercial guayule production—namely, harvest mechanization, processing, and marketing. The challenge, as summarized by Australian scientists, is that guayule is "a new crop to Australia and to the world" and "will require a significant research and development effort before becoming a commercial crop on a large scale."[20]

[16] Interim Report, Guayule Working Party, Commonwealth Scientific and Industrial Research Organization (CSIRO), Mar. 25, 1982, p. 16.

[17] National Academy of Sciences, op. cit., p. 35.

[18] Ibid., pp. 50-52.

[19] *Technical Report,* U.S. Scientific and Technical Exchange Team Visit to New South Wales, Mar. 26 to Apr. 17, 1982 (draft).

[20] Interim Report, CSIRO, op. cit., p. 57.

U.S. GUAYULE PRODUCTION AND RESEARCH

Guayule has been periodically exploited for commercial purposes in the United States. Early in this century, for instance, wild stands in parts of Texas were harvested. The guayule rubber industry in Texas disappeared, however, when the wild plants were overused and not replanted. In 1910, guayule mainly from Mexico provided nearly 50 percent of the natural rubber consumed in the United States and 10 percent of world consumption. Production resumed briefly in the *1920's* when British control of Malaya's rubber monopoly caused prices to triple.[21]

The United States again became interested in guayule, as did Australia, in December 1941 when Malaya fell to the Japanese. The United States, like other Allied nations, lost more than **90** percent of its natural rubber supply. The U.S. Government started the Emergency Rubber Project (ERP) in February *1942* to develop guayule commercially. This project involved more than *1,000* scientists and technicians. Supported by a work force of 9,000 workers, ERP planted almost **32,000** acres of guayule at 13 sites in 3 States. The project produced *1* billion guayule seedlings. Toward the end of the project, 15 tons of rubber were being produced daily at mills near the California towns of Salinas and Bakersfield.

In spite of its promising future, the ERP had a short life. By the end of the war, synthetic rubber was being produced in commercial quantities, and surplus stocks of natural rubber began arriving from Southeast Asia. With these developments, the wartime economic and strategic justification for guayule production in the United States faded. When the project formally ended in *1946,* about 21 million pounds of rubber on **27,000** acres had to be burned or plowed under so that the land could be used for other crops. Most of the seeds from the genetic improvement program were destroyed along with hundreds of millions of seedlings.[22]

In recent years, several factors have created renewed interest in developing a domestic natural rubber industry based on guayule. Included among these are larger deficits between world production and consumption, total U.S. dependency on foreign sources, and the increase in Hevea prices over the past decade.[23]

In *1978,* the Native Latex Commercialization and Economic Development Act was passed, calling for the establishment of a U.S. Joint Commission on Guayule Research and Commercialization, The goal of this Commission has been to determine the potential for U.S. commercialization of guayule.[24] Commission members are drawn from the U.S. Departments of Agriculture, Commerce, and Interior, and the National Science Foundation. In fiscal year *1981* these agencies had a combined budget of about **$2.6** million for guayule research, and in fiscal year *1980, $1.4* million. The funds have been used for research in genetics, agronomic, and processing technology. Since its founding, the Commission has developed an additional 7-year program to carry forward research and development beyond the initial authorization period which ends in *1983.* The Commission plan calls for refining the technology for growing and processing guayule to the point where it can be transferred to the private sector for commercialization.[25] The future of the Commission and its work under the Latex Act is uncertain.

Also, in *1978* the California legislature enacted a pilot program to determine the feasibility of the commercial production of guayule in California. The State of California in *1980* entered into a cooperative agreement with the New South Wales Government to assist in establishing a guayule research and development program.

The modest program of guayule research in the United States is being conducted under government auspices or with government assistance. Firestone and Goodyear Tire and Rubber Companies, for example, have been engaged periodically in research on guayule plantings, some of which involves government support.[26] Texas A&M University, New Mexico State University, Los Angeles State and County Arboretum, and the University of Arizona also have been doing selected guayule research with some government assistance,

Generally, the move toward a massive U.S. commercialization project has been tempered

[21] National Academy of Sciences, op. cit., pp. 17-23.
[22] Ibid.
[23] Joint Commission Report, op. cit., pp. 2 and 3 (see footnote 9).
[24] Native Latex Commercialization and Economic Development Act of 1978 (Public Law 95-592).
[25] Joint Commission Report, op. cit., p. 14 (see footnote 9).
[26] Wheaton interview (see footnote 6).

by political and economic constraints. To replace completely the imported *Hevea* with domestically produced guayule, the United States would have to plant more than 5 million acres, an area about the size of New Jersey .[27] Even if this were possible, the implications of total U.S. rubber independence for U.S. balance of payments and foreign trade with present rubber-producing countries make the undertaking politically complicated at present.[28]

A small step in the direction of U.S. commercialization was made, however, in September 1982 when the Department of the Navy awarded a $400,000 contract to the Gila River Indian Community of Sacaton, Ariz., for growing and processing guayule. The contract calls for the preparation of 10 technical reports on growing and processing a prototype domestic guayule rubber industry in the United States. It also provides for a $20 million guaranteed loan from the Federal Financing Bank to undertake pilot research work. Under this contract, the Gila River Indians will cultivate approximately 5,000 acres of guayule shrubs with harvest planned for 1987. They will negotiate a subcontract with the Firestone Tire & Rubber Co. for research and development of the prototype processing facility. The Indians will own and operate the facility. [29]

[27]1977 National Resources Inventory (revised 1980), Soil Conservation Service, USDA.
[28]Ibid.

[29]Press Release, Senator Barry Goldwater (Arizona), Sept. 29, 1982.

U.S. COOPERATION WITH OTHER COUNTRIES

The United States has entered into a few cooperative arrangements with other countries on guayule research. As mentioned earlier, the United States and New South Wales (through their Departments of Agriculture) signed a cooperative agreement in 1982 to help expedite their respective research projects with the exchange of information on research and development several times each year.[30] Exchanges of seed lines, plant materials, and raw rubber products also are planned.

The U.S. and Australian projects complement each other, the former focusing on irrigated guayule production, the latter on dryland production. If Australia is able to fulfill the findings of feasibility studies on guayule commercialization, it could become not only self-sufficient in natural rubber but also “a major exporting nation.”[31] This development could serve both U.S. and Australian national security interests by providing them with an additional, stable source of supply for natural rubber and its products.[32] In addition, the commercial production of guayule in New South Wales may be more favorable than in California. First, the New South Wales land is available at relatively low cost. Second, rainfall is evenly distributed in the proposed planting areas; thereby requiring little or no irrigation.[33]

The United States is also cooperating with Mexico on a less formal basis in guayule research and development through a Joint Working Group on Agriculture, formed under the U.S.-Mexico agreement for scientific cooperation.[34] Of particular interest to American researchers is the Mexican Government’s pilot processing plant in Saltillo, Mexico. This plant, the world’s only commercial processing plant for guayule, uses a flotation extraction process and has a capacity to process 1 ton of wild guayule daily.[35] Joint projects will be developed based on exchanges of plant material, information, and scientists associated with specific projects.[36]

[30]*Summary Report* (draft), U.S. Delegation, Scientific and Technical Exchange between Departments of Agriculture, New South Wales, Australia, and United States, Apr. 9, 1982.
[31]Ibid.
[32]Owens, op. cit. (see footnote 9).

[33]Siddiqui and Locktov, op. cit., p. 10.
[34]Joint Commission Report, op. cit., pp. 12-13 (SH? footnote 9).
[35]Wheaton interview (see footnote 6).
[36]Joint Commission Report, op. cit., app. 15 (see footnote 9).

Other countries have expressed interest in cooperating with the United States in developing guayule as a potential commercial crop. These include Brazil, Chile, India, Kenya, Israel, and Egypt.[37]

[37] 1 bid., p. 13.

TECHNOLOGY TRANSFER CONSIDERATIONS

The United States can expect to gain much scientific and technical information about guayule growth and production from cooperative research with other countries. With respect to the U.S.-Australian exchange, benefits include:[38]

- speeding up the solution of many of the problems of agronomic production, genetic improvement, and new plant selections;
- developing scientific data relative to dryland cultivation and new varieties that will significantly aid U.S. natural rubber development; and
- strengthening the U.S. and Australian alliance, which is important in case of any future interruption of Hevea supplies from Southeast Asia.

More specifically, the United States has recently considered dryland guayule production in Texas, and studies in New South Wales should particularly benefit this U.S. effort. For example, in New South Wales, different methods for extracting rubber from guayule are being compared. Both the United States and New South Wales are interested in finding a use for byproducts of guayule processing. Research has begun in New South Wales to identify oils, waxes, and volatile compounds that can be obtained from guayule leaves. U.S. researchers such as those at the USDA Biomaterials Conservation Laboratory in Peoria, Ill., should find exchange of information most helpful to them in their work.

As these cooperative exchanges have already shown, there can be complementary value to each country in such an effort. Research and international cooperation are important not only for guayule, Plant research and development for industrial feedstocks as well as for food products has national and international benefits. Such research not only provides alternative sources of supply but also develops a better scientific knowledge and research base for extrapolation to other areas where potential may exist for greater use of arid and semiarid plants (see ch. II).

[38] Technical Report, U.S. Scientific and Technical Exchange Team Visit to New South Wales, Mar. 26 to Apr. 17, 1982.

Chapter VI

Israel's Water Policy: A National Commitment

Chapter VI

Israel's Water Policy: A National Commitment

SUMMARY

Israel's concerted national response to its severe water problems involved the use of several measures that may have relevance for some of the arid/semiarid U.S. agricultural regions. These include:

- development of a vigorous water-data collection and evaluation project, including the mapping of ground water resources to determine their sources and ages;
- close monitoring of withdrawals and recharge to predict ground water level changes and allowable withdrawals;
- management of water demand through the use of such tools as water-use metering, pricing, and allocation; and
- extensive and ongoing research, training, and technical assistance programs that involve the farmer in the design, manufacture, and application of new water management devices and techniques.

INTRODUCTION

Israel's approach to water management has been defined largely by limited freshwater resources, poor natural distribution of those resources, and an expanding and dispersed population.[1] The latter aspect has been nearly as important a factor in determining water policy as the physical characteristics of the land and water resources (see table 9). The population of Israel has more than quintupled since the country's founding in 1948, increasing from about 800,000 to nearly 4 million largely because of a liberal immigration policy. To accommodate this growth, Israel directed its new citizens away from established population centers to new settlements throughout the country. This created not only a demand for more water but also a need to distribute the water to dispersed and remote users at an equitable cost.

The major obstacles to meeting these demands have been:[2]

[1]S. Arlosoroff, "Israel-A Model of Efficient Utilization of a Country's Water Resources," paper prepared for United Nations Conference on Water. Much of this section is derived from this article and an interview in April 1982 with the author.

[2]M. Ben Meir, "Development and Management of Water Resources in Israel, " *Water and Irrigation Review*, Journal of the Water Workers Association of Israel (Tel Aviv), July 1981, p. 15.

Table 9.—Facts About Israel, 1979-80

Total population	3,921,700	
Number employed in agriculture	*83,200*	
Total area	5,021,000 acres	(2,032,000 hectares)
Cultivated area	1,055,117 acres	(427,000 hectares)
Irrigated area[a]	469,490 acres	(190,000 hectares)
Total freshwater available	1,378,400 acre-feet	1.7 billion cubic meters/year
Agricultural water available	973,000 acre-feet	1.2 billion cubic meters/year

[a]From Central Bureau of Statistics, Ministry of Agriculture, Jerusalem.

SOURCE: Statistical Abstract of Israel, 1981.

