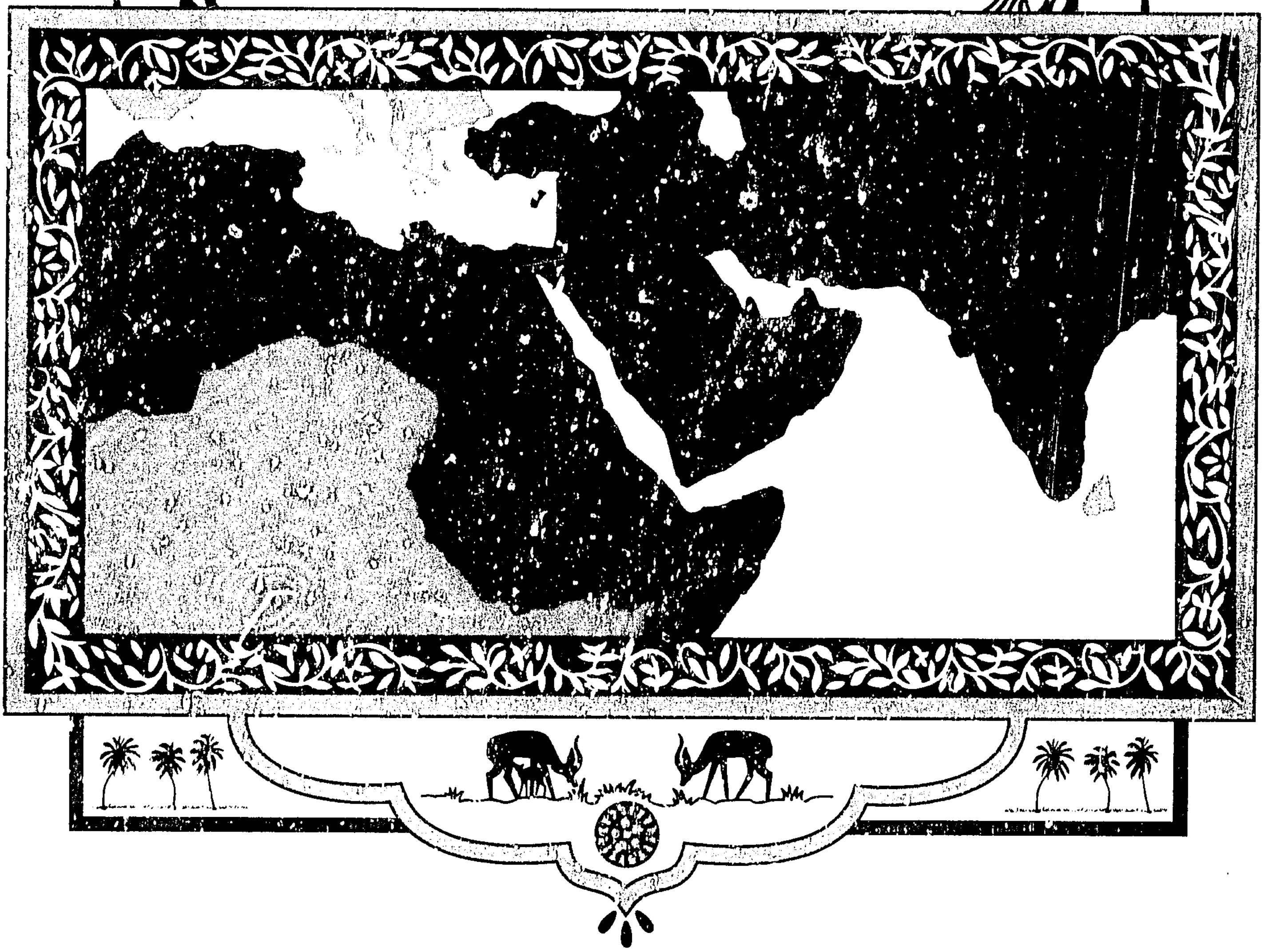
Soil, Water and Crop/Livestock Management Systems

Rainfed Agriculture in the Near East Region



U.S. Agency for International Development

United States Department of Agriculture

International Center for Agricultural Research in the Dry Areas

Soil, Water, and Crop/Livestock Management Systems for Rainfed Agriculture in the Near East Region

Proceedings of the Workshop
at
Amman, Jordan

January 18-23, 1986

Editors:

C.E. Whitman, USDA/USAID, Beltsville, Maryland, USA
J.F. Parr, USDA/USAID, Beltsville, Maryland, USA
R.I. Papendick, USDA, Pullman, Washington, USA
R.E. Meyer, USAID, Washington, D.C., USA

Co-Sponsors:

United States Agency for International Development
United States Department of Agriculture
International Center for Agricultural Research in the Dry Areas

Co-Hosts:

Jordan Ministry of Agriculture, Amman, Jordan
University of Jordan, Amman, Jordan
Jordan University of Science & Technology, Irbid, Jordan
Arab Center for Studies in the Arid Zones and Drylands, Damascus, Syria
Water Authority of Jordan, Amman, Jordan

Washington, DC
October 1989

Foreword

In 1983 the Agricultural Research Service (ARS) of the U.S. Department of Agriculture and the Science and Technology Bureau of the U.S. Agency for International Development (USAID) established a cooperative agreement whereby these agencies would provide technical support for improving soil and water management practices in dryland or rainfed agricultural systems in developing countries of arid and semiarid regions. As a result, the USDA/USAID Dryland Agriculture Project, also known as Technology for Soil Moisture Management (TSMM) was created. This agreement reflects an awareness that dryland or rainfed cropping systems currently produce most of the food and fiber for some 700 million people in the Near East, Sub-Saharan Africa, and Southern Asia. However, in recent years the food grain production per capita in many of the countries in these regions has declined. This can be attributed largely to the lack of proper soil and water management practices and continued degradation of the natural resource base.

The agricultural soils in these countries are often coarse-textured, sandy soils that are low in fertility, low in soil organic matter, and low in water-holding capacity. Rainfall patterns are often erratic and unpredictable, and crop yields can be adversely affected by moisture deficits and drought even during the normal periods of precipitation. Efforts to intensify row-crop production have resulted in severe wind and water erosion and excessive loss of natural rainfall and plant nutrients through runoff. These conditions are similar to those that existed in the drylands of the U.S. Great Plains some 50 years ago which resulted in the Dust Bowl of the 1930s. Since that catastrophic disaster, ARS and land-grant university scientists have conducted extensive research to improve soil, water, and crop management practices. This has led to the development of more stable and sustainable conservation and production systems for dryland agriculture. Such expertise is absolutely essential to USAID's goal of improving the productivity, stability, and sustainability of dryland farming systems in the Third World. This will be a priority activity for the years to come.

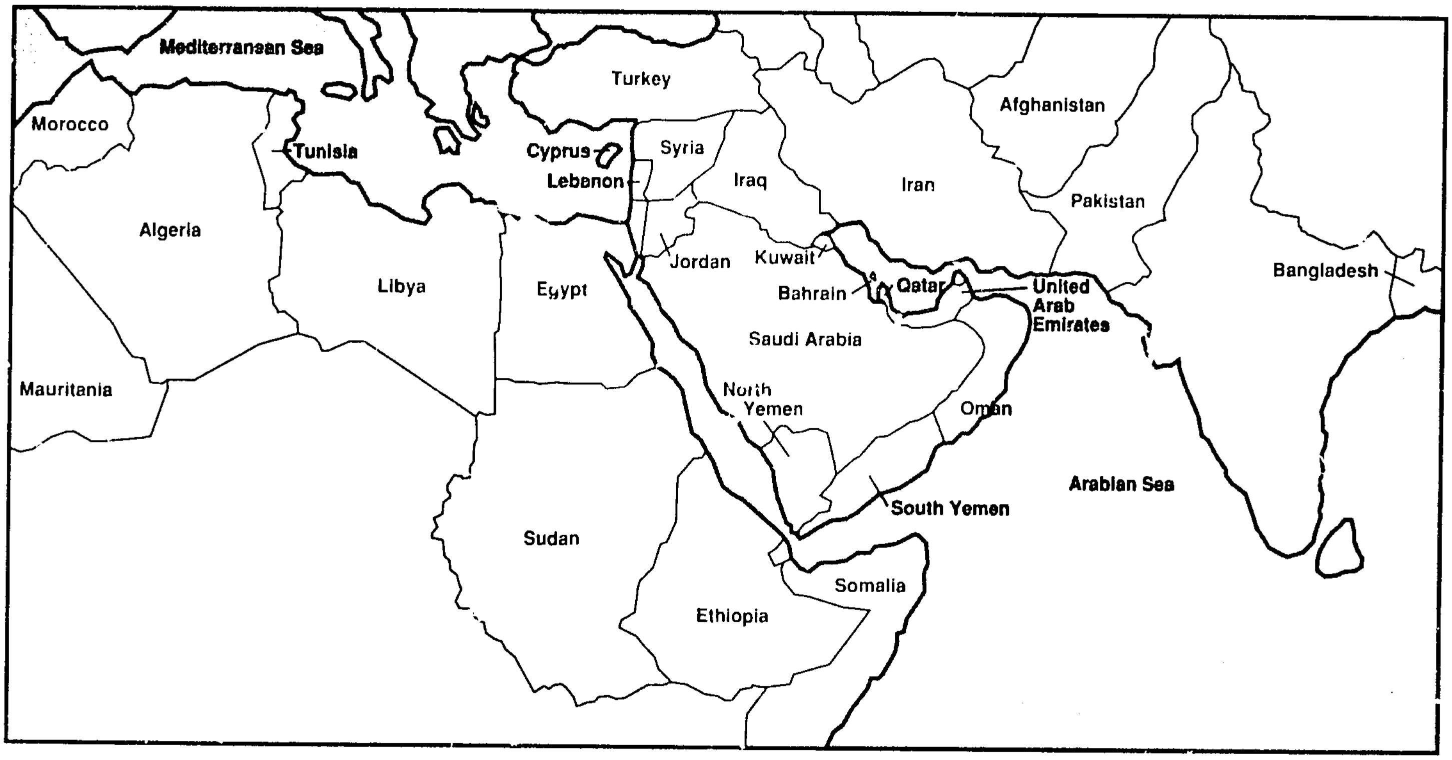
The USDA/USAID Dryland Agriculture Project or TSMM assists developing countries in the economic assessment of their soil, water, and crop/livestock management systems under suboptimal conditions. This is done through the assistance of the Economic Research Service (ERS) of the USDA. TSMM also assists such countries in developing data bases of research information, and research and extension networks that promote cooperative research and exchange of information on agricultural systems management. The Project has catalyzed a two-way flow of technical information on dryland/rainfed farming between the United States and developing countries.

An excellent example of TSMM's contribution to the improvement of dryland farming systems is the Workshop on "Soil, Water and Crop/Livestock Management Systems for Rainfed Agriculture in the Near East Region," that was held during January 18-23, 1986 in Amman, Jordan. Such workshops are invaluable since they critically assess past research, identify gaps in our research data bases, establish a consensus of future research needs and priorities, and provide a firm basis for regional research networks or Ribbon Projects to resolve urgent problems affecting soil, water, and crop/livestock management systems.

The Office of Agriculture of USAID's Science and Technology Bureau is pleased to have supported this important Workshop and the publication of these Proceedings. We hope that these activities will facilitate the development of more productive, profitable, and sustainable agricultural systems by countries in semiarid regions.

D.D. Bathrick
Director, Office of Agriculture
Science and Technology Bureau
U.S. Agency for International Development
Washington, D.C.

Countries Within the ICARDA Mandate



Preface

The dryland areas of the Near East Region are a major source of food and fiber for millions of people. However, current yields are very low compared to yields of the same crops in developed countries. The principal reasons for this are 1) new and improved technologies that might increase crop production are not being readily adopted; 2) improved soil and water conservation methods are not being implemented; 3) there are severe economic constraints to the acceptance of new technologies; 4) the long-term and continued erosion of agricultural soils by both wind and water, and the subsequent loss of soil productivity; 5) limited and often erratic rainfall; 6) inadequate use of chemical fertilizers in the dryland areas; and 7) the low level of crop residue that is returned to the land because of its competitive use as feed for small ruminant animals, mainly sheep.

Thus, with the creation of the USDA/USAID Dryland Agriculture Project, also referred to as Technology for Soil Moisture Management (TSMM), and with strong encouragement by a number of regional and international organizations, a workshop was organized to address the overall problem of declining yields and its multifaceted, complex components.

The Workshop on "Soil, Water and Crop/Livestock Management Systems for Rainfed Agriculture in the Near East Region" was held in Amman, Jordan during January 18-23, 1986. It was cosponsored by the USDA/USAID Dryland Agriculture Project and the International Center for Agricultural Research in the Dry Areas (ICARDA). Some 70 participants from 9 countries (Jordan, Syria, Turkey, Sudan, Pakistan, Egypt, Yemen, England, and the United States) attended the Workshop. Agencies and organizations represented included ICARDA, the Arab Center for the Studies of Arid Zones and Drylands (ACSAD), the Arab Organization for Agricultural Development (AOAD), the Arab Scientific Institute for Research (ASIR), University of Jordan, Jordan University of Science and Technology, the Jordanian Ministry of Agriculture, the Jordan Cooperative Organization (JCO), the Water Authority of Jordan, the German Technical Assistance Agency (GTZ), the Food and Agriculture Organization (FAO), the Jordan-Australia Dryland Farming Project, USAID, and USDA.

The objectives of the Workshop were threefold:

1) To review and discuss the major problems and constraints which limit the productivity of rainfed (dryland) agricultural systems in the Near East Region.
2) To review available data bases of research information and current research on soil, water, and crop/livestock management practices, and to develop strategies and priorities for resolving major problems through research and technology transfer.
3) To consider establishing a research network between national scientists in the Near East Region and U.S. scientists working on similar, high priority problems of rainfed/dryland agriculture, i.e., Ribbon Projects.