1. There is no rainfall during the 6 months of summer, and total rainfall varies greatly from year to year.
2. The principal sources of water, the Jordan River and Sea of Galilee, are located mainly in the northern half of Israel, while more than half of the arable land is in the south.
3. Capacity in the Sea of Galilee and the two major aquifers is insufficient to meet both perennial and seasonal storage needs.
4. Most of the water is needed at elevations much higher than these main sources of supply; the Galilee, actually a lake, is more than 200 meters below sea level. Water must be pumped, and its distribution is energy intensive.
5. The coastal areas next to the Mediterranean contain ground water, but withdrawals must be controlled to prevent seawater intrusion.
6. Freshwater in deeper limestone reservoirs is adjacent to highly saline water bodies. To prevent intrusion of brackish water into the reservoirs, withdrawals must be kept below the annual recharge rate.

Israel's available freshwater resources amount to about 1,378,400 acre-feet (1.7 billion cubic meters) annually. By 1985, an estimated 1,621,700 acre-feet (2 billion cubic meters) per year will be needed or about 15 percent more water.[3] Israel has limited options for increasing water supply. Virtually no untapped sources of freshwater exist, and present ground water levels are not likely to increase. Other water sources are questionable, particularly in terms of quality, and not yet fully developed. They include reclaimed sewage, brackish water, and storm waters. The Israeli Government's plan for agricultural development during the first half of the 1980's estimates that the total volume of water available to agriculture in 1985 will grow only slightly—from a 1980 level of about 973,000 acre-feet (1.2 billion cubic meters) to 1,135,200 acre-feet (1.4 billion cubic meters).[4]

By the end of this century, it is expected that 30 to 40 percent of the water used for irrigation will be reused effluents, and 10 percent of the total amount of water used for agricultural purposes will be brackish water of high salinity.[5] This projection reflects a shift in focus in water resources during the last decade from the development of additional supplies to management of demand.[6] Demand management aims to make a given physical volume of water provide the maximum possible benefit to the community. Since the early 1970's, Israel has followed a policy by which development of new water resources has been considered and weighed against the investments and benefits of demand strategies. This policy has been informally called "drip and automation versus dams, deep boreholes and pipes."*

[3]Arlosoroff, U. N., op. cit.

[4]*Six Year Plan for Agricultural Development, 19801985* (Jerusalem: Ministry of Agriculture, 1981), p. 84.

[5]Ibid., p. 141,

[6]Meir, op. cit. p. 2.

*Comments made by S. Arlosoroff, former Deputy Water Commissioner for Israel in correspondence, Oct. 28, 1982.

WATER USE PROGRAMS

Israel has pursued a concerted, integrated response in dealing with its severe water problems. Managing demand for water is a major element. Other elements include national control of water resources, development of a national water supply system, and technical assistance to farmers and to all sectors of water use.

These programs have been possible for a number of reasons. Israel is a small country; its size has facilitated the widespread installation of water-related technologies. Consequently, distribution of water has not required prohibitive investments in pipelines and canals. The country as a whole has had a serious commitment to the development of a strong national water policy and program effort. The lack of a traditional farming community or a strong private water property rights system at the birth of the nation also has reduced opposition to an extensive national water legislation with strict enforcement provisions.[7]

State Control of Water Resources

Under Israeli law, the water resources in the country are public property. They are subject to the control of the state and are intended for the use of its inhabitants and for the development of the country. The country's first water law regulations were drafted and enacted in 1949. The legislation was gradually amended and perfected until the current comprehensive water law went into effect in 1959.[8]

Supply and Distribution[9]

Israel embarked on an ambitious scheme in the late 1950's to create a national water supply system to meet the demands of a growing population and to distribute water equitably. The backbone of the system, known as the national water grid, is the National Water Carrier, which began operation in 1964.

The Carrier, Israel's largest single development project, consists of a 155-mile (250-kilometer) system of pipelines, canals, and tunnels extending from the Sea of Galilee in the north to the Southern and Western Negev Desert with an extension up to Eilat on the Gulf of the Red Sea. From 1964 to 1975 it transferred an average 283,800 acre-feet (350 million cubic meters) of water annually, operating to maximize use of the land's storage capacity. Regional exchanges of water between sources with high and low salt concentrations have helped to mitigate problems of salinity, During the wet period, when demand is not so great, water from the carrier is used to artificially recharge wells and aquifers. Thus, heavier withdrawals

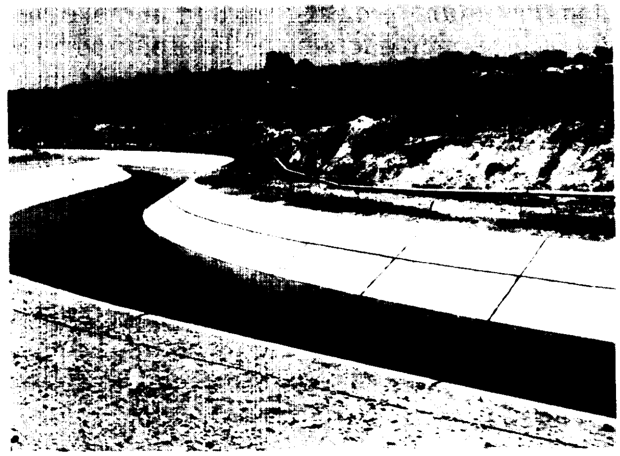


Photo credit" Embassy of Israel

Israeli's National Water Carrier, known as the national water grid

are possible during the dry season. Recharging has the additional effect of mixing high-quality water with lower quality ground water. Wastewater, after tertiary treatment, also is used for recharging. The flexibility of this system of recharge and water transfer enables Israel to achieve a very high degree of efficient water use.

As part of this program, the Government conducts a vigorous water exploration and research project, including mapping of ground waters to determine their source and age, prospecting for new resources, and increasing the flow and use from sources already known. The national grid and close monitoring of withdrawals and recharges allow Israel to predict ground water levels to within a few centimeters. Wastewater reuse, desalinization research and application, and operational cloud seeding for enhancement of precipitation also area part of this effort.

Demand Management[10]

In view of its limited water supplies, Israel has chosen to focus heavily on demand management. This policy has required a complete package of elements, including legislation, administration, sanctions, funds for research and

[7]Arlosoroff interview.

[8]S. Arlosoroff, ''Water Resources Development and Management in Israel, " KIDMA, published by the Israel Chapter of the Society for International Development (Jerusalem), vol. 3, No. 2 (No. 10/1977), p. 5.

[9]Arlosoroff, U. N., op. cit.; and Meir, op. cit.

[10]Arlosoroff interview.

demonstration projects, and in some cases funds to support adoption of the preferred technology. It has been justified in light of the need to maintain or increase irrigated agricultural production under arid/semiarid conditions, when government resources for development of new water resources are limited.

Under this policy, water use is strictly regulated within a licensing and allocation system. The water law prohibits inefficient water use. The primary tools used to discourage inefficient water use are metering, pricing, and allocation.

Metering

All water users, whether in agriculture, industry, or the domestic sector, are metered. Water users are licensed by the Government and the license must be renewed annually. Failure to use water in a manner consistent with the license can lead to its forfeiture. Each license prescribes the quantity of water that can be withdrawn from any source, including underground, runoff, * and sewage effluent sources. Underground sources supply 60 percent of the water consumed by Israel. The water commission has the right of unlimited access to water meters and inspects them regularly. Most water meters must be installed outside buildings. If a meter is inside under lock, the state inspector must be given the key. Farm units are included within the metering requirements, and all farm wells are metered and inspected.

Pricing

The price of water is state controlled. Those people living in areas where water costs less to produce, such as the coastal Mediterranean sector which has access to a shallow aquifer, must pay a levy (based on cubic meter of use) to a national Water Charges Adjustment Fund. In the more remote or high-elevation regions where water costs are high, the Fund pays a subsidy to users. In addition, water rates are set on a progressive block basis—that is, as more water is used, the marginal unit cost becomes higher.

Allocation

As much as 70 percent of Israel's water withdrawal is designated for agricultural water use (table 9). So it is important that allocation of water for farming be strictly managed. Each farmer, cooperative rural settlement (moshau), or collective farm settlement (kibbutz) receives a yearly allocation, based on the type of crop and the average water use for the particular area over time. A citrus grower, for instance, will be told that the allocation for the coming year will be "x" amount. Moreover, the grower may also be told that, in the following year, it will be "x" minus an amount which should be saved because of increased water use efficiency. * This policy of further restricting allocation for the next year is not implemented every year.

The farmer may appeal an allocation judgment to the water commissioner, then to a special Water Tribunal which serves as a court dealing with water disputes. In the event of an adverse decision of the Water Tribunal, the farmer may appeal to the Supreme Court of Justice. Once the allocation is set, however, the farmer must either: 1) implement new techniques to use water more efficiently, or 2) let yields drop as water supplies are reduced and plants are overly stressed using the existing practices. The incentive in this system is that any surplus water a farmer can gain by efficiency may be used to irrigate more land, and thus farmers have a strong motivation to adopt innovative techniques because most of them have more land than available water can irrigate.

As might be expected, the Government's strict regulation of water use has caused a number of problems in administration and enforcement. For instance, it has been suggested that farmers who want to use water without pay-

*Runoff is that portion of the precipitation on a drainage area that is discharged from the area in stream channels. Types include surface runoff, ground water runoff, or seepage.

"Water-use efficiency refers to crop production per unit of water used, irrespective of water source, expressed in units of crop weight per unit of water depth applied to unit area.

ing the per-cubic-meter equalization charge or a higher rate block charge could simply reverse the flow of water through the water meter so that increased water use is subtracted from the reading.[11] This is a criminal offense. However, it forces the water commission to police water users regularly.

On the other hand, the Israeli system encourages farmers to develop and use water-efficient technologies and farming practices. Even when water is restricted, the farmers generally cooperate when they are assured that by adopting new technology and practices they can manage with less water, still boost crop yields, and in most cases increase their net income over time even with the additional capital investments.

Technical Assistance[12]

Finally, the Israeli Government assists farmers in implementing more water-efficient technologies by providing technical assistance. This assistance includes:

- promoting the research and development of efficient cropping and irrigation methods and systems,
- offering technical assistance in their introduction,
- granting loans at attractive interest rates,
- reducing temporarily market prices of water-efficient appliances,
- providing applied research and demonstration projects, and
- wide-scale immediate dissemination of the positive and negative results throughout the country.

The key to Israel's technical assistance and adoption success is the link between the research effort and the farmer. The Israeli Government conducts ongoing agroeconomic studies to convince farmers to adopt new techniques and methods. These studies cover crops, irrigation techniques, and methods that improve water efficiency and profits. Then, by working with progressive farmers, the Government field-tests new technologies such as plastic sprinklers, drip irrigation techniques, automatic metering, and computerized irrigation controls. New irrigation devices and techniques commonly are manufactured by farming communities themselves, an important feature of Israel's technology adoption success. The manufacturers, being also the users, are unlikely to market something that does not work.

Similarly, researchers and kibbutz farmers often are the same individuals. They may work in research in the morning and on the farm in the afternoon, or take leave from the kibbutz to work full time in research. Almost every kibbutz sends a significant proportion of its members for advanced studies (master- and doctorate-level programs) each year. Consequently, there is an ample supply of agricultural engineers and scientists.

[11] Arlosoroff interview.
[12] Ibid.

SELECTED IRRIGATION TECHNOLOGY APPLICATIONS

Israel is recognized as one of the most advanced nations-in applying certain irrigation technologies. These include: 1) irrigation with treated effluent water, 2) drip and sprinkler irrigation, * 3) computer-controlled irrigation, and 4) saline water irrigation. The technologies have been introduced along with new cropping systems, fertilization regimes, plant varieties, and other management aspects to improve agricultural yields. 'Application of fertilizers, pesticides, and other agricultural chemicals with the water through the drip or sprinkler systems has forced farmers to be very careful about each unit of water applied in order to achieve optimal water, nutrient, and chemical application and distribution.

"Drip or trickle irrigation is a system for supplying filtered water directly onto or below the soil surface, Water is carried to each plant through an extensive pipe network which is generally stationary once installed. Sprinkler irrigation is a system of applying water to a field with the use of one or more rotating sprinklers, spray nozzles, or perforated pipes. With each method, water is sprayed into the air under pressure and falls to the ground in various sized drops.

It is difficult to obtain data on increased crop yields resulting from the application of these irrigation technologies because they are an integral part of the larger management packages. Overall, Israel has reported a net agricultural production increase over the decade 1968-78 of an average of 6.8 percent annually. For the same period, purchased inputs rose at an average annual rate of only 4.7 percent (table 10). This was achieved with an approximate 21 percent reduction over the same period in the amount of water allocation per unit of irrigated land (fig. 6). Among the kinds of new technologies Israel has used to increase water efficiency and crop yields are those discussed below.

Wastewater for Reuse

Agricultural and other reuse of domestic sewage and industrial waste is a high priority in Israel. Under the water law, wastewater is publicly owned and is treated legally as if it were freshwater. Although a separate ministry is responsible for wastewater, a legal mechanism exists to coordinate freshwater and wastewater management. According to one report, by the end of the century more than 30 percent of Israel's total wastewater flow will have been recycled for irrigation or industrial use.[13]

[13] J. Shalhevet, "Deciding on Agricultural Research Priorities in Israel, " KIDMA, vol. 7, No. 1 (Jerusalem: spring 1982), p. 24.

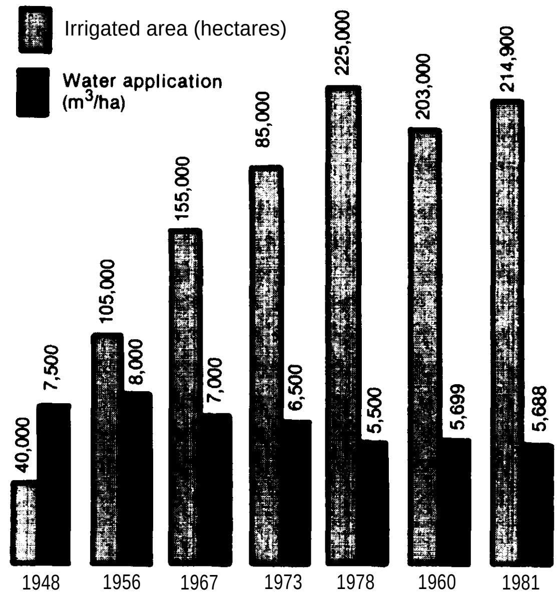
Table 10.—Average Yearly Rates of Change in Percentages in the Major Components of the Agriculture Sector[a] Account, 1968-78 (percent)

	1968-73	1973-78	1968-78
Real rate of change in:			
Agricultural production	5.6	5.5	5.5
Agricultural output[b]	5.9	5.8	5.8
Purchased input in agriculture	6.3	3.2	4.7
Agricultural net domestic product[c d]	5.2	8.4	6.8

[a] Agricultural sector means all agricultural activity (including livestock production, etc.).
[b] Agricultural output is defined as agricultural production *less* intermediate Produce *plus* production for investment.
[c] Net domestic product is defined as income originating in agriculture *less* compensation for damage by nature.
[d] Reflects total income including nonwater-related production.

SOURCE: Centrat Bureau of Statistics and Computations of the Survey and Advice Department, Planning Authority, Ministry of Agriculture, published in *S/x-Year Plan for Agricultural Development,* 1980-85 (Jerusalem: Ministry of Agriculture, 19S1), p. 34.

Figure 6.— Efficient Use of Water



SOURCE: Adapted from Israel Water Commission, from J. Shavalet, KIDMA (Jerusalem), vol. 7, No. 1, spring 1982, fig. 1, p. 24.

A major effort to use wastewater in Israel is the Dan Region Sewage Reclamation Project.[14] The first stage (1975-80) of this project involved treatment of 12,200 acre-feet (15 million cubic meters) of wastewater for reuse. Preliminary findings indicate that the treated water could be fully integrated with the National Grid System if the supply network in the south were converted to a dual system separating water for potable and nonpotable uses. With tertiary treatment and the addition of water from other sources, reclaimed water may be suitable for widespread agricultural use.

The Dan Region Project plans to use 113,500 acre-feet (140 million cubic meters) of wastewater annually from the metropolitan Tel Aviv area for irrigation in the south of Israel. The effluent from Tel Aviv is treated in oxidation lagoons or algae ponds, which eliminate much of the contamination. Additional biological, chemical, and physical (sand filtration) treatments are also employed. Besides agriculture, the project also plans to produce treated water

[14] E. Idelovitch, "Wastewater Reclamation by Advanced Treatment," KIDMA, vol. 3, No. 2 (No. 10/1977), pp. 30-35.

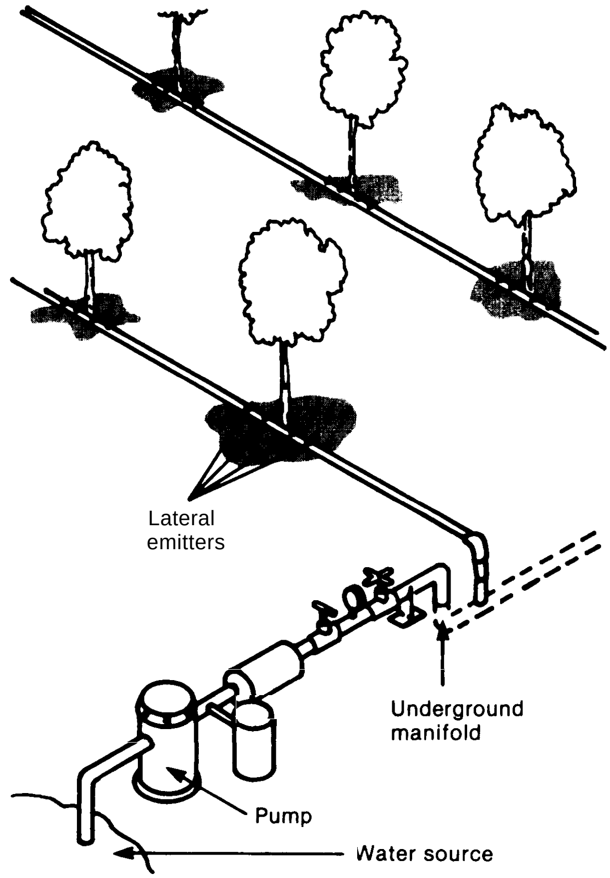
for recharging ground water sources and supplying water for industrial and domestic non-potable purposes.

Irrigation with treated effluent has not been without problems. In 1970, a cholera outbreak was traced to the illegal irrigation of salad crops with raw sewage effluent from East Jerusalem in the West Bank. The water had been collected from the discharge stream. Regulations for effluent quality were tightened, and efforts to broaden the scope of wastewater treatment and use were intensified.[15] A 1971 amendment to the water law now limits the use of treated effluent in irrigation to industrial crops, such as cotton, or to food crops where either the water does not contact the produce directly or the produce is normally cooked before being eaten.[16]

Drip (or Trickle) and Sprinkler Irrigation

Israel has focused heavily on improving low-pressure sprinkler and drip irrigation technologies. In normal gravity fed field or furrow irrigation, plants do not use much of the applied water because of evaporation, percolation past the root zone, and runoff from the surface. With standard sprinkler systems, evaporation and runoff losses also can be heavy. The problem is compounded with heavy runoff because the runoff water takes with it natural or added nutrients critical for the plant growth. In contrast, low-pressure sprinklers and drip irrigation systems deliver virtually all of the water and any added nutrients directly into the plant root zone. The national water grid supplies water under pressure which accommodates these systems, so the use of drip irrigation is expanding. Drip irrigation today accounts for about 10 percent of Israel's total irrigated area.[17] Figures 7 and 8 show the trickle and sprinkler systems of irrigation, respectively.

Figure 7.—Trickle Irrigation System



Trickle irrigation is a system for supplying filtered water directly onto or below the soil surface. Water is carried through an extensive pipe network to each plant. The outlet device that emits water onto or into the soil is called an "emitter." After leaving the emitter, water is distributed to a "wetted zone" by its normal movement through the soil.

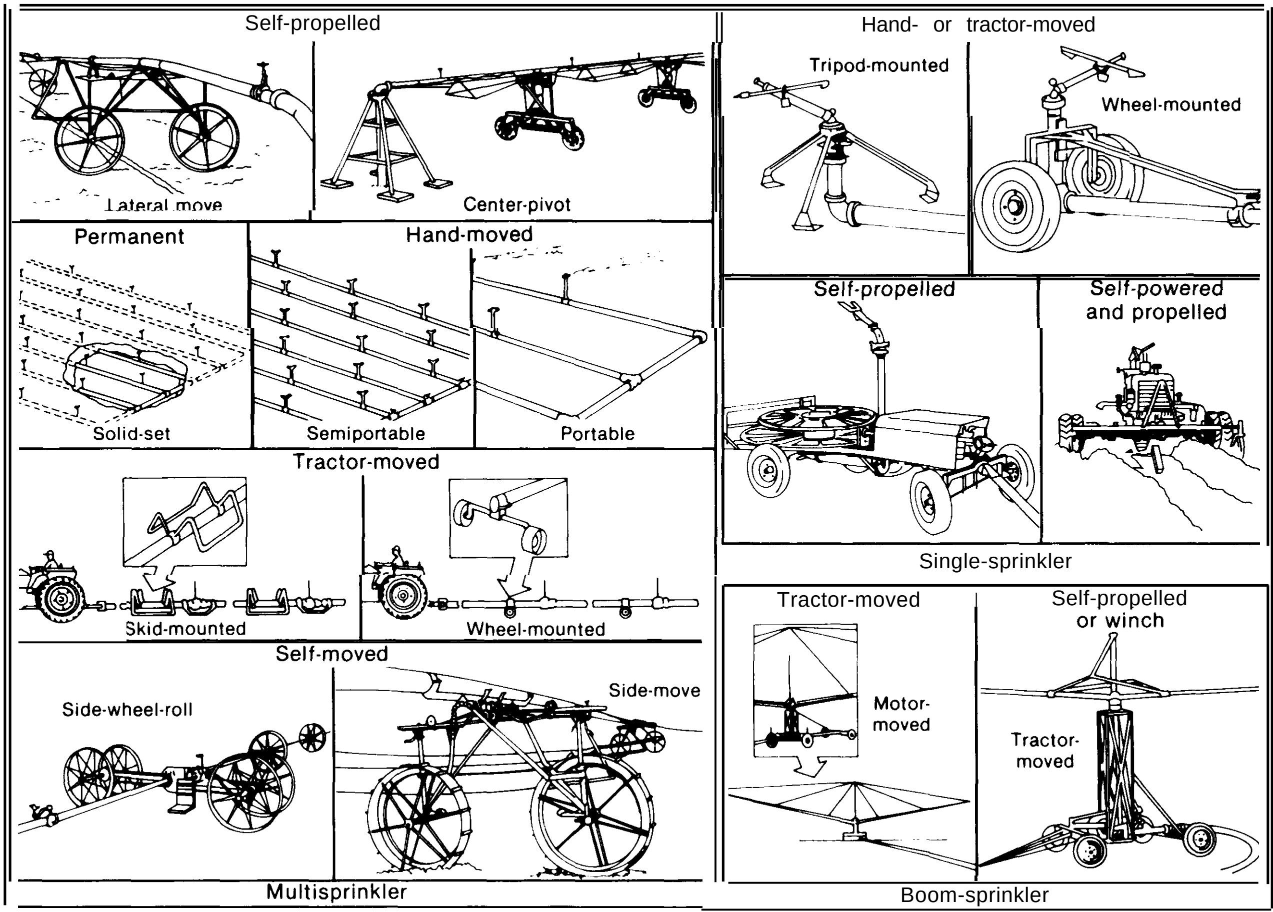
Surface application by the trickle method. Water is applied very slowly onto the surface of the soil through special outlet emitters in plastic pipe.