Following the presentation of technical papers, Working Groups formulated recommendations and priorities for future research in the areas 1) Agroclimatology, Land Use, and Crop Selection, 2) Soil and Water Conservation, 3) Efficient Use of Water by Crops, 4) Soil, Water, and Plant Nutrient Relationships, 5) Effects of Livestock and Crop Residue Practices on Soil/Water Conservation, and 6) Farming Systems and Socioeconomic Considerations.

The Workshop participants recognized that the major constraints which limit crop production in the Near East Region are insufficient rainfall and inadequate water conservation practices on agricultural lands. The key to increased water conservation is the proper use of crop residues to reduce runoff and soil erosion and to ensure that more of the rainfall infiltrates and is retained in the soil profile. Currently, most of the crop residues in the rainfed/dryland areas are consumed by small ruminant animals, mainly sheep, which leaves little or nothing for soil and water conservation purposes. A strong consensus of the Workshop was that future research should focus on the development of crop residue management systems that would optimize crop/livestock production and soil and water conservation in the Near East Region. Research is needed to determine the relative agronomic and economic values of crop residues for both animal feed and resource conservation, and to develop viable alternative management strategies.

Another consensus of the Workshop participants was that the failure to adopt and implement basic soil and water management practices is a major constraint to increasing the productivity and stability of rainfed agriculture in the Near East Region. The entire Region constitutes a highly fragile land resource and environment, and there is limited knowledge as to the technologies that would be appropriate for these conditions. Where research has been conducted, there has often been inadequate characterization of the research sites as to soil types, soil properties, and agroclimatic variables. Consequently, the extrapolation of research results and transfer of technology from such sites to the farm involves considerable risk. There is an urgent need to conduct comprehensive soil survey and land classification studies using modern soil taxonomy to determine the land use capability of agricultural soils in this Region.

The Working Groups emphasized the importance of having a sound technical data base of past and current research on various aspects of soil, water, and crop/livestock management systems for rainfed agriculture in countries of the Near East Region. They also underscored the need to integrate this information into agricultural production systems that are within the technical and economic capability of the farmer so he may achieve a higher level of productivity and profitability, while protecting and conserving the natural resource base.

Agricultural data bases are valuable references for both national and international agencies in developing strategies and priorities for future research, and as national planning documents for the development, conservation, and management of limited soil and water resources. Such a data base has now been compiled for Jordan by Dr. Abdullah A. Jaradat, Jordan University of Science and Technology, Irbid, and is entitled *An Assessment of Research Needs and Priorities for Rainfed Agriculture in Jordan.* Copies can be obtained from Drs. Jaradat, J.F. Parr, or R.E. Meyer. Other countries in the Near East Region may wish to use the Jordan data base as a model in compiling their own.

We hope that the Proceedings of this Workshop will help to develop improved communication and exchange of technical information among scientists in the Near East Region, and to foster linkages with scientists in developed countries who are involved in similar research.

Organizing and Program Committee

Dr. James F. Parr
Coordinator, USDA/USAID
Dryland Agriculture Project
ARS National Program Staff
Beltsville, Maryland

Dr. Raymond E. Meyer
Project Monitor—TSMM
Science & Technology Bureau
U.S. Agency for
International Development
Washington, D.C.

Dr. Robert I. Papendick
Research Leader
Land Management/Water Conservation
Research
USDA/ARS
Pullman, Washington

Dr. Hazel C. Harris
International Center for
Agricultural Research in
the Dry Areas (ICARDA)
Aleppo, Syria

Dr. William R. Furtick
Food and Nutrition Directorate
Science and Technology Bureau
U.S. Agency for International
Development
Washington, D.C.

Acknowledgements

The editors would like to thank Jean Newcomb, Information Staff, Agricultural Research Service, USDA, for her many significant contributions during the course of publication. These include designing the cover, assisting with the format, and serving as a technical consultant to the printers and contractors.

Abbreviations

ACSAD	Arab Center for Studies in the Arid Zones and Drylands, Syria
AOAD	Arab Organization for Agricultural Development, Sudan
ARS	Agricultural Research Service, USDA
ASIR	Arab Scientific Institute for Research, Israel
BARD	Barani Agricultural Research and Development Project, Pakistan
BRGM	Bureau de Recherches Geologique et Minieres, France
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo, Mexico
ERS	Economic Research Service, USDA
FAO	Food and Agriculture Organization, United Nations
GOJ	Government of Jordan
GTZ	German Technical Assistance Agency
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer, USAID
ICARDA	International Center for Agricultural Research in the Dry Areas, Syria
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics, India
IDRC	International Development Research Center, Canada
INRA	Institut National de la Recherche Agronomique, Morocco
JCO	Jordan Cooperative Organization
JFI	Jordan Fertilizer Industry Company
JHADP	Jordan Highland Agricultural Development Project
JUST	Jordan University of Science and Technology
MAAR	Ministry of Agriculture and Agrarian Revolution, Algeria
MOA	Ministry of Agriculture, Jordan
NARC	National Agricultural Research Center, Pakistan
NCARTT	National Center for Agricultural Research and Technology Transfer, Jordan
NFDC	National Fertilizer Development Center, Pakistan
PARC	Pakistan Agricultural Research Council
RAIN	Rainfed Agriculture Information Network
SCRAD	Systematic Commodity/Resource Analysis and Development Process
SCS	Soil Conservation Service, USDA
SMSS	Soil Management Support Services, USAID
TSMM	Technology for Soil Moisture Management, USAID
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UOJFA	University of Jordan Faculty of Agriculture
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
WHARF	World Hunger Alleviation through Response Farming, United States

Table of Contents

Goals and Objectives

Dr. W.R. Furtick
U.S. Agency for International Development Amman, Jordan

The goal of this workshop is improved use and conservation of soil and water resources.

The objectives are twofold, i.e., for Jordan and for other countries in the Near East region.

For Jordan, the objectives are to initiate a process that will over the next few months:

1) More fully define the constraints on each element of agricultural production caused by inadequate water and soil resources.
2) Examine which of these constraints can be reduced or eliminated.
3) Evaluate the best way of overcoming or reducing these constraints.
4) Determine what specific actions are needed.
5) Assign responsibilities to specific individuals or organizations to take these specific actions.
6) Based on action plans developed, provide the resources required to address priority constraints.

This workshop will contribute to this process by:

1) Utilizing the experience of experts from other countries in the region, international and regional organizations and scientists from the United States to help with the initial phases of the process - i.e. providing the data base from which to identify the primary constraints and the actions required to overcome them.
2) Start in getting familiar with the Systematic Commodity/Resource Analysis and Development Process (SCRAD) that will be adapted to the needs of Jordan as a tool in the constraint analysis and the process to overcome these constraints.
3) Formalize a means of completing a Jordan data base on what is already known.
4) Start the momentum required to do something more than talking about the problems.
5) Initiate the dialog and become acquainted with colleagues in the region and beyond that can provide future help and information.

For our visitors from countries in the region and beyond, the Workshop will provide an interchange of information and ideas with colleagues in Jordan. It will also introduce them to the very effective tool of the SCRAD process for problem identification, resolution, and management. Through this Workshop the basis for a future regional network, the Rainfed Agricultural Information Network (RAIN), will be set to bring together scientists working with similar problems for a regular exchange of information and ideas.

During the Workshop you will be exposed to various programs and projects, but we will focus on two that are in the beginning stage, i.e., the Jordan Highlands Agricultural Development Project (JHADP) and RAIN. As already mentioned, the RAIN Project will bring together scientists from the region and beyond that are working on similar problems. The JHADP will establish the National Center for Agricultural Research and Technology Transfer (NCARTT) and its Regional Centers; create an interagency public/private/donor sector coordinating body; bring order out of chaos via SCRAD; and provide supplemental funds to insure implementations.

In summary, then, we will start a process that over a matter of months is designed to: identify major constraints for each important element; determine how to overcome them; assign responsibility for overcoming them; complete the data base of what is already known and has been done; and build the basis for continuing linkages with colleagues outside Jordan.

SECTION I

Overview of Rainfed Agriculture in the Near East Region

Soils of the Arab Countries

A. Osman
Arab Center for the Study of Arid Zones and Drylands,
Damascus, Syria

ABSTRACT. Soil and land use classification can be used to improve agricultural planning and conservation of the soil resource base. Recently ACSAD has applied the USDA soil classification system in an effort to produce a soil map of Arab countries. Objectives of the project are to standardize nomenclature, methods of soil profile description, laboratory analyses, and presentation, including common legends and color systems. To date ACSAD has identified Aridisols (the predominant soils in the region), Inceptisols, and Vertisols in the fertile plains of Syria, Iraq, Sudan, and North Africa, and Torrifluvents in the alluvial plains of important rivers. It is hoped that the soil maps and other information will be used by decision-makers to establish sound agricultural development policy.

Introduction

Soils are valuable resources for food production and agricultural development. They are not renewable and should be conserved for the future generations. As in the developed countries, most of the developing countries have created specialized public services to characterize, conserve, and develop this natural resource. There will be no food without soils. This is why most dense populations and old civilizations are located in the fertile lands of the world.

Soils are not homogeneous in their properties and suitabilities for agriculture. They differ from one location to another according to their forming factors, that is, parent rocks, climate, vegetation, topography, and time. Soil properties are defined by their physical, chemical, biological, and minerological composition. Characterization of soil properties is a long and sophisticated process. It involves specialists of high qualification, field and laboratory equipment, and time.

Soil classification itself is not a simple language. On the contrary, it is sometimes difficult to understand, especially for decision-makers and administrators. Land classification is much more simple, consisting of 6 to 8 land suitability classes and subclasses for agricultural practices. This is one reason that in some developing countries land classification is much more popular than soil classification. Nevertheless, a good land classification map contains much less information than a soil map, and in most cases it is based on some selected information from the soil map itself. The soil classification could be and also should be used for agricultural development.

Methodologies

Numerous systems of soil/land classification have been used in Arab countries. Available maps do not cover all the countries and priority was given to the cultivated and, particularly, the irrigated areas. These maps were prepared by different specialists, e.g., agronomists, geographers, geologists, economists, meteorologists, hydrologists, etc. A typical map is on a scale from 1:20,000 to 1:100,000, i.e., semidetailed to reconnaisance level. The legend is generally specific to the objectives but has been developed mainly to satisfy the needs of administrators and takes into consideration the local agricultural problems. The base map is considered less important. In most cases the map is a kind of sketch or draft minus the location map, the map index, and the contour lines. The accuracy of a typical map is also subject to criticism in most cases. A limited number of reference and typical sites have been completely characterized. Soil description is brief and laboratory analysis has been limited to three textural classes in addition to pH and other simple determinations. This is unfortunately true of many soil studies in different locations in the Arab countries. However, there are some good maps accompanied by good reports presenting detailed information on the methods and the properties of the soils. It will be easy to correlate these maps to another system of soil classification and make a good interpretive map at the country or the regional level on a smaller scale.

Available Information

Most available information describes the cultivated lands according to land use and agricultural production. The Arab countries constitute an area of 1,361 million ha located mainly in the semiarid and arid parts of the world. Only 52 million ha are under cultivation and these are located in the semiarid (Xeric and Ustic) areas, 3.8 percent of the total area. The irrigated area represents about 0.7 percent of the total area, about 9 million ha located mainly in Egypt and Iraq.

The countries that have completely described their soil resources at least at reconnaissance level are limited to Iraq, Tunisia, Yemen Arab Republic, Syria, and Lebanon. A soil map of Saudi Arabia has been recently completed within a contract with the USDA Soil Conservation Service. The French system of soil classification has been used for a long time in Tunisia and other north African countries. ACSAD has completed a soil map of Tunisia, Syria, and Lebanon applying the USDA soil classification system Soil Taxonomy at a scale of 1:1,000,000. This work was carried out within an ACSAD project of the soil map of the Arab countries on 1:1,000,000 scale adopting the USDA Soil Taxonomy as a basic and international system for soil classification. This project is one important collaborative work undertaken by ACSAD and the national soil scientists in the Arab countries.

A synthetic map covering part of Morocco and Sudan has been prepared. Some other countries have limited information on soils such as Somalia, Mauritania, and Yemen Democratic Republic. In Libya an important study of the soil resources has been carried out by Russia on a scale of 1:50,000 covering the northern part of the country and using the Russian system of soil classification. This map contains valuable information on soils and their properties.

ACSAD Soil Map Project

ACSAD is undertaking an important project in the Arab countries to produce a general soil map at a reconnaissance scale of 1:1,000,000 in order to standardize methods of soil profile description, laboratory analysis, presentation with a common legend, and a common color system. The Defense Mapping Agency (DMA) operational navigation chart of the world was selected as a common base map. A consultative committee was formed by eminent professors and soil scientists from FAO, France, USDA/SCS, and the directors of the soil directorates in the Arab countries. A common legend was elaborated and distributed to the Arab soil scientists. ACSAD specialists are responsible for correlation and coordination. Technical and some financial support have been allocated.

Methodology is based mainly on available reliable information with additional adequate ground truth. Satellite imageries could be used for the determination of the soil units. The maps are presented at the subgroup level with information on slope, surface texture, and stoniness.

The project also has an important training component with the cooperation of the Soil Management Support Service (SMSS) of the USDA/SCS and USAID in the United States. Training courses, seminars, workshops, and a forum on Soil Taxonomy were organized jointly with SMSS and ACSAD and the local soil administration in Syria (1980), Morocco (1982), Sudan (1983), Jordan (1984), and Tunisia (1985). Other training courses were organized in Arabic with the cooperation of the Arab Organization for Agricultural Development (AOAD, 1985).

A tremendous amount of information and soil maps have been collected and ACSAD has established a data bank for the soil map project with the cooperation of Bureau de Recherches Geologique et Minieres (BRGM), France to classify and store soil information. Actually thousands of typical soil profiles with soil description and analytical data are available for representative soil units at the subgroup level.

Soil Classification

According to Soil Taxonomy soils of the Arab countries are mainly classified in the Aridisols order. Aridisols are predominantly Calciorthids and Gypsiorthids. The Argids suborder is occasionally identified. This development is related mainly to the soil moisture regime in the region. The Entisols Order is also well represented. Two situations are to be considered. Under the aridic (torric) soil moisture regime, the soils are mainly classified as Torriorthents, while under xeric or ustic soil moisture regimes the soils are classified as Xerorthents or Ustorthents. In the mountainous areas and at high altitudes the soil moisture regime could be udic. This situation exists in the high Atlas range in North Africa and some other locations in the region.