SOURCE: J. Howard Turner and Carl L. Anderson, *Planning for an Irrigation System* (Athens, Ga.: American Association for Vocational Instructional Materials, 1980).

Traditional irrigation technologies used portable metal pipe systems that were towed along the fields and stationary irrigation grids with permanent pipes laid in the soil. The increasing cost effectiveness of using plastic tubing is causing a shift toward stationary irrigation systems because portable systems are labor intensive and unwieldy.

[15] Ibid., p. 30.
[16] Arlosoroff, KIDMA, p. 10.
[17] "Irrigation in Israel," in special issue of *Irrinews (No. 25, 1982),* Newsletter of the International Irrigation Information Center, Bet Degan, Israel.

Figure 8.—Typical Types of Sprinkler Irrigation Systems



SOURCE: J. Howard Turner and Carl L. Anderson, *Planning for an Irrigation System* (Athens, Ga.: American Association for Vocational Instructional Materials, 1980).

However, for large rectangular plots of field crops, such as grains, cotton, maize, and sorghum, Israel is experimenting with dragline sprinkler systems. * These systems use pipes or sprinkler booms positioned across each field and supported on tall towers mounted on tractor-like vehicles on each side of the field. These vehicles move back and forth picking up water from a channel that parallels the field, pumping the water through the pipes for distribution on the soil by means of dragline hoses. The system uses lower water pressure and causes less runoff damage than most other sprinkler systems. It can apply water more uniformly and can cover a considerably larger area.

In contrast, the drip or trickle irrigation systems involve the placement of plastic tubes with low rate emitters along rows of plants. There is one emitter per plant or a pattern of emitters in the case of orchard trees. Using this method, water flow is continuous and slow, evaporation loss minimal, and plants can be fertilized at the same time they are watered. This technique is particularly well suited to perennials such as fruit trees. It also is being applied successfully to cotton and other row crops. The continuous flow method saves labor by eliminating the necessity of turning the irrigation system on and off.

*The United States is experimenting with a similar system called in some publications the linear-move lateral system.

To overcome some of the problems with drip irrigation lines, Israeli technicians have developed a variety of filters that solve most of the clogging problems resulting from water that contains organic and colloidal suspensions. The problem of chemical clogging when fertilizer is fed through the lines is being solved by using acids mixed with water.[18]

Results with drip irrigation, according to an Israeli Ministry of Agriculture report, have been favorable for such vegetable crops as table tomatoes, peppers, eggplants, squash, strawberries, artichokes, and grapes. For fruit trees such as apple, apricot, peach, and almond, drip irrigation also is the preferred method for saving water and maintaining water quality. Percolation of water to the ground water table and extra runoff to surface water is eliminated or reduced, avoiding agricultural, chemical, and natural salt contamination of those water bodies. This method appears to be the least expensive of the irrigation systems for these crops.[19]

Tables 11 and 12 are the results of experiments in the Negev conducted under extreme arid zone conditions with brackish water, showing comparative yields using drip, sprinkler, and furrow irrigation.

Computer-Controlled Irrigation

Irrigation can be almost totally automated by using pressurized irrigation systems. This requires linking the irrigation water lines to a remote control mechanism that uses small computers. Israel introduced these computerized controls into its farm management systems in the early 1970's, At that time, the principal reason for the program was protection for farmers who were in danger from land mines and snipers when they went to the fields to maintain irrigation controls. Later, automated irrigation was developed into a water-efficient technology and a means of increasing crop yields.

Over the past decade, Motorola Israel Ltd. (a subsidiary of Motorola, Inc., U. S. A.) has been the principal company marketing computerized irrigation control systems in Israel. The company manufactures one system for small farms of up to 320 acres (130 hectares) and another for farms of 1,000 to 5,000 acres (400 to 2,000 hectares) or more. In the larger units, a central computer can send instructions via wireless radio or cable to field units equipped with sensors to relay information back to the main system. For large farms, many control mechanisms are run from a central computer. Since the 1970's, more than 50 large units and 1,000 smaller ones have been installed in Israel. They have been exported and are now gradually coming into use in the United States (primar-

[18]Moshe Boaz and Irzhak Halevy, Extension Service, Ministry of Agriculture, Israel, "Trickle Irrigation" (unpublished paper, undated).

Ye Ibid.

Table 11 .—Production Comparisons for Various Crops Under Different Irrigation Systems

	Muskmelon yields	
	Yield (tons per hectare, t/ha)	
Irrigation methods	Total	Export grade
Sprinkler	23.8	13.0
Furrows	24.2	16.7
Drip	43.0	35.0

SOURCE: D. Goldberg, B. Gornat, and D. Rimon, *Drip Irrigation* (Kfar Shmaryahu, Israel: Drip Irrigation Scientific Publication, 1976). Published in Ilan Amir and Benjamin Zur, "Irrigation in Arid Zones: The Israeli Case, " in *Arid Zone Settlement Planning (New* York: Pergamon Press, 1979)

Table 12.—Effect of Irrigation Methods on the Yield of Tomatoes and Cucumbers

	Arava Valley growing season yield (t/ha)			El Arish (Coastal Sand Dunes) growing season yield (t/ha)		
Crop		Drip	Sprinkler		Drip	Sprinkler
Tomatoes	Sept.-March	65.3	39.0	Sept.-March	79.0	30.0
Cucumbers	Nov. -Feb.	39.0	0.0	Apr. -June[a]	1.5	3.6

[a]Summer growth–out of season in this region.

SOURCE: D Goldberg, B. Gornat, and D. Rimon, *Drip Irrigation* (Kfar Shmaryahu, Israel: Drip Irrigation Scientific Publication, 1976). Published in Ilan Amir and Benjamin Zur, "Irrigation in Arid Zones: The Israeli Case, " in *Arid Zone Settlement Planning (New* York: Pergamon Press, 1979).

ily in California, Arizona, and Hawaii) and other countries.[20]

In either the small or large systems, the computer can control water flow; detect leaks; shut off faulty lines; adjust water application for wind speed, air temperature, and soil moisture content; and apply fertilizer on schedule. An added advantage of the computerized systems is their ability to locate malfunctions and alert the operators to make necessary repairs before the faulty element causes too much damage or water loss.

On the basis of systems implemented in Israel, Motorola Israel reports the following benefits:

- increased efficiency in water and energy use in the range of 10 to 30 percent;
- increased yields in the range of 2 to 10 percent;
- accurate and precise application rates, resulting in minimized return flow, aquifer and stream pollution, and related drainage problems;
- labor savings in such areas as the operation of valves, gates, and checking of laterals.[21]

The kibbutz Kfar Aza in the Negev provides an example of a successful computerized irrigation control program. An evaluation of the computerized system installed at that kibbutz reported an overall water savings of 15 percent of the kibbutz allocation.[22] Crop height remained uniform, indicating even plant development. Other advantages cited by a kibbutz official included reduced labor, energy, fertilizer, and maintenance costs. Exact yield increases caused by the computerized controls are difficult to estimate because other management factors also played a large part in crop production. But one estimate put the general yield increase at about 3 percent for vegetables. In addition, the system saved an estimated 25 workdays per season. Furthermore, 25 breakdowns were located in one season, saving an estimated 20 acre-feet (25,000 cubic meters) of water as the system automatically shut the faulty lines down. As a whole, the Israel experience has been that automated systems pay for themselves within 3 to 5 years, even when installed at market interest rates.

Irrigation With Saline Water

Israel has sizable supplies of brackish water, much of it underground in the Negev Desert. At 2,500 parts per million total dissolved salts, the concentration of salt is too high for use in traditional irrigation or for most industrial uses. However, it has been estimated that if uses were found for the water, approximately 81,100 acre-feet (100 million cubic meters) could be drawn from this source annually without serious effect.[23]

Israel has an intensive program of research and development in the use of brackish water for agriculture. In particular, irrigation techniques are being fine-tuned and adapted to local conditions to minimize buildup of salts in the soil while making use of brackish water. At the same time, the genetic improvement of salt-resistant crops is being studied. Brackish water management packages are being used successfully with vegetables, wheat, and cotton. Expectations are that with more research and intensive management experience, additional production advances will be made. *

[20] Telephone interview with Motorola official.

[21] Elisha Yanay, "Computerized Irrigation Control Systems and Their Application in Drip Irrigation," *Drip/Trickle Irrigation* (Fresno, Calif.: Agribusiness Publications, spring 1981), p. 23.

[22] Ami Kahana, "A Computer Controlled Irrigation System in Kibbutz Kfar Aza" (unpublished paper, undated).

[23] Arlosoroff, U. N., op. cit., p. 49.

*In the United States, a salinity level that has been considered high and has led to the construction of desalinization plants is considered a low level in Israel as the result of their brackish water management (S. Arlosoroff, correspondence, Oct. 28, 1982).

TECHNOLOGY TRANSFER CONSIDERATIONS

Israel's success in implementing its agricultural and water-use policy has been the result of a unique combination of factors, including country size, a national program commitment, the public status of water, and special characteristics of its agricultural technology program. The agricultural element has involved educated farmers who have become manufacturers of water appliances and technologies, and leading agricultural researchers who verify and test these technologies,

Water has always been a limiting and critical factor in the national development of Israel's agriculture. Israel's generally arid land leaves little alternative for agriculture other than a strong national effort at total management of the scarce water resource. In addition, the status of Israel's water as a public resource subject to total public control avoids some of the legal complexities related to management and control likely to be encountered in the United States. The United States can still learn, however, from the Israel experience in application of technologies.

The United States and other countries have adapted, to varying degrees, many of the irrigation technologies used by Israel. For example, Motorola Israel Ltd., which first introduced its line of automated irrigation control systems in Israel, subsequently began manufacturing them for the United States and other markets. About 100 small units and four large systems had been sold in the United States as of 1982.[24] Drip irrigation is another technique that has become more popular in the United States following Israeli commercialization proving the technique to be highly efficient, The experience of Israel with the use of drip, trickle, and sprinkler irrigation systems is also being shared with other countries. Israel's methods of allocating and pricing water and reusing effluents are attracting more interest in such areas as the Western United States as demands increase for limited water supplies.[25]

In light of the mutual benefits to be derived in arid and semiarid agriculture, the United States and Israel have been cooperating to promote agricultural research for many years. The United States-Israel Binational Science Foundation (BSF) was established in 1972 by an endowment to promote continued cooperation in science and technology research between the two countries. Through this program, proposals are submitted by collaborating U.S. and Israeli investigators. Of the proposals submitted between 1974 and 1981, 223 were for agricultural research; 69 of these (8 percent of the total number of grants) were approved.[26]

In 1977, the United States-Israel Binational Agricultural Research and Development Fund (BARD) was established to provide a more formal mechanism for the United States and Israel to share and collaborate on agricultural research of mutual benefit. Since this program is devoted entirely to agricultural research and development, the number of BSF grants in agriculture has been reduced. In 1978 BARD began funding proposals out of the income from its $80-million endowment.[27] A Technical Advisory Committee comprised of five U.S. and five Israeli scientists makes recommendations on the research proposals submitted. Most of the projects have been for 3 years, and many of them are with the University of California at Riverside and Davis. Administration of the program in the United States is handled by the U.S. Department of Agriculture. Appendix E

[24] C. G. Karasov, "Irrigation Efficiency in Water Delivery," *Technology,* March/April 1982, p. 71.

[25] Arlosoroff interview.

[26] United States-Israel Binational Science Foundation, *Annual Report 1981,* Jerusalem, Israel, 28 pp.

[27] BARD Abstracts of Supported Projects 1979-1980, U.S. Department of Agriculture, Federal Building, Hyattsville, Md., 259 pp.

contains abstracts of some of the proposals related to water management in Israel. Although it is too soon to determine specific technological benefits from this research, the cooperation between the two scientific communities and the exposure of different approaches should contribute to new developments and discoveries of mutual benefit.

Appendixes

Appendix A

Contacts List (by chapter)

General

Contacts

Thomas G. Bahr
Office of Water Policy
U.S. Department of the Interior

James Cowan
NASULG
Washington, D.C.

Robert M. Hagan
(advisory panel)

Gerry J. Hammond
USDA/SCS
Washington, D.C.

David E. Herrick
(advisory panel)

Carl Hodges
University of Arizona
Tucson

William Long
U.S. Department of State

David McClintock
(formerly with AID)

Cyrus McKell
(advisory panel)

Clifford J. Murino
(advisory panel)

Don Plucknett
Consultative Group on International Agricultural Research
The World Bank
Washington, D.C.

Steve Rollins
USDA/ARS
Beltsville, Md.

Chapter I

Contacts

Harold E. Dregne
(advisory panel)

M. Evenari
Department of Botany
Hebrew University of Jerusalem
Rehovot, Israel

Frederick L. Hotes
The World Bank
Washington, D.C.

A. Issar
Ben Gurion University of the Negev
Beersheva, Israel

James Walker
AID

Chapter II

Contacts

M. Wayne Adams
Department of Crop and Soil Sciences
Michigan State University
East Lansing

Anthony E. Hall
Department of Botany and Plant Sciences
University of California
Riverside

Don Isleib
Bean/Cowpea CRSP
Michigan State University
East Lansing

Don Plucknett
(see general listing)

Djibrail Sene
Minister of Rural Development
Senegal

Donald H. Wallace
Department of Plant Breeding
Cornell University

Organizations

Centro International de Agricultural Tropical
Cali, Columbia

Instituto de Ciencia y Technologiá Agrícolas
Guatemala

International Crops Research Institute for the Semitropics
Andhra Pradesh, India

National Center for Agronomic Research
Bambey, Senegal

Chapter III

Contacts

L. H. Blankenship
Texas A&M Research Extension
Uvalde, Tex.

Lewis Cohen
AID

Raymond F. Dasmann
University of California, Santa Cruz

Charles DeYoung
Dean, College of Agriculture
Texas A&I University

William Goodwin
Lilly Endowment

Horace Gore
Texas Parks & Wildlife Department

David Hopcraft
Athi River, Kenya

Robert McDowell
Department of Animal Science
Cornell University

Art Mossman
Humbolt University

John Neave
AID

Charles Schreiner IV
Y-O Ranch
Mountain Home, Tex.

Daniel Sisler
Department of Animal Science
Cornell University

James G. Teer
Department of Wildlife and Fisheries Sciences
Texas A&M University

Gabriel Van Latham
N H Bank of Paris
New York

Frederic H. Wagner
College of Natural Resources
Utah State University
Logan

Charles Williams
National Center for Housing Management
Washington, D.C.

Organizations

Africare
International Livestock Center for Africa
Nairobi, Kenya

Max McGraw Wildlife Foundation
Dundee, Ill.

National Buffalo Association
Custer, S. Dak.

Southwest Research Laboratories
Los Alamitos, Calif.

Welder Wildlife Foundation
Sinton, Tex.

Chapter IV

Contacts

Michael Cernea
World Bank

Wayne Clyma
Colorado State University
Fort Collins

Ralph Cummings
(former chairman, Technical Advisory
Committee to CGIAR on proposed
International Irrigation Management Institute)

Worth Fitzgerald
AID

David M. Freeman
Department of Sociology
Colorado State University
Fort Collins

Tejpal S. Gill
AID

Max K. Lowdermilk
ASIA/TR/ARD

Everett Richardson
Engineering Research Center
Colorado State University
Fort Collins

Gaylord Skogerboe
(from Colorado State University)
Visiting Professor at Department of Agriculture
Utah State University
Logan

Thomas Trout
Snake River Conservation Research Center
Soil and Water Conservation Division
USDA/ARS
Fort Collins, Colo.

Organizations

Bureau for Program and Policy Coordination
Studies Division
U.S. Department of State

Consultative Group on International Agricultural Research
World Bank

International Center for Agricultural Research in the Dry Areas
Beirut, Lebanon
Aleppo, Syria

International Crops Research Institute for the Semi-Arid Tropics
Hyderbaad, India

International Food Policy Research Institute
Washington, D.C.

International Irrigation Information Center
Bet Dagan, Israel

Water Management Synthesis Project
Colorado State University
Fort Collins

Chapter V

Contacts

Robin Claxton
Chief, Division of Plant Industries
Department of Agriculture
Sydney, Australia

Frank Cutting
Principal Agronomist
Department of Agriculture
Sydney, Australia

Gary Day
Commissioner for North America
Government of New South Wales
Los Angeles, Calif.

Kenneth Foster
Office of Arid Land Studies
University of Arizona
Tucson

Gerald Gleason
Secretary, Premier's Department
Sydney, Australia

W. C. K. Hammer
Agricultural Counselor
Embassy of Australia

Enrique Campos Lopez
Director, Centro de Investigaciones en Quimica Aplicada
Saltillo, Coahuila
Mexico

Richard Wheaton
Domestic Rubber Program
USDA

Organizations

Board on Agriculture and Renewable Resources
National Academy of Sciences

Division of Plant Industry
Institution of Biological Resources
Commonwealth Scientific and Industrial Research Organization
Canberra City, Australia

The Joint Commission on Guayule
USDA/Department of Commerce

Chapter VI

Contacts

Saul Arlosoroff*
World Bank

Jacob Avni
Agricultural Counselor
Embassy of Israel

Marvin E. Jensen
USDA/ARS
Fort Collins, Colo.

Jan van Schilfgaarde
U.S. Salinity Laboratory
Riverside, Calif.

Elisha Yanay
Motorola Israel Ltd.
Tel Aviv, Israel

Organizations

Applied Research Institute
Ben-Gurion University of the Negev
Beersheva, Israel

*Mr. Arlosoroff's comments are personal and given from his previous work experience. They do not represent or reflect the views of the World Bank.

Faculty of Agricultural Engineering
Israel Institute of Technology
Haifa, Israel

Faculty of Agriculture
Hebrew University of Jerusalem
Rehovot, Israel

Institute for Desert Research
Ben-Gurion University of the Negev
Sde Boker, Israel

International Irrigation Information Center
Bet Dagan, Israel

Irrigation and Soil Field Service
Ministry of Agriculture
Tel Aviv, Israel

Israel Center of Waterworks Appliances
Ramat Aviv, Israel

Israel Chapter of the Society for International Development
Jerusalem

Israel Water Workers Association
Tel Aviv, Israel

Rural Planning and Development Authority
Ministry of Agriculture
Jerusalem

Soils and Water Institute
Bet Dagan, Israel

Technical Assistance and Foreign Relations Department
Ministry of Agriculture
Jerusalem, Israel

Water Commission
Ministry of Agriculture
Tel Aviv, Israel

Appendix B

Preliminary Inventory of Materials Available for Improving Irrigation Water Management in Asia*

The ASIA/TR/ARD Irrigation Team Studies of five Asian countries to identify major issues and strategies for the *1980's* found a critical need for transfer of irrigation knowledge within and across countries,

In the field of Irrigation Water Management, ASIA/TR/ARD is making an effort to bring together relevant technical handbooks, manuals, and training materials which will be useful to Mission staff and host country individuals. It is hoped that technical materials produced by projects and having potential transfer value will be added to this list over time. (The above text has been condensed from the original,)

*Evaluated and compiled by Max K. Lowdermilk of ASIA/TR/ARD staff as a resource to Missions and host countries, June 1981. These are to be updated periodically.

Table B-1.—Preliminary Inventory of Materials Available for Improving Irrigation Water Management in Asia[a]

Type/name of materials	Technical Report No. (TR)[b]	AID: Project name and number
A. Technical Reports/Manuals		
1. Problem Identification Manual by Lowdermilk, et al., 1980	TR 65B	Pakistan Water Management Research Project Contract AIDllR-c-1411
2. Development of Solutions Manual by Sparling, et al., 1980	TR 65C, 1980	"
3. Project Implementation Manual by Hautaluoma, et al., 1980	TR 65D, 1980	"
4. Analysis of Basin-Furrow Irrigation by Peri and Skogerboe, 1980	TR 61	"
5. Development and Design of Water Course Function Jet Pumps by Kemper, Trout, and Aust, 1980	TR 64	"
6. Recalibration of Small Cutthroat Flumes by Skogerboe, 1979	(Special report)	"
7. Watercourse Improvement Manual by Trout and Kemper, 1980	TR 58	"
8. Evaluation and Improvement of Basin Irrigation Systems by Peri and Skogerboe, 1979	TR 49A	"
9. Evaluation and Improvement of Basin Irrigation Systems by Peri, Skogerboe, and Norum, 1979	TR 49B	"
10. Summary of Skimming Well Investigations by Meworter, 1980	TR 63	"
11. Evaluation and Improvement of Border Irrigation by Peri, Norum, and Skogerboe, 1979	TR 49C	"
12. Matching Cropping Systems to Water Supply Using an Integrative Model by John Ruess, 1980	TR 62	"
13. Installation and Field Use of Cutthroat Flumes for Water Management by Skogerboe, Bennet, and Walker	TR 19	"
14. Design of Irrigation Drop Structures by Soon-Kuk Kwan	TR 33	"
15. Calibration and Application of Jensen-Haise Evaporation Equation by Clyma and Chowdhry	TR 40	"
16. Optimization of Lengths of Alternative Watercourse Improvement Programs by John Reuss, 1980	TR49	"

Type/name of materials	AID publication number
17. Farm Irrigation System Evaluation: A Guide for Management by J. L. Merrian and Jack Keller	PN-AAG-745
18. Water Requirements Manual for Irrigated Crops and Rainfed Agriculture by G. H. Hargreves	PN-AAB-676
19. Irrigation System Evaluation and Improvement by J. L. Merrian, Jack Keller, and J. F. Alfaro	PN-AAB-439
20. Small Wells Manual: Location, Design Construction, Use and Maintenance by U. P. Gibson and R. D. Singer, U.S. Office of War on Hunger Health Service	AN-9351236
21. Dryland Agriculture in Winter Precipitation Regions of the World: Status of State of the Technical Art by Oregon State University, Office of International Agriculture, 1979	PN-AAH-329

Table B-1.—Preliminary Inventory of Materials Available for Improving Irrigation Water Management in Asia[a]—Continued

Type/name of materials	AID publication number
22. The Impact of Groundwater Development in Arid Lands: A Literature Review and Annotated Bibliography, Arizona State University, Office of Arid Lands Studies, 1977	PN-AAH-500
23. Solar Energy, Water, and Industrial Systems in Arid Lands, Techno-ecological Overview and Annotated Bibliography by C. Duffield, University of Arizona, Office of Arid Lands Studies, 1978	PN-AAH-499

Type/name of materials	AID Duplication number	AID project name and number
24. Technical Reports to Accompany Planning Guides under C2 to C6 heading[c] will be made available on the topics of Precision Land Leveling, Small Pumps, Farmer Involvement and Small Structures by DS/AGR Water Management Synthesis Project (WMSP) during late 1981 and early 1982	TR 57	Water Management Synthesis Project AID DSA N-C-0058
25. Optimization of Lengths of Alternative Water Course Improvement Programs, by John Reuss		Pakistan Water Management Research Project AID/TR-C 1411
26. Trapezoidal Flumes for Egyptian Water Use Project by Robinson, 1980	Staff Report FC-1	AID/NE-c-1351
27. Cutthroat Flume Metric Equations by Helal, 1980	Staff Paper No. 6	.