In the fertile plains of Syria, Iraq, Sudan, and North Africa soils are predominantly Inceptisols and Vertisols. Under dense natural vegetation, Mollisols are developed. They belong mainly to the Lithic subgroups. Other important soils are formed on alluvial material of the Nile, the Euphrates, and other important rivers. These soils are classified mainly as Torrifluvents and they produce high yields under irrigation. Examples of soils of the area are given in Tables 1 and 2.

Table 1. Soils of Syria

Order	Predominant Soil	Area
		km^2
Aridisols	Typic Calciorthids and Gypsiorthids	107,508
Inceptisols	Calcixerollic Xerochrepts	45,667
Entisols	Typic Xerorthents, Rock outcrops	22,024
Vertisols	Typic Chromoxererts	6,074
Mollisols	Lithic Calcixerolls	2,910
Others	(Andisols)	997

Table 2. Soils of Yemen Arab Republic

Order	Predominant Soil	Area
		km^2
Aridisols	Typic Calciorthids	10,097
Entisols	Typic Torriorthents	70,223
Inceptisols	Typic Ustropepts	4,923
Mollisols	Typic Calciustolls	2,809
Rock outcrops	Lithic subgroups	29,259

Mediterranean-Type Climate, Wheat Production and Response Farming

J.I. Stewart
World Hunger Alleviation through Response Farming, Davis, California, USA

ABSTRACT. A new rainfall analysis, specific for the crop to be produced, shows that in Mediterranean-type climates on a transect from Morocco through Cyprus to Jordan, both wheat season rainfall amount and the duration of the rainy period are correlated with the effective date of onset of the rains. The earlier the onset after October 1, the greater the rainfall expectation and therefore the potential wheat yield. This finding has far-reaching implications for risk assessment and management in Near East region agriculture. Farm level decisions including all levels of inputs and virtually all practices, may be modified in the future at the advent of each growing season, based on nothing more complicated than the actual date of onset.

Present practice is to characterize a location or zone by the mean annual rainfall, and to devise fixed cropping system recommendations to be followed every year with a minimum of modification for actual rainfall occurrences. The new analysis shows a locale may be much more clearly characterized through quantification of several crop season historical rainfall means calculated separately for each of any number of selected onset periods, e.g. months.

At Amman, Jordan for example, mean annual rainfall over 31 years of record was 283 mm. Deleting rains lost prior to effective onset and following crop maturity, the long-term wheat season mean rainfall was 253 mm. Empirical water production function studies in Jordan suggest mean wheat yield using traditional technology should average 510 kg ha^{-1}. Research elsewhere suggests nitrogen at 31 kg ha^{-1} and improved weed control should raise average wheat yield to 1135 kg ha^{-1}.

The new analysis does not argue with these figures but instead clarifies the situation the farmer actually faces season by season. The 31-year record shows no October onsets at Amman, but November onsets 8 times or 26 percent of all years. Wheat season rainfall averaged 332 mm and persisted 161 days. In no instance did rainfall drop below 205 mm, the failure level where production should fall below 300 kg ha^{-1}. Traditional technology should produce 855 kg ha^{-1} with 332 mm, while improved technology, including 52 kg ha^{-1} N, should produce 1890 kg ha^{-1}.

Contrast the above with January onsets which numbered 9 in 31 years or 29 percent of all years. Of these, 5 would have failed because mean wheat season rainfall in these years was only 213 mm. If one planted every year, expected average yield (traditional) would be 335 kg ha^{-1}, or, with 21 kg ha^{-1} N and weed control, 755 kg ha^{-1} wheat grain.

Overall, the analysis suggests 10 crop failures in 31 years or about 1 in 3 years. This, coupled with the above information, raises serious questions about fixed recommendations to farmers based on mean annual rainfall. The author concludes that a response farming approach based on a more thorough quantification of rainfall variability as related to onset date may greatly improve farmer adoption rates and satisfaction rates with improved technologies.

Introduction

Agriculture and agricultural research in the Near East region today face a challenge unprecedented in history, but we also possess new tools with which to meet it. The challenge results from a combination of human and natural forces. The requirement for food is doubling with population approximately every 25 years, but rainfall, from whence the water to grow food derives, is extremely variable and almost wholly unpredictable. If, for example, normal annual rainfall were 350 mm, actual rainfall might be as little as 100 mm or as much as 700 mm.

The brighter side of the picture is that we now possess, also for the first time, many long and detailed weather records and the computing power required to analyze them virtually any way we can imagine. And imagination is precisely what is required. We must imagine ourselves in the shoes of the farmer because if food production is increased, it will be due to his actions. These in turn will be based on his personal experiences in farming and on the advice he receives, and chooses to accept, from others. So we must acquaint ourselves with the farmers' questions - exactly what does he need to know in order to improve his actions and what is the last date that the information will be useful to him?

Some hold that we cannot predict rainfall. But each time the farmer prepares his fields and plants his crops for a new season, his actions are based on his expectations for rainfall in the season at hand. He does in fact make a prediction, however crude, and act on it. Despite the fact that his prediction is based on a relatively limited span of time and experience and despite the fallibility of human memory, peasant farmers the world over have by and large managed to produce the food required to stay alive.

However desirable, farmers do not require sharp predictions about seasonal rainfall - their decisions can be made much more rational and productive if they can be provided with a narrowed range of rainfall possibilities for the approaching season. For example, it would be extremely helpful if one knew (with a very high degree of probability) that rainfall this season would total 100 to 350 mm, or 350 to 700 mm, rather than 100 to 700 mm.

This paper shows that levels of predictability similar to that suggested above do indeed exist in Mediterranean-type rainfall patterns right across the region from Morocco to Jordan. The companion paper entitled "Response Farming for Improvement of Rainfed Crop Production in Jordan", shows that 1) the Jordanian wheat/barley farmers are well aware of this predictability and use it to guide their operations, and 2) the perfect memory embodied in long and detailed weather records, coupled with today's awesome computing power, can very much improve on the farmers' predictions and provide farmers with guidance for virtually all of their decisions including land forming and tillage, crop/variety selection and apportionment in the field, seeding and fertilization rates, weeding practices, etc. All these agronomic practices, and more, are influenced by water expectations.

Response farming is a term coined by the author to describe a flexible farming system based on a rainfall (season total, duration) forecast followed by an appropriate agronomic response. The system was evolved within the USDA/USAID/Kenya Agricultural Research Institute Dryland Cropping Systems Research Project between 1977 and 1983, following the finding that the monsoonal rainfall of eastern Kenya exhibited a highly usable degree of predictability, similar to that to be described (Stewart, 1980; Stewart and Hash, 1982; Stewart and Kashasha, 1984; Stewart and Faught, 1984). A further analysis in neighboring Rwanda indicated similar predictability there in the same monsoonal climate. Recent analyses in the wholly different Mediterranean climate of Morocco, Cyprus, and Jordan also show similar predictability, which is the topic of this paper.

Wheat, the Common Crop

Throughout the Near East region, rainfed agriculture is dominant, occupying 88 percent of the total cultivated land in eleven countries studied in depth by the Food and Agriculture Organization of the United Nations (FAO, 1982). In nearly all of these countries, wheat is the principal rainfed crop. Therefore, the present analyses are made with respect to wheat production.

Yields of rainfed wheat in the study countries cited above were found to be low, less than 1 t ha^{-1}, and the cropping intensity in the rainfed sector was only 57 percent. The present study develops information to alleviate both of these problems. Guidance can be provided to farmers both for reduced-risk selection among alternative crops to plant, and for improving their levels of inputs, particularly fertilizers, to more closely match rainfall levels for yield maximization per unit of water.

Table 1. Long Term Mean Rainfall (mm) at Three Selected Wheat Producing Locations in the Near East Region, Monthly and Annual.

Sites	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Year
							mm						
Settat	8	44	50	68	64	67	50	45	17	3	0	0	416
Nicosia	10	26	35	75	69	48	36	20	18	11	2	6	356
Amman	0	6	30	52	66	57	52	16	4	0	0	0	283

Rainfall Characteristics at Selected Wheat Production Sites

Long term daily rainfall records were obtained from three wheat production sites which form a transect across the Mediterranean Basin. The first record is from Settat, Morocco (1908 to 1982), supplied by courtesy of Dr. Darrell Watts, Leader, USAID/INRA Dryland Agriculture Applied Research Project. The second record is from Nicosia, Cyprus (1916 to 1979), supplied courtesy of the Cyprus Meteorological Department, and the third is from Old Amman Airport, Jordan (1937 to 1984), supplied courtesy of the Water Authority of Jordan.

Some data are missing from each record, so for sake of direct comparison, only the 31 years common to all three records were analyzed in the present study. These begin with 1937/38 and end with 1978/79. Nine years within this period are missing. Long term mean rainfall figures for the three selected locations are shown in Table 1 by months as well as annually.

It is simple coincidence that the three selected sites in Table 1 decline in normal rainfall amount as one proceeds from Morocco in the west to Jordan in the east. Different selections might reverse or change this order. However, it is of direct interest to note that rainfall in the main part of the rainy season (December, January, February, March) is nearly equal at all three sites, being 249, 228 and 227 mm, respectively. Thus there is a decline in both early and late rainfall as one proceeds from west to east.

Defining the Rainy Season for Wheat Production

A key concept in defining the date of onset of the rainy season for crop production is that rainfall accumulated in the surface soil layer must be sufficient to penetrate beyond the seeding depth such that it can both germinate the seed and fulfill the needs of the young seedlings until further rains are assured (with a very high degree of probability). This is approximately how farmers define the start of the rains because it suits their needs for crop production purposes. Hence, it suits our analytical needs also.

This introduces the other meteorological parameters which together determine the evaporative conditions of the atmosphere - primarily sunshine, temperature, wind, and humidity. It also introduces soil factors affecting runoff and infiltration such as slope, crusting, etc. These weather and soil factors play a part in determining the balance between water accumulation in the surface soil and rainfall.

In the present analyses, the date of onset is defined as the first day when accumulated soil water reaches 30 mm or more. Runoff losses are assumed to be zero, so a 30+ mm rain in one day meets the criterion for onset. However, if the 30 mm must be accumulated over a period of two or more days, then appropriate evaporation losses are applied, making the total rainfall required more than 30 mm. This requires simple water balance calculations based on knowledge of how evaporation from the soil surface proceeds in different wetting/drying sequences. It helps to explain why many previous analysts have not taken the same approach to rainfall analysis.

For the end of the season, the present analysis assumes wheat in the region is physiologically mature as of May 31 and can no longer gainfully utilize water. Additionally, the amount which can be evapotranspired in the last month or particularly half-month, is distinctly limited due to rapidly progressing leaf senescence. Once again some specialized knowledge is required to evaluate the possible effectiveness of heavy May rains. In fact though, May rains are only rarely heavy in the locations analyzed, so in most cases all May rain is considered part of the gross seasonal rainfall. Thus the wheat season rainfall here is the total from the date of onset (including the accumulated soil water on that date) through May 31. The duration of the rainy season is the number of days from onset to the last date prior to June 1 when rain equals or exceeds 1.0 mm. Thus wheat season rainfall approaches, but is almost invariably somewhat less than total annual rainfall.

Correlating Season Rainfall Amount and Duration with Date of Onset

Figures 1, 2, and 3, respectively, show how total season rainfall amount over the 31 common years of record relates to the date of onset for wheat production in Morocco, Cyprus, and Jordan. Each of these three scatter diagrams shows a similar downward trend in seasonal rainfall expectation with later onset of the rains. This has important implications for guiding decisions by farmers. The companion paper (*op cit*) describes 1) how farmers in that country today (and historically) respond to different dates of onset of the rains and, 2) how we can assist them further by quantifying both the rainfall predictors and the optimal responses.

In Figures 1, 2, and 3, vertical lines separate the months from September through February when onset might occur. Two horizontal lines are drawn at seasonal rainfall levels of 205 mm and 335 mm, to indicate wheat yield expectations. These lines are indicative only, because there is no direct relationship between crop yields and rainfall levels, and the indirect relationship which does exist is highly dependent on other factors such as fertilizer usage.

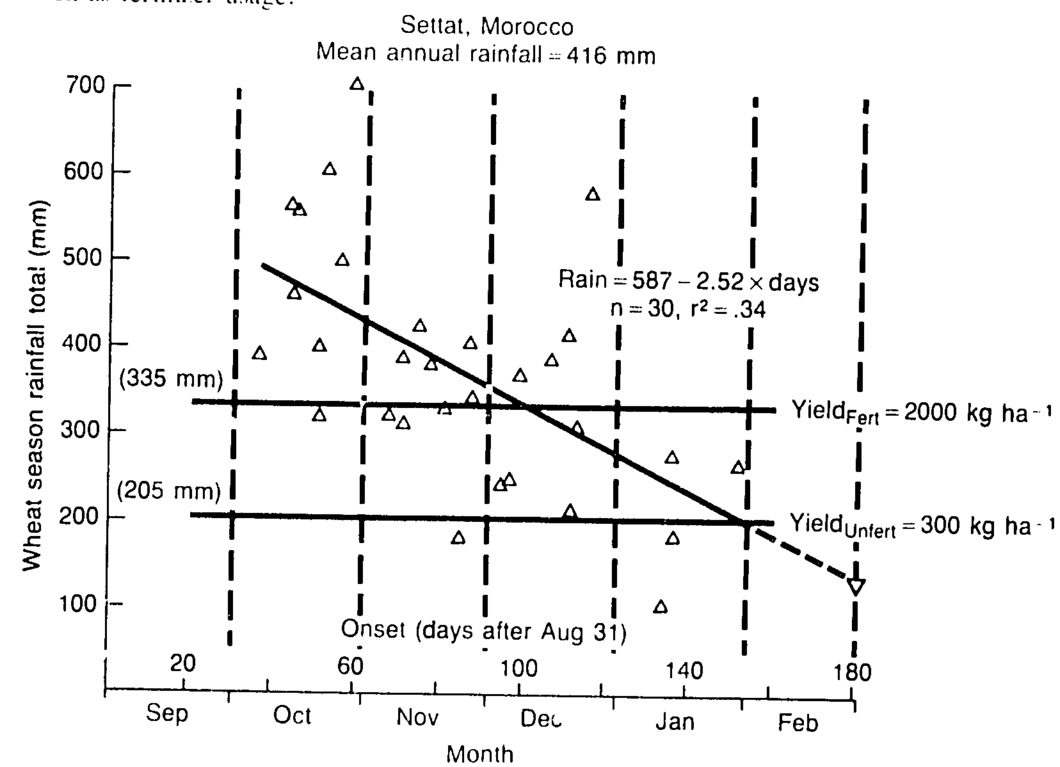


Figure 1. Decline of Wheat Season Rainfall Expectancy with Later Onset of the Rains at Settat, Morocco.