Type/name of materials	Available from
28. On-Farm Water Management Field Manual, December 1980, Volume I Reference Manual on soils, inventory and planning, soil-water-plant relationships, agronomy, engineering, equipment, economics, and management	Water management wing ministry of food, agriculture, and cooperation, Government of Pakistan, Islamabad
29. On-Farm Water Management Field Manual, Volume II, Precision and Leveling, 1980	″
30. On-Farm Water Management Field Manual Ill, Water Course Equipment, 1980	″
31. On-Farm Water Management Field Manual III, Volume IV, Irrigation Water Management, 1980	″
32. On-Farm Water Management Field Manual Standards for Practice Materials and Studies, 1980	″
33. Annual Reports which contain technical material and methods	
a) Pakistan Water Management Project, 1970-80	AID/Ta-C-1411
b) Egyptian Water Use and Management Project, 1978	AID/NE-c-1351
34. Technical Papers from Egyptian Water Use and Management Project	AID/NE-c-1351
Volume IV Technical Articles	
a) Optimal Design of Furrow Irrigation Systems by J. Mohan Reddy and Wayne Clyma, 1980	AID/NE-c-1351
b) Irrigation System Improvement Concepts by Wayne Clyma and Thomas W. Ley, 1980	AID/NE-c-1351
c) A Data Management System for Interdisciplinary Research in Agricultural Water Use by J. C. Loftis and Wayne Clyma, 1980	AID/NE-c-1351
Volume Ill	
d) STAFF PAPER #23: A Procedure for Evaluating the Cost of Lifting Water for Irrigation in Egypt by Hassan Wahby, Gene Quenemoen, and Mohamed Helal, June 1980	AID/NE-c-1351
e) STAFF PAPER #28: Roller Bedshaper for Basin-Furrow Irrigation by N. Illsley and A. Cheema, 1980	AID/NE-c-1351
f) STAFF PAPER #29: Economic Feasibility of Concrete Lining for the Beni Magdoul Canal and Branch Canal by Gamal Ayad, G. Nasr Farid, and Gene Quenemoen, April 1978	AID/NE-c-1351
g) STAFF PAPER #30: Programs for Calculators HP-67 and HP-97 by Gamal A. Ayad, 1980	AID/NE-c-1351

Table B-1.—Preliminary Inventory of Materials Available for Improving Irrigation Water Management in Asia[a]—Continued

Type/name of materials	Available from
h) STAFF PAPER #45: Optimal Design of Border Irrigation Systems by J. Mohan Reddy and Wayne Clyma, 1980	AID/NE-c-1351
i) STAFF PAPER #46A: Irrigation System Improvement by Simulation and Optimization: 1, Theory by J. Mohan Reddy and Wayne Clyma, 1980	AID/NE-c-1351
j) STAFF PAPER #46B: Irrigation System Improvement by Simulation and Optimization: 2, Application by J. Mohan Reddy and Wayne Clyma, 1980	AID/NE-c-1351
k) STAFF PAPER #37: A Systematic Framework for Development of Solutions by Max K. Lowdermilk, April 1980	AID/NE-c-1351
1) STAFF PAPER #39: Evaluation of Furrow Irrigation Systems by Thomas W. Ley and Wayne Clyma, 1980	AID/NE-c-1351
m) STAFF PAPER #40: Evaluation of Graded Border Irrigation Systems by Thomas W. Ley and Wayne Clyma, 1980	AID/NE-c-1351
35. Special Technical Reports from FAO on Irrigation and Drainage (order direct from FAO Sales Agents in your country or FAO, via della Terma di Caracalla 00100, Rome, Italy)	AID/NE-c-1351

Type/name of materials	AID publication number	AID project name and number
B. Water Management Training Materials (manuals and audio visuals)		
1. Training Manual for Agricultural Water Management Specialists, edited by Westfall, 1980	TR 64	Pakistan Water Management Research Project AID/Ta C-1411
2. Monitoring and Evaluation Manual: Diagnostic Analysis on Farm Irrigation Systems (Volume 1, Systems Analysis Conceptual; Volume 11, Specific How-to-do Procedures)	TR 64	Water Management Synthesis Project AID-DSAN-C-0058
3. Investment in Water Management (137 slides and cassette tape, written script) by Kemper, et al., 1979	with ASIA/TR/ARD	Pakistan Water Management Research Project AID/Ta C-1411
4. Pakistan Land of Promise (slide show, cassettes, written script) shows system problems and potential, by Lowdermilk, et al., 1978	with ASIA/TR/ARD	Pakistan Water Management Research Project AID/Ta C-1411
5. Water Management on Small Farms (slides, cassettes, written script, strategy guide, and technical guide)	AID Southwest Research Institute 1980	AID/Ta-1479
6. Precision Land Leveling (16mm movie), 1970	with ASIA/TR/ARD	Pakistan Water Management Research Project AID/Ta C-1411
7. Technical Film on Survey and Steaking a Field for Precision Land Leveling, 1970	with ASIA/TR/ARD	Pakistan Water Management Research Project AID/Ta C-1411
8. Research-Development Process for Improvement of Farm Water Management, a Videotape Interdisciplinary by Colorado State University, Instructional-Media Division, Fort Collins, Colo., expected completion fall 1981 by Clyma and Lowdermilk in spring 1982	available from CSU	No project
9. Improving Agricultural Production through On-Farm Water Management by Lattimer, et al.	no number	Pakistan Water Management Research Project AID/Ta C-1411
10. Training Manuals for On-Farm Analysis of Irrigation Systems, Volumes I and II, summer 1981	no number	AID
C. ***Planning Guides for improved Water Management***		
1. Planning and Implementing Procedures for Constructing Agricultural-Related Research Programs in Low-Income Nations by Lowdermilk, et al.	TR 46	Pakistan Water Management Research Project AID/Ta C-1411

Table B-1.—Preliminary Inventory of Materials Available for improving irrigation Water Management in Asia[a]—Continued

Type/name of materials	AID publication number	AID project name and number
2. Planning Guide for Precision Land Leveling Programs (available summer 1981) by Clyma, et al.	No. 1	Water Management Synthesis Project AID-DSAN-C-0058
3. Planning Guide for Low-Lift Pumps in Irrigation Projects (available winter 1982) by Keller, et al.		Water Management Synthesis-Project AID-DSAN-C-0058
4. Planning Guide for Farmer Involvement in Irrigation Improvement Projects (available summer 1981) by Lowdermilk, et al.	No. 2	Water Management Synthesis Project AID-DSAN-C-0058
5. Planning Guide for Small Structures for Water Management Improvement (available spring 1982)	No.	Water Management Synthesis Project AID-DSAN-C-0058
6. Planning Guide for Water Management for Small Farmers (available fall 1981)	No.	Water Management Synthesis Project AID-DSAN-C-0058
7. A Research-Development Process for On-Farm Water Management by Clyma, Lowdermilk, and Corey, 1977	TR 47	Pakistan Water Management Research Project AID/Ta C-1411
8. Development Process for Improving Water Management on Farms by Skogerboe, Lowdermilk, Sparling, and Hautaluoma, 1980	TR 65A	Pakistan Water Management Research Project AID/Ta C-1411

D. Other Materials

1. **Social** Organizational Aspects of Irrigation Water Management: A Bibliographic Resource (write to Dr. David Freeman, Sociology Department, Natural Resources Group, Colorado State University, Fort Collins, Colo. 80523)
2. *Water Management News:* occasional Newsletter on WM developments around the world. Send request to be placed on Mailing List to Water Management Synthesis Project Coordinator, Engineering Research Center, Colorado State University, Fort Collins, Colo. 80521
3. *Asian Regional Irrigation Communication Network* (a newsletter of which the 10th issue was September 1980. Provides list of reports, monographs, and descriptions of new research projects, with a primary focus on socioeconomic dimensions of water management). Write to Agricultural Development Council Office, Bangkok, P.O. Box 11-1172, Bangkok 11, Thailand
4. */RR/NEWS:* Newsletter of the International Irrigation Center, Israel-Volcani Center, P.O. Box 49,50250 Bet Dagan or Canada, P.O. Box 8500, Ottawa KIG3H9
5. *WAMANA:* A quarterly newsletter on water management. Indian Institute of Management, 33 Langford Road, Bangalore, India 560027

[a]FAO materials originally listed by AID have been omitted from this table, since they did not result from AID's Pakistan and other Asian irrigation projects.
[b]TR denotes Technical Report. The AID Technical Reports and Manuals are gradually being placed in the AID/DIU file, and copies are made available through that office.
[c]See C section.

SOURCE: Max K. Lowdermilk, U.S. Agency for International Development, 1981,

Appendix C

The Economics of the Commercialization of Guayule in New South Wales*

Guayule as an Alternative Crop in New South Wales

In addressing the subject of guayule as a potential dryland crop in New South Wales, it must be realized that it is not suitable as a replacement for any currently profitable cash crop but for use on land which can no longer support crops that require an excess amount of water.

Various crops are dryland farmed along the western slopes of New South Wales including wheat, barley, sorghum, and sunflowers. Of these, wheat is by far the most predominant crop.

There is not sufficient data on guayule to accurately make a comparison with other crops. Taking into consideration that such factors as rubber yield per acre and price per lb/rubber are strictly projections, a budget can be developed that will contribute to a broad understanding of the economic potential of guayule in New South Wales.

Due to the fact that there is no commercial guayule that has reached productive maturity in either the United States or Australia, budgets must be developed from information attainable from other crops and meager data on guayule.

The Office of Arid Lands Studies in Tucson, Ariz., under a contract with the State of California, Department of Food and Agriculture, has recently developed budgets for guayule production in four different areas of California including the San Joaquin Valley, Southern California desert, Sacramento Valley, and the central coast area. Of these four budgets, the San Joaquin Valley area is the most favorable of the four locations because of its low cost of production per acre. This particular budget will serve as a model from which to develop the estimated costs of producing 1 acre of dryland guayule in New South Wales.

*Source: A.Siddigui and P. Lockton, *A Feasibility Study on the Commercialization of Guayule in New South Wales, Australia*, Division of Plant Industry, California Department of Food and Agriculture, Sacramento, Calif., December 1981.

Estimated Costs of Producing 1 Acre of Guayule in New South Wales

With respect to the estimated cost of producing *1* acre of dryland guayule, the following points should be made.

A 5-year growing cycle is used in this budget although this time period is variable due to the amount of rainfall a specific site would receive. Plant density varies according to irrigated or dryland cultures. Because of an increase in potential climatic uncertainties contributing to plant loss (due to a longer production period of 5 years), a total of *15,000* seedlings/acre is used at a cost of $().() S/seedling. Seedlings cost approximately $0.04 each delivered, although growers anticipate that an increase in commercial plantings will result in a drop to $0.03 per plant.

Weeds have been a problem in various experimental guayule plantings and will invariably present a problem in New South Wales, In this budget chemical weed control, cultivation, and hand hoeing are all included. No herbicides are registered for guayule and, therefore, the chemical weed control cost is an estimated amount. Fertilizer is also included in this budget, although exact amounts would typically be dependent on results from soil analyses taken from specific sites.

Although rent value of land, interest on variable costs, and a charge for management profit are not necessary out-of-pocket costs, they are legitimate charges. If the land was not planted with guayule, the landowner has the option of leasing the land for other crops. An interest charge of 15 percent on borrowed production costs is included. This has been calculated on variable production costs and rent value of land,

A return to management of **$26** per acre per year is used. In various parts of California a percentage of the gross is the accepted method, but with the time lag of 5 years between planting and harvesting for guayule, a uniform charge per year is used.

Scenarios A and B represent two different yields of rubber per acre. It must be stressed that these are estimated amounts and are not necessarily applicable to typical dryland yields.

Following these calculated production costs is a break-even table that is based on the estimated total production costs and a variety of yields and prices. Yields vary from ***1,000*** to ***3,000*** lb of rubber per acre, while rubber prices run from ***$0.40*** to $1.00 / lb.

Scenario A	*Australian $*
Total production costs	$-1,099
Processing ((),235/lb X 1,500 lb rubber)	+353
Subtotal	$1,452
Less byproduct value (0.244/lb X 1,500 lb rubber)	–366
Total costs	$1,086
Break-even price for rubber (1,500 lb/acre)	$0.724
11/30/81 New York price of rubber 0.485	0.422
Loss/lb	$0.302
Loss/acre	$657

A yield of **1,500** lb of rubber per acre over a 5-year period represents a current realistic figure of a dryland situation. This figure is based on personal interviews with various California guayule researchers and estimates of yield conducted by the Emergency Rubber Project.

Scenario B	*Australian $*
Total production costs	$1,099
Processing (0.235/lb X 3,000 lb rubber)	+705
Subtotal	$1,804
Less byproduct value (0.244/lb X 3,000 lb rubber)	–732
Total costs	$1,072
Break-even price for rubber (3,000 lb/acre)	$0.357
11/30/81 New York price of rubber 0.485	0.422
Profit/lb	$0.065
Profit/acre	$195

Research conducted by the California Department of Food and Agriculture in conjunction with various other guayule researchers has resulted in the belief that new improved varieties of guayule should produce more rubber in less time, and, therefore, a yield of 2,500 to 3,000 lb of rubber per acre is a representative estimate of future yields. It is hoped that seed from these varieties will become available in approximately 5 to 10 years,

Table C-1.—Estimated Costs of Producing 1 Acre of Dryland Guayule in New South Wales, Australia[a]

	Australian $
First year	
Establish stand (idle farm land)	
Disk (2 x)	14
List and shape beds	12
Fertilizer	4
Chemical weed control	13
Seedlings—15,000/acre	392
Planting	80
	515
Culture	
Cultivate (2 x)	13
Cash farm overhead	9
	22
Second year	
Cultivation	13
Chemical weed control	7
Cash farm overhead	7
	27
Third year	
Chemical weed control	7
Cash farm overhead	7
	14
Fourth year	
Chemical weed control	7
Cash farm overhead	7
	14
Fifth year	
Cash farm overhead	5
Dig plants	39
Windrow	9
Bale	78
Haul (field to processing plant)	44
	175
Subtotal	$767
Rent value of land @ $8/acre/yr x 5 yrs.	40
interest—5 yrs @ 150/0	162
Profit to management	130
Subtotal	$332
Total production costs	$1,099

[a]Based on the rate of exchange as of Nov. 30, 1981: $1.00 U.S. = $0.87 Australian.

Table C-2.—Per Acre Income Above Costs (processing costs included)

Yield	Price of rubber per pound						
Pounds of rubber per acre	0.40	0.50	0.60	0.70	0.80	0.90	1.00
1,000	–690	–590	–490	–390	–290	–190	–90
1,500	–486	–336	–186	–36	+ 114	+264	+414
2,000	–281	–81	+119	+319	+519	+719	+919
2,500	–77	+173	+423	+673	+923	+1,173	+1,423
3,000	+128	+428	+728	+1,028	+1,328	+1,628	+1,928

NOTE: If 2,000 lb of rubber per acre were produced, rubber prices would have to be near $O.6011b to break even or pay all production costs. In December 1981, smoked sheets of rubber in New York were priced at less than $0.50/lb. At current prices, guayule Is not an economical crop to grow at present estimated yields of 1,500 lb/acre.

New improved varieties of guayule should produce more rubber in less time, and therefore a yield of 2,500 to 3,000 lb of rubber per acre is a realistic projection of future yields. The table shows that at 2,500 lb of rubber per acre, rubber prices would have to be near $(X50/lb to break even, and at 3,000 lb of rubber per acre they would have to approach $0.40/lb.

Conclusions and Recommendations

Conclusions

The development of a guayule industry in New South Wales would have a significant impact on the state's economy. Most importantly, it would create a viable agro-industry to supply local and export markets and would lessen Australia's reliance on imported rubber. In addition, it would create employment opportunities in remote areas.

An optimistic assessment of the potential of developing a guayule rubber industry in the western slopes and plains of New South Wales is based on the following factors:

1. Millions of hectares of light textured soils, especially the "Mallee" types, are available.
2. The economics of growing guayule in New South Wales is more favorable than in the United States because of the relatively low cost of land along the north-south belt stretching through central New South Wales.
3. With the average annual rainfall of *350* to *500* mm distributed evenly throughout the year in the central north-south belt through New South Wales, guayule would require little or no irrigation.
4. Prevailing temperatures and soil types in the central north-south belt appear suitable for guayule cultivation.
5. Unlike the hevea rubber industry, guayule is not a labor-intensive crop, as it is easily adapted to mechanization.
6. The New South Wales Department of Agriculture has a successful record of introducing new crops (e.g., cotton, rapeseed, and lupins) into the state. The Department, therefore, has a capable staff and the necessary facilities to initiate a guayule development program in New South Wales.

Recommendations

The establishment of guayule as a commercial industry in New South Wales is dependent on not only environmental conditions but such factors as land prices, the present-day agricultural situation, and, most importantly, the implementation of a successful development program,

The following are recommendations that were made by the senior author to the Premier of New South Wales and the Department of Agriculture at the conclusion of his trip to New South Wales in November *1980.* At this point, all of the recommendations have been accepted and are being implemented. The program is now 1 year old.

Along with each recommendation is a summary of the corresponding action that has been put into effect by the New South Wales Department of Agriculture, This information has been excerpted from the ***Initial Report of Guayule Research and Develop ment in New South Wales*** by P. L. Milthorpe.

1. **A 3-year guayule development program similar to the one in the State of California be initiated immediately in New South Wales to determine whether or not a viable industry can be established.**

Early in 1981, a special Treasury grant was approved by the Premier which allocated the required financial support necessary to implement a 3-year guayule development project. The project consists of four steps as follows:

a) identification of the most suitable soils and climate for guayule cultivation;
b) development of the optimum package of agronomic technology;
c) evaluation of genetic material to identify the best material developed in overseas breeding programs; and
d) evaluation of the rate of rubber accumulation in the laboratory.

2. **Guayule test plots ranging from *0.25* to 5.0 hectares be established at Narrabri, Trangie, Condobolin, Hillston, and Yanco. Both transplant and direct seeding methods of planting should be explored** under irrigated and dryland farming situations.

Initial plantings of seedlings were made at Condobolin and Yanco in November 1980 followed by further plantings at the research centers at Narrabri and Trangie in mid-January. Additional plantings were made at North Star, Warialda, Hillston, Wagga Wagga, and Deniliguin.

Generally, the same procedure was adopted for planting at each site. This involved hand planting 8- to 10-week-old hardened-off seedlings. These were initially grown in 10 cm plastic pots and later in 4 x 4 x 15 cm tubes, The plants were immediately irrigated when planted and then were watered periodically until the rain began,

To date, no work has been conducted on direct seeding, Once pelleted seed is available, this method of planting will be evaluated.

3. **A guayule genetic resource collection of all varieties received from California and other sources should be established at Condobolin with the goal of increasing the seed of these varieties.**

Appendix D
BARD Abstracts

Supported Projects 1979-80

Soil and Water

1. Soil Salinity Effects on the Spatial Variability of Hydraulic Conductivity
2. Solute Transport in Heterogeneous Unsaturated Field Soil: Measurements, Prediction, and Application to Crop Production
3. Water Management Model for Drainage of Irrigated Lands in Semi-Arid Zones
4. Salinity Control in Irrigated Agriculture Under Dynamic Conditions
5. Application of Pesticides via Drip Irrigation Systems
6. Effect of Moisture Content, Soil Texture, Soil Structure, ESP, and Soil Solution Concentration on Bulk Soil EC
7. The Chemistry of Soil Crust Management
8. Use of Solar Energy for the Detoxification of Organic Pollutants in Water for Agricultural Reuse
9. The Effect of Clay-Organic Complexes in Soils on the Behavior "and 'Activity of Soil Applied Herbicides

Agricultural Engineering

1. Utilization of Waste Heat From Power Plants for Agricultural Uses
2. Greenhouse Operation for Best Aerial Environment
3. Engineering Analysis of Mechanical Damage to Fruits and Vegetables Resulting From Impact
4. Separation of Clods and Rocks in a Fluidized Bed
5. Determining Optimum Performance for Milking Equipment, Procedure, and Systems
6. Engineering and Horticultural Research on Improving the Mechanical Harvesting of Peppers
7. System Analysis and Design of Biofilters for the Three Components of Macrobrachium Production

Plant Protection

1. Spiders as Biological Control Agents of Agricultural Pests
2. Plant Protection by a Plasmid Induced Killer System for a Plant Pathogen
3. Development and Epidemiology of Fungicide-Resistant Plant Pathogens in an Integrated Pest Management Program for Pome and Stone Fruit Production
4. Forecasting Epidemics of Non-Persistent Viruses in Annual Crops by ELISA and Use of the "Helper" Factor for Resistance Breeding
5. Characterization and Mode of Action of Phvtotoxins Produced by ***Alternaria dauci*** and Other *Alternaria* spp., and Their Potential Use in Selection for Disease Resistant Crop
6. Management of Scale Pests Through Utilization of Their Pheromones, Kairomones, and Natural Enemies
7. The Role of Epiculticular Leaf Waxes in Resistance of Plants Against Powdery Mildews
8. Ascorbic Acid Deficiency in Phytophagous Insects—Its Biochemical Nature and Its Role in Insect Hostplant Relationship
9. Control of Soil-Borne Plant Pathogens by Solarization of Soils by Means of Polyethylene Mulching: Phytopathological, Microbiological, Agronomic, Chemical, and Physical Approaches
10. Responses of Tephritid Fruit Flies to Baits
11. A Study of the Mechanism of Photosynthetic Herbicide Action With the Aim of Improving Weed Control and Thereby Increasing the Efficiency of Water and Soil Utilization
12. Genetic Studies of Meal-Fly Preparatory to Biological Control Using Pseudo-Y Chromosome Meiotic Drive
13. Resistance and Interference phenomena in Plant-Virus Interactions
14. Quantitative Evaluation of Natural Enemy Impact Against the Homopteran Pests of Citrus
15. Management of Bulb Mites ***(Rhizoglyphus*** spp.) Through a Study of Their Biology and Ecology
16. Biological Control of Sap Beetles Attacking Fruit Crops (Dates and Grapes)
17. Serological Detection of Strawberry Mild Yellow-Edge Virus
18. Studies on Baculoviruses as a Potential Agent for Pest Control
19. Studies of Plant Root-Knot Nematode *(Meloidogyne incognita* and M. *javanica)* Interrelationships
20. Epidemiology and Control of Bacterial Leaf Spot Diseases in Vegetables: *Pseudomonas lachrymans*—Angular Leaf Spot of Cucumbers, *Xanthomanas* vesicatoria–Bacterial Scab of Pepper and Tomato, *Pseudomonas tomato*—Bacterial Speck of Tomato