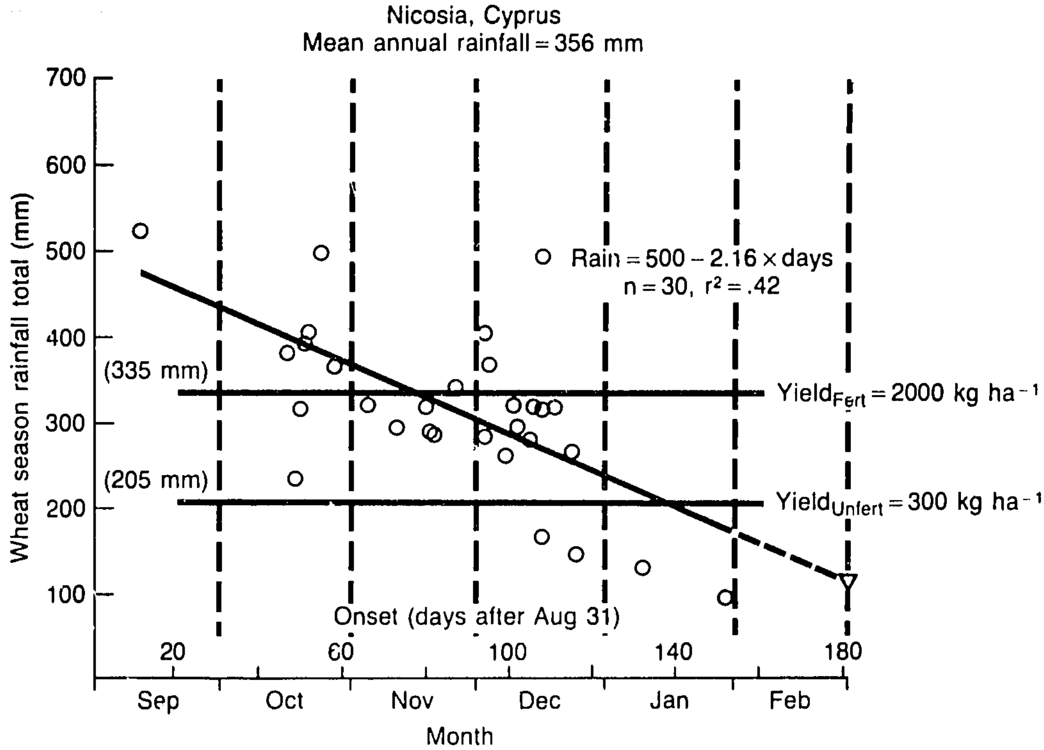


Figure 2. Decline of Wheat Season Rainfall Expectancy with Later Onset of the Rains at Nicosia, Cyprus.

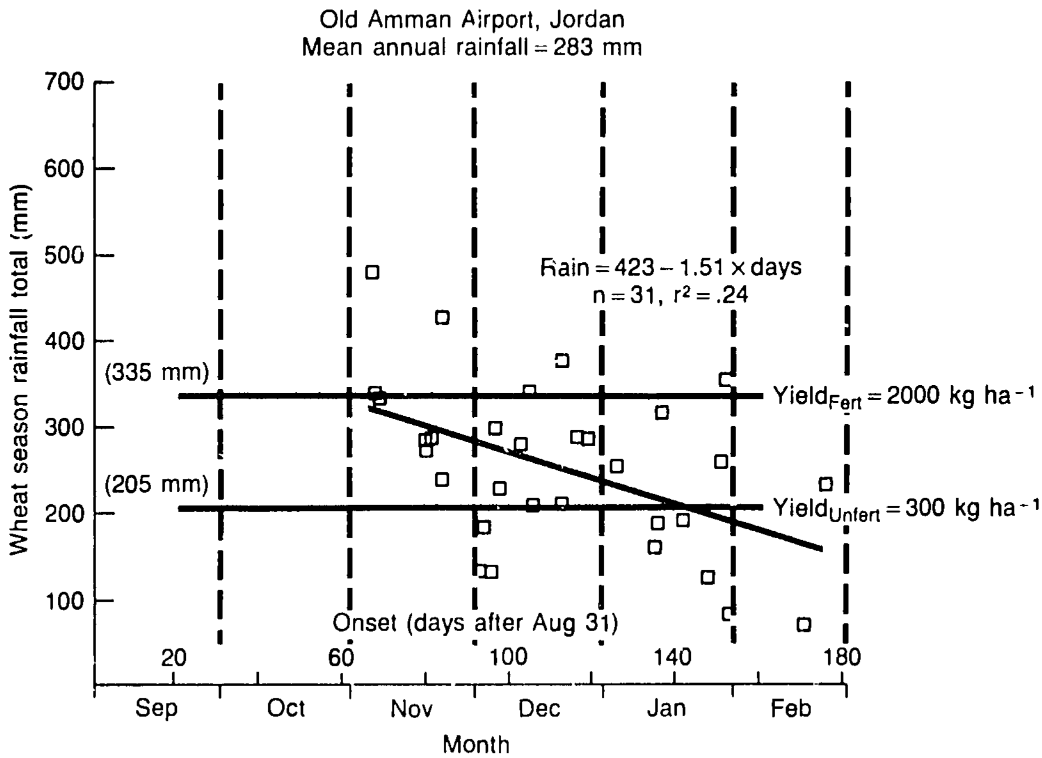


Figure 3. Decline of Wheat Season Rainfall Expectancy with Later Onset of the Rains at Old Amman Airport, Jordan.

Nevertheless, the lines as drawn are based on real data from Jordan and elsewhere, and the important factor of fertility is at least cursorily dealt with. For example, farmers in rainfall zones dipping below 205 mm generally do not fertilize. This is the case in Jordan where such a season should produce about 300 kg ha^{-1} of wheat, below which the crop is considered to be a total failure in that country. On the other hand, Mediterranean farmers expecting around 335 mm of rain would often fertilize, and could expect a yield like 2000 kg ha^{-1}. Yields higher than this would be considered good, while between 2000 and 300 kg ha^{-1} would be considered fair to poor.

In this regard, it is interesting to compare the above judgements by the writer with the perception of the wheat farmers in Cyprus, as put forth by the team of FAO experts who carried out the Regional Study on Rainfed Agriculture (FAO, 1982). They say "Cereal farmers in Cyprus expect that in every 10 years, they may have three good seasons, four moderate seasons, two poor and one very dry year." Figure 2 shows for 31 years, 10 good years, 13 fair years, 3 poor years, and 5 very dry years. Note the number 1 in the inverted triangle at the far right of Figure 2. This may also be seen in Figure 1 for Morocco, and indicates that in 1 of the 31 years there was no onset under the present definition, thus a total crop failure.

The important findings illustrated in Figures 1, 2, and 3 are summarized in Table 2. For each of the three study sites, Table 2 shows how many years onset occurred in each month from October to February (the single September onset in Cyprus is included in October). Next, the frequency of onset in each month is given, expressed as a percentage of all years. After that the actual mean wheat season rainfall total is shown separately for years grouped on the basis of month of onset. The final row shows (not seen in the figures) the mean duration of the rainy period for the groups of years above.

Table 2 reveals some interesting findings, as follow:

1) The median date of onset becomes later as one moves from west to east. Actual dates are November 24 in Morocco, December 3 in Cyprus and December 15 in Jordan.

2) The median date of the last wheat season rain is much earlier in Jordan (April 20) than in Cyprus (May 16) or Morocco (May 9). Thus the duration of the rainy period following onset in any given month is markedly less in Jordan than at the other more westerly sites.

3) At all three locations, mean season duration declines approximately one day with each day's delay in onset. This indicates that timing of the last rain is essentially unaffected by the date of onset.

4) Overall mean wheat season rainfall amounts at the three locations are Settat, 361 mm; Nicosia, 303 mm; and Amman, 252 mm. In Morocco and Cyprus, October onset seasons average well above these means, while November and December onset seasons average close to the overall means and January onset seasons average far below - at or below the failure level. In Jordan, where onset is later, November onset seasons average well above the overall mean, December onsets are near the mean, January is far below, essentially at the failure level, while February is far below the failure level.

Water Production Functions: Practical Interpretations

Tables 3, 4, and 5 are based on all the previous information, and on two additional interpretations. The first of these are wheat water production functions for both traditional (unfertilized) and advanced (fertilized) wheat cropping conditions. The second interpretation estimates the amount of fertilizer nitrogen (N) required to bridge the yield gap between the traditional and advanced systems.

Table 2. Rainfall Transect from Morocco to Jordan via Cyprus, Based on 31 Common Years of Record Starting in 1937/38 and Ending in 1978/79. Showing Numbers and Percentages of Years with Onset in Each Month, Together with Associated Wheat Season Rainfall Averages and Durations.

Location	Findings	Month of Rainfall Onset for Wheat					
		Oct	Nov	Dec	Jan	Feb	None
Morocco (Settat) R† = 416 mm	No. of onsets‡	9	9	8	4	0	1
	Onset, % of years	29	29	26	13	0	3
	Mean rainfall, mm§	500	343	345	208	—	
	Mean duration, days¶	202	177	145	117	—	
Cyprus (Nicosia) R = 356 mm	No. of onsets	8	6	14	2	0	1
	Onset, % of years	26	19	45	7	0	3
	Mean rainfall, mm	389	307	302	112	—	
	Mean duration, days	209	187	148	120	—	
Jordan (Amman Airport) R = 283 mm	No. of onsets	0	8	12	9	2	0
	Onset, % of years	0	26	38	29	7	0
	Mean rainfall, mm	—	332	246	213	150	—
	Mean duration, days	—	161	133	98	38	—

† R is total mean rainfall measured in the 31 years of record.

‡ Onset of the rainy season for wheat production, defined here as the first date when 30 mm or more of rainfall have accumulated in the soil.

§ Mean rainfall here refers to the wheat season rainfall, beginning with the accumulation at onset and ending May 31.

¶ Mean duration of the wheat season is the number of days from onset to the last rain of 1 mm or more prior to June 1.

The water production functions used are shown in the footnotes of Table 3. The function for traditional agriculture derives from actual data on yields and rainfall over a series of years in selected areas of Jordan. The underlying data were collected and published by the Arab Organization for Agricultural Development (AOAD, 1977) and the Water Authority of Jordan (1985).

The function for advanced agriculture derives from a synthesis by the writer of research findings from many sources. It fits the conditions in Jordan best, but is also reasonable for Morocco and Cyprus. A key consideration is that the yield vs. evapotranspiration (ET) function for wheat is linear, starting with zero yield at approximately 100 mm ET_a (actual evapotranspiration) and rising to a maximum yield of 6400 kg ha^{-1} when the water requirement is satisfied ($ET_a = ET_m$ (maximum ET)). The water requirement estimated for Amman is 597 mm (somewhat less in Morocco and Cyprus), so yield per unit of ET_a is 12.9 kg ha^{-1} mm^{-1}. But rainfall is not 100 percent efficient, so an estimate of efficiency is required.

Table 3. Settat, Morocco: Historical Pattern of Rainy Season Onset for Wheat Production by Months, and Rainfall Means for Seasons Beginning Each Month. Additionally, for Both Unfertilized and Fertilized Conditions, Estimates are Presented of Wheat Yield Potentials and Corresponding Nitrogen Requirements for Seasons with Onset in Each Month.

Practices	Findings	Month of Rainfall Onset for Wheat†					
		Oct	Nov	Dec	Jan	Feb	None
No added fertilizer (Normal fallow & rotations)	No. of onsets	9	9	8	4	0	1
	No. successful crops‡	9	8	8	2	0	0
	Success rate, %	100	89	100	50	—	—
	Mean rainfall, mm	500	343	345	208	—	—
	Mean potential yield, kg ha^{-1}§	1,200	925	935	325	—	—
Nitrogen added as indicated, plus phosphorus as required (Research needed)	No. successful crops	9	9	8	3	0	0
	Success rate, %	100	100	100	75	0	0
	Mean potential wheat yield, kg ha^{-1}	3,470	1,980	2,000	695	—	
	Nitrogen requirement, kg ha^{-1}¶	114	53	53	18	—	—

† Onset of the rainy season for wheat production is here defined as the first date (from 1 Oct onward) when rainfall accumulation in the soil, over and above evaporation during the accumulation period, equals or exceeds 30 mm.

‡ A successful wheat yield is here defined at 300+ kg ha^{-1}. Water production function research indicates a wheat season rainfall total of approximately 205 mm or 165 mm is required for a 300 kg ha^{-1} yield, respectively, in unfertilized versus fertilized conditions.

§ Potential wheat yields are estimated using the following water production functions. The function for unfertilized wheat derives from empirical findings in Jordan (Data from AOAD, 1977 and the Water Authority of Jordan, 1985). The function for fertilized wheat assumes only 74% of rainfall is actually evapotranspired.
Unfertilized: $Y(kg\ ha^{-1}) = 4.45 \times Rain\ (mm) - 602,\ Y_{max} = 1,200$
Fertilized: $Y(kg\ ha^{-1}) = 9.5 \times Rain\ (mm) - 1280,\ Y_{max} = 6,400$

¶ The nitrogen rates shown incorporate the following assumptions:
1) Nitrogen required is that which is sufficient to increase the wheat yield from the unfertilized potential to the fertilized potential;
2) Wheat straw = 1-1/2 × wheat grain;

3) Wheat straw = 0.5 percent N, wheat grain = 1.8 percent N;
4) Efficiency of N uptake and utilization is 50 percent;
5) Considering all of the above, N fertilizer requirement is approximately 5 percent of the increase in grain yield.

Table 4. Nicosia, Cyprus: Historical Pattern of Rainy Season Onset for Wheat Production by Months, and Rainfall Means for Seasons Beginning Each Month. Additionally, for Both Unfertilized and Fertilized Conditions, Estimates are Presented of Wheat Yield Potentials and Corresponding Nitrogen Requirements for Seasons with Onset in Each Month.

Fertilization Practices	Analytical Findings	Month of Rainfall Onset for Wheat					
		Oct	Nov	Dec	Jan	Feb	None
No added fertilizer (Normal fallow & rotations)	No. of onsets	8	6	14	2	0	1
	No. successful crops	8	6	12	0	0	0
	Success rate, %	100	100	86	0	0	0
	Mean rainfall, mm	389	307	302	112	—	—
	Mean potential yield, kg ha^{-1}	1,130	765	740	NA	—	—
Nitrogen added as indicated, plus phosphorus as required (Research needed)	No. successful crops	8	6	13	0	0	0
	Success rate, %	100	100	93	0	0	0
	Mean potential wheat yield, kg ha^{-1}	2,415	1,635	1,590	NA	—	—
	Nitrogen requirement, kg ha^{-1}	64	43	42	NA	—	—

Table 5. Old Amman Airport, Jordan: Historical Pattern of Rainy Season Onset for Wheat Production by Months, and Rainfall Means for Seasons Beginning in Each Month. Additionally, for Both Unfertilized and Fertilized Conditions, Estimates are Presented for Wheat Yield Potentials and Corresponding Nitrogen Requirements for Seasons with Onset in Each Month.

Fertilization Practices	Analytical Findings	Month of Rainfall Onset for Wheat					
		Oct	Nov	Dec	Jan	Feb	None
No added fertilizer (Normal fallow & rotations)	No. of onsets	0	8	12	9	2	0
	No. successful crops	0	8	9	4	0	0
	Success rate, %	0	100	75	44	0	0
	Mean rainfall, mm	—	332	246	213	150	—
	Mean potential Yield, kg ha^{-1}	—	875	495	345	NA	—
Nitrogen added as indicated, plus phosphorus as required (Research needed)	No. successful crops	0	8	10	6	0	0
	Success rate, %	0	100	83	67	0	0
	Mean potential wheat yield, kg ha^{-1}	—	1,875	1,055	745	NA	—
	Nitrogen requirement, kg ha^{-1}	—	50	28	20	NA	—

Returning to the traditional function, based on actual data, the zero yield intercept is at 135 mm of rainfall. Assuming 100 mm represents ET_a (above), 135 mm suggests an efficiency of 74 percent. Of course, as ET_a approaches ET_m and yield approaches the potential yield, this efficiency would decline. However, our interest here is only in the lower portion of the yield curve, so the suggested efficiency of 74 percent is adopted for purposes of this paper. Therefore, the advanced agriculture function rises at a rate of 9.5 kg ha^{-1} wheat per mm of rainfall.

The last footnote of Table 3 explains the considerations taken in estimating nitrogen fertilizer requirements to bridge the gap between yields expected in advanced agriculture versus traditional agriculture. The key factors are the weight relations between grain and straw and their respective N contents, and an assumed utilization efficiency of 50 percent. In the end these considerations suggest that the weight of applied N should be approximately 5 percent of the weight of anticipated grain yield increase.

Generalized Response Farming Considerations

The information in Tables 3, 4, and 5 addresses a number of decisions farmers must make each season. A sampling of these might be:

1) Should I plant dry or wait for the rains?
2) Should I plant wheat or some other crop?
3) On what signal should I switch to another crop? What other crop?
4) If planting wheat, what variety? What seeding rate?
5) What portion of my overall wheat hectarage should be planted?
6) Should N fertilizer be applied? If yes, when and at what rates?

The real question is whether the farmer is better served by a single set of answers to the above and other questions - a package of practices so to speak, to be followed every year, based presumably on overall mean rainfall conditions - or by more than one set, i.e., a flexible set of answers which change whenever the expected rainfall conditions in the season at hand have shifted markedly away from the long term norm. To answer this question, let us think a bit about how the information presented in this paper might influence decisions in the questions above.

With respect to question 1, dry planting, i.e., planting before the onset of the rainy period, is an important decision because it preempts most if not all of the other decisions. It implies the adoption of a single set of practices every year no matter what the actual rainfall conditions may be thereafter. The principal adjustment which might then be made for actual conditions would be the application of additional N fertilizer at say tillering time, provided rains had been normal or better.

This is not meant to be a criticism of dry planting but rather a simple statement of fact. Of course there could also be modified programs in which some minimal hectarage is dry planted with practices for the rest of the area dependent on how and when the rainfall season begins.

In any case dry planting means that the risk of total crop failure, and the loss of all costs associated with establishing and tending the crop, is accepted. It is informative to see just how great this risk is and, because most years of total failure have late (or no) onset of the rains, how the level of risk mounts with later onset. Table 6 shows first the overall risks of failure at the three locations prior to any possible onset (as of October 1 at Settat and Nicosia; November 1 at Amman), then how the level of risk climbs with delayed onset thereafter.

Table 6 suggests caution may be in order when dry planting wheat in Mediterranean climates. It tells us that if planting October 1 in Settat or Nicosia one would expect to lose everything one year in 10 or two years in 10, respectively. At Amman (November 1) the expected failure rate is three years in 10. These failure rates can be ameliorated somewhat with the use of advanced technology including fertilizers.

The risks of failure rise with delayed onset. For example, if January 1 arrives and onset has not occurred, the decision to plant some other crop is probably in order at all three sites. This will happen at Settat one year in six, at Nicosia, one year in 10, and at Amman, one year in three. When it happens, the risks of losing all have risen to 60 percent at Settat and Amman and 100 percent at Nicosia. Advanced technology reduces these risks a little bit at Settat and Amman, to 40 percent and 50 percent, respectively. At Nicosia the rate remains 100 percent.

Table 6. Risks of Total Wheat Crop Failure Due to Limited Rainfall at Three Mediterranean Locations, as of Specified Dates - Assuming in Each Case that Onset of the Rainy Season Has not Occurred. Risks are Expressed as Numbers of Years of Expected Failure in a 10 Year Period, and Are Shown Separately for Traditional (Unfertilized) and Advanced (Fertilized, Etc.) Levels of Technology.

Date	Traditional			Advanced		
	Settat	Nicosia	Amman	Settat	Nicosia	Amman
Oct. 1	1	2	NA	1	1	NA
Nov. 1	2	2	3	1	2	2
Dec. 1	2	3	4	2	2	3
Jan. 1	6	10	6	4	10	5
Feb. 1	NA†	NA	10	NA	NA	10

† NA, not available.

Illustrative Response Farming Strategies for Wheat Production

This paper shows a relationship exists between seasonal rainfall expectation and the date of onset. If one were to follow a response farming strategy, dry planting would be eliminated because the predictor of future rainfall is onset, which by definition means the rains have started and the seedbed is moist. Of course this does not in any way preclude earlier working of the soil for purposes of land forming or seedbed preparation. Generally speaking, this would be desirable so that planting, once begun, could proceed expeditiously.

The companion paper (*op cit*) discusses the situation in Jordan and strategies for dealing with it in considerable detail. Therefore, illustrations of how response farming recommendations might appear are shown here for Settat and Nicosia only. The reader is cautioned that this paper is based solely on only one preliminary rainfall analysis in each country, and is not intended for use in guiding farm operations at this state. Rather, it is intended to set the stage for further research oriented toward dealing with the highly variable rainfall conditions farmers must deal with.

Tables 7 and 8 outline ways in which rainfall variability might be dealt with on a season by season basis at Settat, Morocco and Nicosia, Cyprus, respectively.

The two big advantages of response farming as indicated in Tables 7 and 8 are 1) that total wheat crop failures are eliminated and, 2) that inputs, especially fertilizer N levels and seeding rates, are more closely linked to actual rainfall and yield expectations.

Each of these advantages is linked to a disadvantage. While eliminating crop failures, some small to modest (but nevertheless successful) crop yields are also missed by not planting the most desired crop. For example, if the program in Table 7 were followed, wheat would not be planted in 5 of 31 years. Only 2 of those years were total failures, while the other 3 would have produced average yields of 1 t ha^{-1}, provided they were fertilized.

Similarly, 5 of 31 years would not have been planted in Nicosia (Table 8). However, 4 of those would have been total failures. Only 1 year would have produced a modest yield about 1.25 t ha^{-1}. Thus the value of the response farming approach is more easily recognized in lower rainfall zones.

Table 7. Response Farming Strategy for Wheat Production at Settat, Morocco (Illustrative Only).

Response	Date of Onset			
	Oct	Nov	Dec	Jan Onward
Start planting	Onset	Onset	Onset	Alternative crop
Seeding rate†	Y=2500-4000 kg ha^{-1}‡	Y=1900-2500 kg ha^{-1}	Y=1100-2500 kg ha^{-1}	NA
Initial N rate, kg ha^{-1}‡	70	50	30	NA
Tiller N rate, kg ha^{-1}§	70	20	40	NA

† Use seeding rate shown by localized research to be optimal for the expected yield range shown here (Y).
‡ Initial N rate is applied every season at planting time. Fertilizer requirements other than N require localized research.
§ Tiller N rate is added at the tillering stage, provided rainfall is above a specified level to be determined in a more rigorous analysis.

Table 8. Response Farming Strategy for Wheat Production at Nicosia, Cyprus (Illustrative Only).

Response	Date of Onset		
	By Oct 31	By Dec 20	Dec 2 Onward
Start planting	Onset	Onset	Alternative crop
Seeding rate†	Y=1600-2400 kg ha^{-1}	Y=1600 kg ha^{-1}	NA
Initial N rate,‡ kg ha^{-1}	40	40	NA
Tiller N rate§, kg ha^{-1}	20	None	NA

† Use seeding rate shown by localized research to be optimal for the expected yield range shown here (Y).
‡ Initial N rate is applied every season at planting time. Fertilizer requirements other than N require localized research.
§ Tiller N rate is added at the tillering stage, provided rainfall is above a specified level to be determined in a more rigorous analysis.

The disadvantage of more closely fitting input levels to requirements is that it is more troublesome than using fixed levels - more troublesome for the farmer and perhaps even more so for the suppliers of inputs - probably most so for fertilizer suppliers. To be practical about these realities of life, it might well be best to recommend some compromise mode of fertilization which incorporates whatever flexibility exists in the supply system, then relies on a basic fixed rate of fertilizer for the rest.

An additional advantage to the response farming approach, whether fertilizer rates are compromised or not, is that better planning can be done for the planting of alternative crops when that becomes necessary. It will no longer be a case of wheat dying, so what do we do now? The action to be taken will be clear the moment it is found that the rains have not begun by the target dates established.

Summary

Data presented for three locations which transect the Mediterranean from west to east show that in all three cases, rainfall amount in the wheat production season, and the duration of rainfall from onset to crop maturity both decline with later onset of the rains.

For example, mean annual rainfall at Settat, Morocco is 416 mm, and mean wheat season rainfall is 361 mm. But if October passes without onset occurring, the farmer faces a much different situation. The rainfall record shows for all years with onset after October the mean wheat season rainfall is 304 mm. As of December 1 this figure has declined to 277 mm and on January 1 it is 166 mm. The same trend is true for Nicosia, Cyprus and for Amman, Jordan.

In real life this means that the probability figures seen in our usual rainfall analyses are only valid for a short period (strictly speaking, one day) during the possible time table for onset. In nearly all years, the reality is that published probabilities are either too pessimistic (when onset is early) or too optimistic (when onset is late).

For example, at Settat, the mean wheat season rainfall for all years with onset in October is not 361 mm, but 500 mm. It then declines to 343 mm for years with November onsets. The figure is nearly identical for December onsets, then falls to 208 mm for January onsets. Clearly one would wish to do things differently if mean rainfall is 500 mm than if it is 208 mm.

The response farming approach is to take cognizance of the types of findings described above, in order to provide farmers more meaningful guidance about the real rainfall expectation in the season just beginning, and the steps he might take to maximize his yields and returns with the expected water supply.

Details of altered rainfall expectations with later onset are presented for all three locations. Illustrative guidelines for farmer response to optimize wheat production are developed for Settat and Nicosia. The companion paper constitutes a case study for Jordan and shows similar information for Amman.

The indicated response when onset is very late is to switch from wheat to an alternative crop. At Settat the appropriate date for switching crops is January 1 and at Nicosia it is December 20. At both locations the record indicates alternative crops should be planted 5 years out of 31. At both locations this would eliminate total crop failures which would occur with wheat in two of the 5 years at Settat and 4 of the 5 years at Nicosia. The other years should have produced modest wheat crops of the order of 1 t ha^{-1}.

Three principal advantages of the response farming approach are as follows:

1) Total wheat crop failure associated with very late onset is eliminated through switching to alternative crops.

2) Knowledge of the frequency with which alternative crops will be required, and of the exact date when the decision to switch becomes applicable, is very helpful to the farmer in terms of preparation to plant the alternative crop.

3) Levels of key inputs, particularly fertilizers and seeds, are more closely matched to actual rainfall conditions, resulting both in cost savings and in maximization of yields and returns per unit of rainfall.

The main disadvantage is that farmers and suppliers may find difficulty in meeting input needs, particularly fertilizers which are changing markedly from season to season with only limited advance notice.

Conclusions

Wheat season rainfall throughout the Mediterranean declines with later onset of the rainfall season. Thus, the mean rainfall and expected minimums at different probabilities are not constant as implied in most rainfall analyses, but in fact are significantly higher when onset is early and significantly lower when onset is late.