Food Technology

1. Design and Delivery of Optimal Thermal Sterilization Processes for Low-Acid Canned Foods
2. The Role of Calcium in Fruit Ripening and in Alleviating Post-Harvest Physiological Disorders
3. Biochemical Aspects of the Effect of Altered Compositions of Atmospheric Gases on Stored Product Insects
4. Production, Regulation, and Mode of Action of Ethylene in Fruit Ripening, Senescence, and Decay
5. Kinetics of Oxidation of Dehydrated Food at Low Oxygen, and Development of Accelerated Tests
6. Mechanism of Heat and Irradiation Synergism
7. Physiology and Prevention of Latent Infections in Fruits
8. Application and Mode of Action of Plastic Film to Extend Life of Fruits and Vegetables
9. Improving the Keeping Quality of Agricultural Perishable Commodities Under Controlled Atmospheres
10. Prevention of Browning in Fruits and Vegetable Foods

Field Crops

1. Breeding Potential of the Wild Genepool of Lentil
2. The Collection, Evaluation, and Utilization of Wild Emmer ***(Triticum dicoccoides)*** for Wheat Breeding
3. Genetic Resources Information System for Israel and the United States: A Feasibility Study
4. The Effect of Water Stress on ***Solarium*** Species of Potential Use as Source of Steroidal Drugs; Physiological, Biochemical, Agricultural, and Genetical Aspects
5. Physiological Disorders in Vegetable Crops: Basic and Practical Aspects
6. Development of Melons Suitable for Once-Over Mechanical Harvest
7. Physiological Genetics of Cold Tolerance in the Tomato
8. Development of a Management-Oriented Dynamic Simulation Model for Cotton Production
9. ***Pennisetum americanum X purpureum:*** A Potential Forage Crop for Maximum Production of Digestible Nutrients Under Subtropical Conditions
10. Utilization of System Analysis for the Development and Implementation of Improved Decision Criteria for Cotton Crop Management
11. Peanut Breeding for Higher Yields and Quality and Evaluation of Methodology
12. Heritability and Physiology of Anther Culture and Inhibitor Selections in Wheat
13. The Dynamic Aspects of Heterosis in Interspecific Crosses of Cotton—A Plant Modeling Approach

Horticulture

1. Concentration and Metabolism of Indolyc Growth Hormones in Fruit Trees
2. Citrus Protoplasm Fusion
3. Climatic Requirements for Rest Completion in Dormant Peach and Apple Buds
4. Improvement of Yield Levels in Citrus With Special Emphasis on Shamouti and Valencia Oranges: Hormone and Carbohydrate Interactions
5. Administration and Management of Citrus Groves With Aerial Color Infra-red Photography Using Low-Cost Microprocessors
6. Development of a Mechanized Meadow Orchard System for Fresh Market Peaches
7. Vegetative Propagation of Selected Clones of ***Eucalyptus camaldulensis*** Dehn

Animal Production

1. Optimization of Dairy Cattle Breeding Strategy in Israel and in the United States
2. Investigation of Genetic and Physiological Variability of Milking Cows by Biochemical and Metabolic Studies of Milk Production in Udder, on the Cellular Level
3. Oyster production in the Outflow of Salt Water Fish Ponds
4. Introduction of the Giant Malaysian Prawn ***Macrobrachium rosenbergii*** (de Man) Into Brackish Water Aquiculture
5. Nutrition and Reproduction of Turkeys Under Different Environmental Conditions
6. Genetic Variation in Minimum Body Weight Required for the Onset of Sexual Maturity in Broiler Chickens, and Its Genetic Covariation With Growth-Rate Components
7. Breeding Efficiency and Milk Yield of Dairy Cows in Relation to Nutritional Status and Planned Differences in Conception Intervals
8. The Control of Meiotic Maturation in Mammals
9. Study of Systemic Granuloma, a Diet Related Disease of the Cultured Marine Fish ***Sparus aurata***
10. Selective Breeding of Farmed Fish
11. Hormone Production by the Bovine Blastocyst

12. The Promotion of Prolific Strains of Sheep by Crossbreeding and by Nutritional and Managerial Means
13. Rotifer Resting Eggs and Their Application to Marine Aquiculture
14. Development of Systems for Integrating Aquaculture With Water Storage and Irrigation

Animal Protection

1. Genetic Factors Affecting the Rate of Development of Immunological Maturity With Respect to Disease Agents in Poultry
2. Studies on the Ecology of Animal Influenza Viruses in Israel
3. Virologic, Immunologic, Epidemic, and Pathogenetic Studies of Slow Viral Lung Diseases in Sheep
4. Study of the Lymphoproliferative Disease of Turkey and Its Causative Virus
5. Specific Biochemical Test for Detecting Fatty Liver in Farm Animals
6. Early Embryonic Environment and Early Embryonic Death in Dairy Cattle
7. Development of a Method for Obtaining Salmonella-Free Poultry Feed. Pilot Scale Study for Subsequent Large Scale Implementation
8. Physiological Age-Grading and Survival Rate in ***Culidoides (Diptera: Ceratopogonidae)*** as a Means of Determining Vector Capacity
9 Endocrine Control of Prolapsed Oviduct in Hens
10 Bacterial and Leucocytic Contents and Enzyme Levels in Milk as Methods for the Determination of Milk Quality and for the Early Detection of Mastitis
11. Interaction of Newcastle Disease Virus Strains of Different Virulence With Cell Receptors
12. Vaccination of Chickens Against *Mycoplasma gallisepticum*

Agricultural Economics

1. Agricultural Planning With Production Rigidities: Theory and Practice
2. Grain Stocks and Price Policies in Israel
3. Some Dynamic Aspects of Technological Change in Agriculture
4. Multi-Product Agricultural Supply Response Estimation in Israel and the United States
5. Analysis of Efficient Regional Allocation of Irrigation Water With Emphasis on Salinity and the Related Cost Sharing Scheme
6. Agricultural Growth-Methodology, Measurement, and Applications to Israeli Agriculture
i'. Welfare Implications of Price Stabilization Policies Implemented by Israeli Agricultural Marketing Boards
8. The Impact of Inflation on Investment in Agricultural Capital
9. Estimation of an Agricultural Production Function From Data Obtained From Complex Sample Surveys

General

1. The Mechanism of Osmotic Accommodation to Water and Saline Stress in Plant Cells; and the Role of Hormones in Modulating This Response
2. The Role of Polyamides in Growth and Senescence of Plants Under Stress Conditions With Special Reference to Horticulturally Important Organs and Tissues
3. The Chemical Identity and Physiological Action of Regulatory Peptides in Reproductive Maturation of Insects
4. Drought and Freezing Damage to Plants in Relation to the Structure and Function to the ATP Synthesizing Enzyme From Chloroplasts
5, Improvement of Salt Tolerance in Higher Plants—Research on the Levels of the Whole Plant, Isolated Tissues, and Cells
6. Development of Somatic Hybridization Systems Involving Cytoplasmic Traits
7. Plastom Manipulation in Plant Protoplasm Systems
8. Planning of Research in Agricultural Extension and Extension Training
9. Interactions Between Ethylene and Other Growth Regulators in Aging Tissues
10, The Effect of Plant and Environmental Factors on Photosynthetic Efficiency
11. Factors Determining the Sensitivity of Abscising Plant Organs to Ethylene, With Special Reference to Auxin Metabolism and Transport
12. The Introduction of Vesicular-Arbuscular Mycorrhizae Into Modern Crop Production Practices
13. Development of Gene Transplant Technology for Crop Plants
14. A Comparison of the Mechanism of Cellulose Synthesis in Bacteria and Higher Plants
15, Resistance to Water and Salt Stress Through Somatic Cell Selection

Approved Subjects 1982

Soil and Water

Slow-release water-borne microparticles for incorporation of pesticides into soils

The mineralogical and chemical forms of boron, molybdenum, and selenium in fly ash and their mobility and interaction in soils
Reactions in soil and response of plants to various fluorine sources
Control of nonfumigant nematicide distribution and activity in irrigated soils
Improving estimates of evapotranspiration from meteorological data for the control of irrigation for cotton and other field crops
Managing multi-source irrigation water of different qualities for optimum crop production
Crop response to saline water management in the presence of spatially variable soil water properties
Developments of methods for designing drainage systems for irrigated lands with nonuniform boundary conditions

Agricultural Engineering

Separation of extraneous matter from agricultural products by the difference in the coefficient of restitution
Long distance vertical spreader for granular materials

Plant Protection

Naturally occurring steroids from solanaceous plants as potential insect antifeedants
Natural arthropod defense mechanisms of deciduous trees, adaptable for use in agriculture
Evaluation of parasitoids for the control of whiteflies
Genetic and biological control of Septoria diseases of wheat
Double stranded RNA-infectious hypovirulence factors in plant protection
Genetic manipulation of almond moth ***(Ephestia cautella)*** populations as a means of reducing or preventing insecticide resistance
Enhancement of citrus resistance to tephritid fruit flies
Studies on nutrition, physiology, and molecular genetics of spiroplasmas with reference to diagnosis and pathogenesis

Food Technology

Chilling injury during avocado and mango fruit storage: development and prevention
Mechanisms and prevention of lipid oxidation in muscle foods
Protection of grain from insect damage through storage in semiarid and arid regions
Post-mortem quality changes of the freshwater prawn ***Macrobrachium rosenbergii*** during refrigerated / ice-chilled storage
Factors influencing the quality characteristics of frozen and dehydrated fruits and vegetables

Field Crops

Regulation of corn dormancy
Testing the efficiency of different lamps and illumination regimes for photoperiodic irradiation of agricultural crops
Development of cantaloupe varieties and advanced breeding lines with resistance to the fungus disease complex in both the USA and Israel with special emphasis on resistance to downy mildew
Genetic diversity of wild emmer wheat, ***Triticum dicoccoides,*** in the Near East in relation to wheat breeding
Genetic and chemical control of alkaloid biosynthesis in ***Papaver bracteatum*** and ***Papaver somniferum***
Studies on carcinogenic solarium plants of potential value as source of active vitamin D-like derivatives
Study of cytoplasmic male sterility in lentil

Horticulture

Isozyme markers as a tool in avocado research
Avocado fruit abscission
Response of peach and nectarine germ plasm to an annual top removal pruning system

Animal Protection

Physiological criteria for improvement of production efficiency in beef cows subjected to nutritional and environmental 'stress' due to fluctuating seasonal grazing conditions
Development of improved methodology for estimating genetic merit of bulls and cows in the USA and Israel
Nutrition-physiology-environment interactions in turkeys
Stable isotope ratio as naturally occurring tracers in the aquiculture food web
An integrated approach to the breeding, nutrition, reproduction, and management of geese

Animal Protection

Detection of rift valley fever ELISA antibody and antigen in livestock
Studies of pathogenesis and prevention of milk fever of dairy cows

Immunization of cattle with antigens derived from continuous ***in vitro*** cultures of *Babesia bovis*

Evaluation of polyethylene intramammary device (IMD) in mastitis control

Agricultural Economics

Grain stocks and price policies in Israel; an evaluation of alternative policy combinations and their performance under rapid inflation

Pricing and R&D for quality of agricultural products: the case of tomatoes

Economic development and changing structure of the family farm

General

Photoacoustic monitoring of plant leaves, in combination with photothermal radiometry and fluorescence—tools for assessing plant condition, photosynthesis, and productivity

0