A new type of rainfall analysis, which is crop specific, determines specific dates of onset for production of the designated crop in each of the past seasons in the rainfall record, and, through regression analysis, quantifies the decline in mean crop season rainfall and the total range of rainfall possibilities with the passage of time throughout the possible onset period.

Water production functions relating crop yields both to evapotranspiration (determined in experiment station research procedures) and to total rainfall (determined in on-farm and meteorological station measurements), under both traditional and advanced technology conditions, provide the information required to determine expected yield levels at different rainfall levels. Thus input requirements such as seed and fertilizer rates, as well as specific dates after which the crop failure rate becomes unacceptably high, and a switch to an alternative crop are indicated.

Additional research on response farming in the Near East region is warranted.

References

AOAD. 1977. Technical and economic feasibility study for the development of rainfed agriculture in the Amman Governorate of the Hashemite Kingdom of Jordan. AOAD, Khartoum, Sudan.

FAO. 1982. Regional study on rainfed agriculture and agroclimatic inventory of eleven countries in the Near East region. FAO/UN Near East Regional Office, Land and Water Development Division, Rome, Italy.

Stewart, J.I. 1980. Effective rainfall analysis to guide farm practices and predict yields. Proc. of the 4th Annual General Meeting of the Soil Science Society of East Africa, Arusha, Tanzania. October 1980.

Stewart, J.I 1986. Formulation of response farming recommendations for variable rainfall in Jordan: An illustrative case study. Companion presentation, this Workshop.

Stewart, J.I. and C.T. Hash. 1982. Impact of weather analysis on agricultural production and planning decisions for the semiarid areas of Kenya. J. Applied Meteorol. 21:477-494.

Stewart, J.I. and W.A. Faught. 1984. Response farming of maize and beans at Katumani, Machakos District, Kenya: Recommendations, yield expectations and economic benefits. E. Afr. Agric. For. J. 44:29-51.

Stewart, J.I. and D.A.R. Kashasha. 1984. Rainfall criteria to enable response farming through crop-based climate analysis. E. Afr. Agric. For. J. 44:58-79.

Water Authority of Jordan. 1985. Rainfall in Jordan, daily at all stations, 1976-80; Annual Records, all years, all stations. Amman, Jordan.

Rainfed Farming Systems of the Near East Region

D. Tully
International Center for Agricultural Research in the Dry Areas, Aleppo, Syria.

ABSTRACT. Agriculture is a major sector of the economy of the Near East region, and approximately half of the population lives in rural areas. Nevertheless, agriculture's share in national economies has been shrinking, and in many countries food production per capita has been in decline. This has sparked a renewed interest in agriculture in the region, including rainfed crop production.

The Near East is marked by a duality between large farms, often state-run, and small private holdings. The large farms are usually involved in commercial crop production, while the small farms are more often subsistence-oriented. Small farmers invest more in livestock, which may contribute half of their incomes, and they also work off-farm. Small farmers produce much of their crops for home consumption, particularly durum wheat, dairy products, and pulses.

The most common crops are wheat, barley, and pulses, usually grown in cereal-fallow or cereal-legume rotations. Weedy fallows are popular among small farmers because they provide livestock feed, but large farms often cultivate fallows to maximize moisture storage. Livestock graze croplands after harvest and through the subsequent fallow year, and this provides the bulk of their feed intake.

Mechanization has been extensive, affecting both small and large farms. Small farmers usually hire custom operators. Machinery used for tillage and sowing is diverse, and could likely be improved.

Policy towards agriculture is a critical factor in determining production. Rainfed agriculture, particularly in drylands, may be neglected relative to other crop production; similarly, small farmers may be given less incentives than large farmers. However, with encouragement the small farmers and dry areas should be able to achieve substantial increases in productivity.

Introduction

It would be presumptuous to try to describe all farming systems of the Near East in a single short paper; this is a topic for several books. I will draw out some of the features that are most common in the region, and of greatest importance. In keeping with the purposes of this Workshop, I will concentrate on rainfed farming systems, and will give greater attention to the cultivation of field crops rather than trees. I rely on my colleagues to discuss soils, water, and climate in detail, but would like to note that these are also important parts of farming systems.

The geographical focus of the paper must be clearly defined. In looking across the region, the greatest similarity in rainfed farming systems is found among the countries of the Arab Mediterranean and Iraq. In these countries a common pattern of rainfall, both in time and space, combines with many shared aspects of history and policy. To a large extent, the climate and farming systems are similar to those found in Cyprus and Turkey, although there are differences which will be discussed as we go along. The farming systems of the Arabian peninsula are rather more distinct, being based on spring and summer rainfall and, to a large extent, different crops than the Mediterranean; therefore, the Yemens and Saudi Arabia will receive less attention. Countries with extremely small rainfed areas, such as Egypt, Oman, and Bahrain, will be omitted.

It would be desirable to include those countries of sub-Saharan Africa which may be considered part of the region, as well as Iran, Afghanistan, and Pakistan, which include extensive rainfed crop lands. I have regretfully not done so because it would involve too many diverse farming systems for one paper.

Agriculture is an economically important, but secondary sector in the countries we will be discussing. Statistics are incomplete, but in most countries with substantial land resources, agriculture represents approximately 15-20 percent of Gross Domestic Product (GDP) (Table 1). At 6 percent, Algeria is particularly low for a country with over 7 million ha of arable land; this would seem to be a result of its heavy emphasis on industrialization and development of oil resources in recent decades. In general GDP figures underestimate the importance of agriculture because they do not adequately value subsistence production or household labor. Approximately half of the population lives in rural areas, and in most countries one-third to one-half of the workforce is primarily engaged in agriculture. Providing employment and most of the food requirements for half of the population is obviously an important, if undercounted, contribution to the economy of the region.

The importance of agriculture has been recognized by many countries in the Middle East in recent decades, stimulated by sharp declines in their ability to feed their populations from their own resources. Turkey was the first country of the region to focus on this issue and has now reached self-sufficiency in food (Hanson *et al.*, 1982). Over the last 15 years, self-sufficiency of the Arab countries, individually and as a group, has declined for a broad range of commodities, particularly cereals (AOAD, 1983). In response, recent development plans from Algeria, Jordan, Libya, Morocco, Syria, Tunisia, and other countries show an increased emphasis on agriculture, and many countries have maintained or adopted policies which stimulate part or all of the agricultural sector. The potentials of rainfed areas as well as rangelands and irrigated areas are being considered with new appreciation (Butter, 1985; Europa Publications, 1984; USDA, 1985).

Rainfed Farming Areas of the Near East Region

The Mediterranean climate is well-known. Rainfall comes in winter and early spring, and falls in greatest quantity near the sea. Rainfall decreases as one goes inland, and in all countries but Turkey and Cyprus the farmlands give way to large expanses of arid grazing lands or desert. In the Arabian peninsula, most rainfed areas are in the southwestern highlands, and have spring and summer rainfall. Rainfed farming systems generally occur in areas with 200 to 600 mm mean annual rainfall. In the small areas with more than 600 mm, either irrigation or tree crops usually predominate; on the other hand, with less than 200 mm, crop production is rarely economically feasible. With the notable exception of Iraq, countries with sizable rainfed areas have irrigation on only 2 to 10 percent of their crop areas.

The Social Context of Farming

Holding Size

Before discussing more technical aspects of the farming systems, it is useful to ask who the farmers are and to consider their circumstances. One of the most important factors in understanding farmer practices is the farm size. Holding size distributions are given in Table 2. The data do not distinguish land by productivity, rainfall group, or irrigation, but they give a general idea of the patterns of land ownership.

In all countries of the region, the vast majority of farmers are cultivating areas of 10 ha or less, often as little as one or two ha. However, such farms frequently make up less than 25 percent of the arable land. At the other extreme, farms of 50 ha and over are a small percentage of the total number of farms, but occupy from 14 to 45 percent of the land in all but one country. Since most of these countries have carried out land reforms involving expropriation of large farms, these large holdings are usually found on land expropriated from urban landlords or foreign settlers. They are frequently under direct or indirect government administration, as collectives, cooperatives, or state farms, and occasionally as government land leased to commercial farmers. The land on the large farms is generally of higher quality and in the most favored areas. In some countries, such land is scheduled for eventual redistribution in small plots, but governments are often slow to release control of these resources.

Table 1. Agriculture in the National Economies (World Bank, 1984).

Country	Agriculture % of GDP		Agriculture % of Labor		Urban % of Population		Food Prod Per Cap
	1960	1981	1960	1980	1960	1982	80/82 as % of 69/71
Algeria	16	6	67	25	30	45	75
Libya		2	53	19	23	58	127
Morocco	23	18	62	52	29	42	84
Tunisia	24	15	56	35	36	54	128
Iraq	17		53	42	43	70	87
Jordan		7	44	20	43	60	70
Lebanon	11		38	11	40	77	134
Syria		19	54	33	37	49	168
Turkey	41	21	79	54	30	44	115
Saudi Arabia		1	71	61	30	69	9
Y.A.R.		26	83	75	3	14	93
P.D.R.Y.		12	70	45	28	38	92

In between these two extremes lie middle-sized farms of 10 to 50 ha; they form a substantial minority of farms and land area in all countries. Farmers in this category may have a similar orientation and background to the small farmers, but they get a greater share of their income from crop production, and may have more resources to call upon. For example, such farmers more often own tractors in Turkey (Aricanli and Somel, 1979) and they have better access to credit and extension services in most countries.

Thus, there is a duality in the agricultural sector of most countries, between small (and very small) farms with much of the rural population but little of the land, and big farms with few farmers. This is essential to an understanding of the diverse farming practices which will be discussed below. This duality often presents a difficult policy choice for governments and donors: whether to invest in greater crop production on the large, easily reached farms, or to focus on improving rural incomes for the largest number of people. Earlier projects, such as the Increase in Cereals Production Project in Morocco initiated in 1968, often chose to ignore the small farmers in the belief that the economic returns of working with them were not worth the cost (Hogan *et al.*, 1984). Currently there is a greater appreciation of equity issues and the importance of increasing the security of rural life, and small farmers are more often included in development programs.

Holding size is a simple measure that obscures other factors. Patterns of joint ownerships, leasing, tenancy, and sharecropping also affect the nature of land holdings. Large farms may be sharecropped by small farmers, but small farms may also be leased on a cash or sharecropping basis to large operators. Small farmers may lease land from other small farmers to bring the holding size to an acceptable level (Hogan and Hansen, 1983; Hogan *et al.*, 1984; Johnson *et al.*, 1983). Contract services may also be provided on a share basis. More research is needed on the effect of these structures on farm decisions, particularly decisions to adopt new technology. It is clear, however, that they may involve several parties with differing goals in the decision process, and may divide limited farm income into very small amounts per party. Extension efforts need to be aware of local patterns of land access and design incentives accordingly.

Table 2. Distribution of Land Holdings (AOAD, 1984; for Turkey, official statistics cited in Ulusan, 1980; for Lebanon, Saab, 1973).

Country	Percentage of Farms					Percentage of Land				
	0-5 ha	5-10 ha	10-50 ha	50-100 ha	100+ ha	0-5 ha	5-10 ha	10-50 ha	50-100 ha	100+ ha
Algeria	61.6	17.6	18.9	1.4	0.5	14.2	15.7	47.0	11.8	11.4
Libya	46.8	20.6	29.4	2.4	0.8	6.5	9.8	40.8	10.8	32.1
Morocco	73.7	14.9	10.7	0.5	0.2	24.5	20.7	37.7	7.2	10.0
Tunisia	42.1	21.3	32.3	3.0	1.2	6.6	10.5	43.9	13.3	25.7
Iraq	39.7	25.4	32.6	1.2	1.2	6.9	12.4	39.7	6.3	34.8
Jordan	63.5	17.0	17.4	1.4	0.7	13.6	14.6	41.9	11.6	18.3
Lebanon	92	6	3	0.5		44.0	16.0	25.0	15.0	
Syria	56.4	17.4	23.5	1.8	0.9	10.7	11.3	45.7	11.1	21.1
Turkey	72.9	19.2	7.0	0.6	0.2	26.6	39.5	19.8	8.8	5.3
Saudi Arabia	75.4	11.1	12.1	1.0	0.8	14.3	10.4	31.5	8.7	35.0
Y.A.R.	88.5	7.4	4.0	0	0.1	43.5	22.5	29.4	1.2	3.3

Small farmers are sometimes considered an obstacle to change. However, small farmers have been ready to adopt new practices when suitable technologies have been developed, and when both information and financing are made available. Turkey's farmers, 73 percent of whom cultivate five ha or less, are among the highest input users of the region; Syria's small-scale wheat farmers also show high rates of use of fertilizers, herbicides, and improved seed; and other examples could be cited (Aricanlı and Somel, 1979; Rassam and Tully, 1986a). The key factor is the development of an appropriate technology which meets farmers' needs. There is no reason that improved seed, fertilizers, herbicides, and tillage practices cannot improve yields on small farms as well as large, if they are made available in a reasonable form.

Household Strategies

Farm households are large, due both to large family sizes and the common occurrence of extended families, usually composed of married children and their parents. Mean household sizes of 10 or more are commonly reported. Some observers, however, have noted a growing number of nuclear family households, which may be related to increasing wage employment (Bates and Rassam, 1983). In some countries, the young are emigrating from rural areas, leaving farming in the hands of the older generation (Papachristodoulou, 1979; USDA, 1985).

With large families on small farm areas, it is inevitable that subsistence production accounts for a considerable amount of farm output, and therefore has an important effect on the nutritional status of a large part of the population. Surveys have shown substantial on-farm consumption of farm produce (Arabiat *et al.*, 1983; D. Nygaard, unpublished data from Tunisia). The FAO food balance figures give an indication of food consumption patterns on a national basis (Table 3). Cereal consumption in this region is approximately 200 kg y^{-1} $person^{-1}$, providing over half of both calories and protein in most cases. This is primarily made up of wheat, although considerable barley is consumed in Morocco and Algeria, imported rice in Saudi Arabia, and millet and sorghum in Yemen. Milk products, mostly produced on-farm, are the main source of high-quality protein; meat consumption is limited to 15 to 20 kg y^{-1} $person^{-1}$, except in the oil-rich countries. Rural people often consume less than these figures indicate, and it appears that deficiencies in nutritional levels and caloric intake are endemic in many rural areas (Fikry, 1983; Miladi, 1983; Mokbel, 1985).

Table 3. Sources of Nutrition (FAO, 1984c).

Country	Percentage of Calories					Percentage of Protein			
	Cereal	Pulses	Meat	Milk Etc.	Fat & Ghee	Cereal	Pulses	Meat	Milk Etc.
Algeria	56.8	2.0	2.0	6.0	2.0	66.5	5.3	6.3	12.5
Libya	40.3	1.5	6.0	6.2	2.2	45.4	4.1	21.1	12.9
Morocco	63.0	1.8	2.6	1.7	1.8	71.6	4.6	8.4	4.4
Tunisia	55.8	2.6	2.7	3.7	1.3	60.8	6.0	8.4	8.5
Syria	50.4	3.3	4.0	4.6	3.9	51.0	6.9	9.6	12.8
Turkey	53.7	2.3	3.5	3.8	2.3	55.9	5.1	10.3	10.4
Saudi Arabia	44.7	1.0	7.7	7.2	8.6	41.0	2.5	21.1	17.1
Y.A.R.	67.3	4.7	4.3	4.0	1.4	62.6	9.8	10.4	8.3
P.D.R.Y.	60.3	0.3	2.9	4.5	5.6	60.5	0.7	7.5	13.1

Large farms are usually focused on crop production, but small farmers typically try to manage risk and increase income by diversifying out of crop production into livestock and off-farm employment (Hogan *et al.*, 1984). In addition to their valuable dietary contribution, livestock provide an income through the sale of lambs and dairy products, and they provide a hedge against bad crop years and poor prices. The role of livestock will be discussed in more detail below.

Off-farm employment has become increasingly available in the region, as a result of rapid development of industrial and service sectors in urban areas, as well as the increased opportunities for international migration. Income from this source has been estimated at 24 to 37 percent of household income in several studies in Syria (Rassam, 1984; Rassam and Tully, 1986b; Somel *et al.*, 1984). In Cyprus the majority of farmers consider agriculture a secondary occupation (Papachristodoulou, 1979), while in a Tunisian survey 67 percent of households with less than 10 ha had off-farm income (ICARDA, 1985).

Off-farm employment adds stability to rural incomes, but it also has an effect on the availability of labor (Hogan and Hansen, 1983). This has partly been offset by mechanization of the major agricultural tasks, as will be described below. The remaining nonmechanized tasks, such as weeding, animal care, and dairy activities, are carried out to a large extent by household labor on small farms. Women, who work off-farm much less frequently than men, represent an increasing part of available household labor. Women have always worked in agriculture in the Near East, and their work load appears to be increasing in many areas (Hammam, 1981; Youseff *et al.*, 1979).

When hired labor is needed for seasonal nonmechanized tasks, such as harvesting legumes or tree crops, there may be scarcity or high cost due to competition with urban employment. In Syria the proportion of males in the unskilled rural labor force is low due to competition with urban jobs (Rassam and Tully, 1986b). As mechanization has increased the seasonality of labor demand, rural workers have been unable to sustain themselves and have moved to cities (Bates and Rassam, 1983, citing unpublished material from N. Hopkins). Thus the impetus to continue mechanization of agriculture is high.

Crop Production

The prevailing crops in areas of winter rainfall are cereals, primarily wheat and barley, with small areas of rye or oats in some countries. On the other hand, millet and sorghum are the dominant cereals of the Arabian peninsula. In Turkey, bread wheat predominates, but in the Arab countries most of the wheat is durum, which is the basis of the flat breads, bulgher, and couscous that form the core of diets. Both durum and soft wheat are grown in wet areas as well as dry, with the wet areas more often using high-yielding varieties. Durum is grown in large part for consumption by the farm household, but may be replaced by soft wheat on larger, surplus-oriented farms. In Algeria, for example, only 12 percent of private sector cereal area is soft wheat, compared to 43 percent in the socialist (government controlled) sector (Benzaghou, 1979; cf. ICARDA, 1985 for Tunisia). Soft wheat is more often consumed in cities, often as a component of subsidized bread made with imported wheat.

Barley is grown primarily for livestock feed, but it is also a significant food crop in Morocco and Algeria. Grazing resources have been decreasing while demand from the urban population for animal products has grown; thus demand for barley to feed animals has been strong. In many countries barley area increased in the 1974 to 1983 period while wheat area decreased or remained stable (Table 4). Barley is often considered a crop for dry or infertile conditions. However, international statistics show no strong pattern of planting barley in dry areas (MAAR, 1979), and a survey in northwestern Syria showed no significant relationship between cereal choice and rainfall or soil type (unpublished data). Indeed, in Iraq 53 percent of the barley area is irrigated (Hermis and Hussain, 1979), and in Turkey 41 percent (MAAR, 1979).

Table 4. Use of Land (FAO, 1984a).

Country	Arable Crops	Permanent Crops	Total Crops	Irrigated Crops	Rainfed Total	Wheat Area 1974-76	Wheat Area 1981-83	Barley Area 1974-76	Barley Area 1981-83	Pulses Area 1981-83
	10^3ha									
Algeria	6,827	642	7,469	310	7,159	2,240	1,741	826	880	122
Libya	1,738	315	2,053	200	1,853	210	266	374	264	9
Morocco	7,269	430	7,699	426	7,273	1,843	1,770	2,026	2,142	347
Tunisia	3,440	1,420	4,860	123	4,737	967	809	367	490	144
Iraq	5,100	187	5,287	1,572	3,715	1,513	1,187	554	958	46
Jordan	357	34	391	36	355	158	104	57	52	16
Lebanon	240	108	348	85	263	47	18	13	5	10
Syria	5,356	369	5,725	547	5,178	1,607	1,256	960	1,485	201
Cyprus	365	67	432	94	338	64	14	56	50	6
Turkey	24,977	2,787	27,764	1,983	25,781	9,142	9,040	2,599	2,951	909
Saudi Arabia	1,108	71	1,179	382	797	73	173	9	7	4
Y.A.R.	2,737	450	3,187	230	2,957	68	66	57	52	70
P.D.R.Y.	175	20	195	53	142	11	15	1	2	

The next most important category after cereals is pulses. Although they only occupy 5 to 10 percent of the area planted to cereals, they largely meet local demand and are exported from Turkey, Syria, Tunisia, and Morocco. The most important pulses are broad bean, chickpea, and lentil in winter rainfall areas, and cowpea under summer rainfall. Broad bean is commonly irrigated or limited to the wettest zones; chickpea and lentil may benefit from irrigation but can tolerate somewhat lower rainfall. These legumes are most commonly grown in rotation with cereals. They are usually not grown in areas of low rainfall or on poor soils, because yields are low and risky while costs are high (Tully, 1984). Local economic conditions would appear to determine how good yields have to be to make legume cultivation worthwhile. The current limit of legume cultivation in Syria is at approximately 300 to 350 mm mean annual rainfall. In Morocco 70 percent of the legume area is found in areas with at least 400 mm of rainfall (Newberg *et al.*, 1982) and in Tunisia legumes are also limited to the wetter areas (Ketata *et al.*, 1979).

Expansion of legume area as a replacement for fallow is often put forward as a way to increase output. However most fallow is in dry areas and includes large areas of shallow and stony soils. Increases in legume area will depend upon the development of techniques which increase the value of legume crops to acceptable levels under relatively poor conditions (Tully, 1984).

Other crops are very diverse, and mostly fall in the category of summer crops suitable for rotation with cereals. These will usually be planted in spring after a winter fallow, and grow through summer on stored moisture. Such crops include watermelon, cantaloupe, sesame, and sunflower. Irrigated crops may also be grown in rotation with rainfed wheat, possibly in a double-crop system. Rainfed potatoes and other vegetables are sometimes found in wetter areas. As shown in Table 5, tree crops are also a regular component of agriculture in this region, and include citrus and other fruits, olives, and nuts. Tree crops are important exports in several countries.

Table 5. Machinery and Fertilizer Use (Tractors, Combines, FAO, 1984a; Fertilizer per Ha, World Bank, 1984; T Fertilizer, FAO, 1984b).

Country	Tractors		Combines		Fertilizer		N	P_2O_5
	1974/76	1982	1974/76	1982	1970	1981	80-83 Avg.	80-83 Avg.
					100 g ha⁻¹		*t*	*t*
Algeria	41,53[illegible]	45,000	3,850	4,200	174	262	65,985	90,964
Libya	6,767	16,000			64	375	29,435	42,170
Morocco	19,992	25,100	2,708	3,400	130	239	99,225	83,250
Tunisia	29,000	36,200	3,267	3,650	82	180	30,300	38,020
Iraq	19,741	29,956	5,028	5,490	35	141	66,109	18,584
Jordan	3,736	4,600	190	280	20	53	5,549	5,712
Lebanon	3,000	3,000	90	90	1,279	1,006	16,050	12,600
Syria	15,548	35,533	1,901	2,958	67	232	84,435	47,201
Cyprus	9,767	11,000	300	420			9,502	6,045
Turkey	241,339	489,813	11,542	13,477	166	454	788,820	565,711
Saudi Arabia	800	1,400	277	480	44	602	35,425	19,159
Y.A.R.	1,010	2,100			1	43	10,530	763
P.D.R.Y.	1,190	1,270	12	15		88	1,622	176

The most common crop rotation in the region is cereal-fallow. However, the word fallow has different meanings. In the central plateau of Turkey, wheat researchers in the 1960s and 1970s developed a technique of shallow cultivations in the fallow year to reduce weeds and maximize moisture storage. This has allowed the high-yielding varieties to perform well, increasing output considerably (Guler *et al.*, 1979; Hanson *et al.*, 1982). A similar practice is used in the socialist sector of Algeria, although moisture storage appears to be of minor importance compared to weed control in this case (Benzaghou, 1979). Presumably this is because higher temperatures encourage weed populations while making moisture storage more difficult. Cultivated fallows are also practiced in some areas of Tunisia, Syria, and other countries.

However, the more common practice, especially for small farmers, is an uncultivated fallow. Particularly in North Africa, the weeds and volunteer crops on the fallow land are considered a valuable livestock feed in spring. Note that this is the time when lambs are weaned, and also the time of greatest milk production by the ewes; thus a green fodder has a high value at this time. Farmers' adherence to the uncultivated fallow regime indicates a preference to maintain this livestock feed even at the cost of reduced cereal yields.

Finally, in some areas cultivation of the fallow is more related to equipment cost and availability than to other factors. In areas of Syria with less than 300 mm mean annual rainfall, for example, weed levels are low, and moisture storage under fallow is minimal (ICARDA, 1983). Some farmers cultivate to prepare the seed bed in spring, some in autumn, while others merely sow on uncultivated land (Somel *et al.*, 1984). The latter is especially true on shallow soils.

As mentioned earlier, rotations of legumes and other crops with cereals are much less common. In part this reflects the value of a weedy fallow, but also the higher costs associated with noncereal crops. ICARDA is working to develop erect legume species and appropriate mechanical harvesters for this region; if successful, the area sown to legumes can be expected to increase. Work is also under way at ICARDA to test the feasibility of self-regenerating and annually sown legumes as grazing crops in rotation with cereals (ICARDA, 1985). Cyprus has had some success in encouraging rotations with forage legumes (Photiades, 1979), and this strategy continues to attract interest throughout the region.

Three course rotations are less common. They may include one or two years of cereal, in rotation with fallow, legumes, and/or summer crops. Continuous cereal cultivation is also found, and fertilizers may allow yields to be sustained for several years in this regime; however, productivity eventually declines (Cooper, 1986).

Crop production is extensively mechanized in the Near East compared to other regions of the world. Tractors and other machinery were introduced by settlers, colonial agencies during the Second World War, and the Marshall Plan in Turkey. Agricultural machinery led to an expansion of crop areas in virtually the entire region, and fueled the movement of rural populations to cities and other countries. The pace of mechanization has varied from country to country, but at this stage it is possible to say that mechanized tillage is the norm in the region, with mechanization of other operations proceeding briskly. Animal tillage continues in some areas, most often in drier or mountainous regions and on small farms (Aricanli and Somel, 1979; Campbell *et al.*, 1977).

Tillage practices are extremely diverse. As indicated, fallows may be cultivated or not, and seed beds may be prepared in autumn, in spring, or not at all. A wide variety of implements is employed in tillage, including discs, moldboard plows, chisel plows, and sweeps. Aside from the Turkish wheat project which focused on tillage, I have seen very little reported research on the relative merits of various cultivation regimes. However, a constant theme in the expatriate development literature is the inappropriateness of deep cultivations in these low rainfall areas (Carter, 1975; Hogan *et al.*, 1984; Newberg et al., 1982). Deep tillage is said to reduce moisture storage, encourage weeds, bury desirable pasture species, and increase erosion. It has been suggested that plows developed for high rainfall European conditions were introduced along with tractors, without proper consideration of the needs of the area. Nevertheless, deep tillage appears to be general in North Africa, Jordan, and Iraq and is carried out on the majority of wheat fields in wetter areas of Syria.

Sowing is also highly variable. Where animal traction is used, seed may be covered with a shallow plow or a spike-tooth harrow (Campbell *et al.*, 1977). In North Africa and Jordan, the most common practice appears to be hand broadcasting followed by a disc harrow, which leads to a fairly erratic crop geometry and poor fertilizer placement (Arabiat *et al.*, 1983; Campbell *et al.*, 1977). Drilling is common in Iraq and Turkey, while in Syria a common practice is to broadcast over shallow ridges and cover the seed by splitting or flattening the ridges with a cultivator or bar. Again, it seems highly likely that practices are being determined by equipment availability rather than yield maximization (Hogan and Hansen, 1983).

Thus, tillage and planting techniques are extremely varied, and there appears to be no good evidence that current techniques are advantageous in terms of yields or other factors. This would appear to be a fertile field for research to devise better systems, and for policies to bring these systems to the farmers. The issue of equipment availability is vital; for example, shallow tillage practices recommended by the Jordan Wheat Research and Development Project (1967 to 1975) could not be adopted by farmers because of lack of tools (Hogan and Furtick, 1983).

Harvest mechanization is a bit less general than tillage. Cereal harvesting by combine is fairly common in most countries but is limited by the lack of suitable machinery for stony or sloping fields, and by many farmers' desire to collect the maximum biological yield by hand pulling or cutting in order to provide winter feed. In Iraq 20 percent of cereal is hand harvested (Hermis and Hussain, 1979), while in the barley fields of northern Syria the figure is 31 percent (Somel *et al.*, 1984). Even in most areas where cereals are hand harvested, however, mechanical threshing is common. Legume harvesting is mechanized to some degree in Turkey, but because of inappropriate equipment, is largely manual in the region; similarly, legume threshing is rarely done by machine. Summer crops and tree crops are generally harvested manually.

It is often assumed that mechanical operations are not feasible if farm sizes are small. However, the Near East has seen widespread adoption of custom services, in which farmers hire equipment operators as needed (Arabiat *et al.*, 1983; ICARDA, 1985; Johnson *et al.*, 1983). Rented and owned tractors were found to operate with equal technical and economic efficiency in Turkey (Somel, 1979). The availability of custom tillage has led to a rapid spread of mechanization to poorer farms in Morocco, Tunisia, Turkey, Syria, and elsewhere.

In terms of other agricultural inputs, practices are also diverse. Fertilizer use is low to moderate by world standards, but clearly has been increasing in all countries (Table 5). Many of the countries have phosphate or oil resources which are utilized in fertilizer plants. Herbicide use on cereals is quite popular on small farms in Turkey and Syria, and on large farms everywhere, but it is not as common as fertilizer use on small farms in North Africa (ICARDA, 1985). This may be related to the economic value of weeds as livestock feed. The use of high-yielding varieties is also variable. Their use depends very much on access to the seed, which is often limited for small farmers (Newburg *et al.*, 1982).

Livestock

The importance of livestock is indicated by the fact that we have been unable to discuss three central issues - nutrition, income, and crop rotations - without reference to them. At this stage let us focus on livestock and consider more fully their place in the system.

Sheep, goats, and cattle are the most important livestock species in the region (Table 6). Sheep and goats combined are about six times more numerous than cattle, but the latter are more important for dairy production than the small stock, and in some countries they contribute more red meat as well. The statistics are not broken down by location of stock, but in general one can say that a substantial number of the sheep are found in steppe areas, while many of the cattle are in dairies or irrigated areas. Of stock kept on farms, cattle tend to be more common in wetter areas and sheep in drier zones. Some of the cattle are draft animals, although this is becoming less common.

Livestock play a key role in the mixed farming areas, particularly for small farmers in dry zones. Livestock contribute as much income as crops in dry areas of Morocco and Cyprus (Campbell *et al.*, 1977; Papachristodoulou, 1979), and this is probably typical of the region. Nevertheless, they are often undernourished, and programs to support livestock production in mixed farming systems are rare.

Feeding of livestock follows a yearly cycle. The rains begin in October or November, and fresh fodder is first available in winter or early spring, depending on temperatures. Thus spring is a time of relatively abundant livestock feed. Fallow areas and grazing lands are at their most productive, supplemented by weeds pulled from crops; indeed, weeding may be delayed to increase the amount of fodder (Newberg *et al.*, 1982). Cereal crops may be grazed as well, which some farmers claim is beneficial to the crops. Income from stock sales and dairy products is at a peak; this sustains many farmers until the crop harvest.

Table 6. Livestock Production (FAO, 1984a).

Country	Animals 81/83			Meat 81/83			Milk 81/83	
	Sheep	Goats	Cattle	Sheep	Goats	Cattle	Sheep Goats	Cow
	.........*10³*.......			......*10³ t*.....			...*10³ t*...	
Algeria	13,730	2,763	1,389	68	13	43	316	530
Libya	4,598	1,412	175	53	2	29	54	64
Morocco	14,913	6,240	3,047	59	23	116	50	790
Tunisia	4,980	875	572	24	3	34	30	226
Iraq	11,883	3,767	3,033	43	15	55	234	1,075
Jordan	1,021	540	37	6	7	2	40	4
Lebanon	143	442	53	11	4	9	56	91
Syria	10,969	1,103	799	88	7	34	539	599
Cyprus	518	360	43	6	4	4	64	51
Turkey	49,288	18,727	17,003	294	108	211	1,865	3,613
Saudi Arabia	3,333	2,200	450	102	8	22	164	252
Y.A.R.	3,150	7,500	950	13	38	14	183	64
P.D.R.Y.	997	1,350	120	6	5	2	37	8

After harvesting in May and June, crop stubbles and aftermath become available. This consists of weeds and a few inches of straw. The rest of the straw is gathered up after combine harvesting to be stored for winter use. After hand harvesting, only weeds remain. The stubble is enough in some areas to sustain small stock through the summer months. Standing crops of grain, mostly poor crops too short for combine harvesting, supplement the stubble in other areas. Dairy cattle may require additional feed at this time, sometimes provided in the form of agro industrial by-products.

Depending on the location, irrigated or summer crop residues may be available towards the end of summer, locally or at some distance. These tend to be fairly high in nutritive value, but are the last fresh fodder until the subsequent spring. With the beginning of the rains, livestock feeding is at its most difficult point. Depending on temperature, winter grazing may be good, but it is unreliable. In colder areas animals need to be fed conserved feeds for two to five months. This feed is largely composed of barley grain plus cereal straw; where available, legume straw is also highly valued. The potential of cereal straw should not be underestimated; in a Syrian mixed-farming area, it provided 30 to 43 percent of metabolizable energy and 16 to 24 percent of crude protein to farmers' flocks in the winter feeding period (Jaubert and Oglah, 1985). In some countries with irrigated cotton or beet crops, agro-industrial by-products may also be available at reasonable cost.

Thus in a normal year, livestock make use of cereal straw and stubble as well as some of the grain crop, graze associated fallows, and failed crops, provide income and valuable nutrients before the harvest, and act as a repository of value. In a poor crop year, livestock act as a buffer. Pastures are poor in such a year, but the higher proportion of failed crops provides spring and summer feed for the livestock. Usually the price is less than the value of a good harvest but still sufficient to offset planting costs and provide a portion of the normal harvest income to farmers. Crop grazing also allows livestock owners to reduce their herds gradually over several months, and permits officials responsible for livestock to prepare for a grain shortage in winter rather than an immediate shortage at harvest time.

The value of manure is widely appreciated in sub-Saharan Africa, but it is not clear how great its importance is in the Near East. Certainly some organic matter is added to soils by grazing practices, and some farmers collect and apply manure to their fields. It would be useful to know how effective current practices are in this respect, and whether better management of manure could be used to improve the fertility of the land.

Some agricultural strategies call for a reduction in the role of livestock in mixed farming areas, or a decrease in their current feed resources. This is true of systems of cultivated fallow and, to some extent, herbicide use. These technologies have been acceptable on large farms oriented to commercial cereal production. However, widespread adoption of such strategies could encounter several obstacles. First, how will the increasing demands for meat and dairy products by urban consumers and a growing population be met? Specialized meat and dairy operations will be hard pressed to compete with the opportunistic use of free or cheap feeds by mixed farming households. Second, the nutrition, income, and risk aversion aspects of mixed farming are difficult to replace. Even where substantial cash from off-farm employment is available, the distribution system is not adequate in the vast majority of countries to provide fresh dairy products on a regular basis. Crop insurance or compensation is rare, available only in Cyprus to my knowledge (Samios, 1979). Thus a crop production technology which operates to the detriment of livestock has high opportunity costs for both farmers and urban consumers, and may require substantial indirect support to be viable.

However, new systems which increase cereal production while also increasing the availability of spring and summer feed resources might avoid these problems. Rotations with legume pastures are, in theory, the most promising possibility; they will provide fodder and also allow a level of weed control. It remains to be seen whether farmers will judge them to be more economically attractive than weedy fallows.

Rainfed Farming in the Larger System

Rainfed crop and livestock production takes place in a larger context. The expansion of cultivated area, occurring almost universally in this region in the war and post-war years, has been fueled by urban investment in mechanization and urban demands for foods and exports. Policies for investment, pricing of goods, extension of new technologies, provision of agricultural inputs, and research priorities all affect the vitality of the farming sector. As mentioned earlier, there is a high awareness of the importance of agriculture by most governments in the region. Nevertheless, policies which are pro-agriculture may still discourage development of parts of the sector. Policies have often been, officially or practically, structured to favor large farms over small, irrigated agriculture over rainfed, and high rainfall areas over low (Campbell *et al.*, 1977; Hogan *et al.*, 1984). This applies to the availability of inputs, credit, and extension, as well as research.

While such an approach may maximize short-term food production for the market, it leaves a large part of the population, namely the poorest farmers, facing a declining standard of living. Furthermore, policies toward provision of services and construction in rural areas affect the quality of life and the desirability of continuing to live on farms. The overly rapid urban growth in the region, with associated housing, food, and social problems, is in large part the cost of having neglected small-scale farming in the past.

These factors are currently being given greater consideration. In Tunisia, for example, the last development plan links agricultural policy to improving rural life rather than just increasing production, with the explicit goal of stemming rural depopulation (Europa Publications, 1984). In Syria, the extension of rural roads and services, particularly in the 1970s, encouraged relatively slow urban growth while giving rural people access to new employment opportunities (Tully, 1985). Efforts such as the Highland Agricultural Development Project in Jordan and the Mid-America International Agricultural Consortium (MIAC) project in Morocco, and indeed this Workshop, show a heightened interest in developing the low productivity farm areas.

This should help to establish a more secure basis for rural life, and benefit urban residents as well.

References

AOAD. 1983. Yearbook of agricultural statistics. Vol. 3. AOAD, Khartoum, Sudan.

AOAD. 1984. Yearbook of agricultural statistics. Vol. 4. AOAD, Khartoum, Sudan.

Arabiat, S., D. Nygaard, and K. Somel. 1983. Factors affecting wheat production in Jordan. ICARDA, Aleppo, Syria.

Aricanli, T., and K. Somel. 1979. Observations on developments in agriculture and land distribution in Turkey. (In Turkish.) Studies in Development 6:91-110.

Bates, D., and A. Rassam. 1983. Peoples and cultures of the Middle East. Prentice Hall, Englewood Cliffs, NJ.

Benzaghou, M.M. 1979. Situation des cereales e Algerie. p. 15-21. *In* The gap between: Present farm yield and the potential. Vol. 1. Proc. Fifth Regional Cereals Workshop, Algiers, 5-9 May 1979. Ministry of Agriculture and Agrarian Revolution, Algeria; CIMMYT, Mexico; and ICARDA, Syria.

Butter, D. 1985. Syria budgets for increased investment. Middle East Economic Digest 3 (August, 1985).

Campbell, R.R., R.H. Follett, H.B. Howell, R. Riddle, J.T. Stubbendieck, and D.G. Hanway. 1977. Applied agronomic research program for dryland farming in 200-400 mm rainfall zone of Morocco. USAID PN-AAF-329. Washington, DC.

Carter, E.D. 1975. The potential for increasing cereal and livestock production in Algeria. CIMMYT, Mexico City, Mexico.

Cooper, P. 1986. The implications of crop rotation, year, and residual effects on fertilizer responses of barley. *In* ICARDA Annual Report 1985. ICARDA, Aleppo, Syria.

Europa Publications. 1984. The Middle East and North Africa 1984-85. Europa Publications, London, UK.

FAO. 1984a. 1983 FAO production yearbook. Vol. 37. FAO, Rome, Italy.

FAO. 1984b. 1983 FAO fertilizer yearbook. Vol. 33. FAO, Rome, Italy.

FAO. 1984c. Food balance sheets 1979-81 average. FAO, Rome, Italy.

Fikry, M. 1983. Social implications of the wheat development program (Project Ble). p. C1-C47. *In* W.F. Johnson C.E. Ferguson, and M. Fikry (ed.) Tunisia: The wheat development program. USAID PN-AAL-329. Washington, DC.

Guler, M., I. Unver, M. Pala, N. Durutan, and M. Karaca. 1979. The fallow system and cereal production in the dryland areas of Turkey. p. 75-86. *In* The gap between: Present farm yield and the potential. Vol. 2. Proc. Fifth Regional Cereals Workshop, Algiers, 5-9 May 1979. Ministry of Agriculture and Agrarian Revolution, Algeria; CIMMYT, Mexico; and ICARDA, Syria.

Hammam, M. 1981. Labor migration and the sexual division of work. MERIP Reports 95:5-11.

Hanson, H., N.E. Borlaug, and R.G. Anderson. 1982. Wheat in the Third World. Westview, Boulder, CO.

Hermis, Y.A., and S.A.A. Hussain. p. 69-78. *In* The gap between: Present farm yield and the potential. Vol. 1. Proc. Fifth Regional Cereals Workshop, Algiers, 5-9 May 1979. Ministry of Agriculture and Agrarian Revolution, Algeria; CIMMYT, Mexico; and ICARDA, Syria.

Hogan, E.B., and W.R. Furtick. 1983. Jordan wheat research and production. USAID, Washington, DC.

Hogan, E.B., W.R. Furtick, and J.A. Grayzel. 1984. Morocco increase in cereal production project. USAID, Washington, DC.

Hogan, E.B., and G. Hansen. 1983. Jordan wheat research and production. USAID, Washington, DC.

ICARDA. 1983. Annual Report 1982. ICARDA, Aleppo, Syria.

ICARDA. 1985. Annual Report 1984. ICARDA, Aleppo, Syria.

Jaubert, R., and M. Oglah. 1985. Supplementary feeding of Awassi ewes in the barley zone of North-West Syria. Proc. International Conference on Animal Production in Arid Zones. Damascus, Syria, 7-12 September, 1985. ACSAD, Damascus, Syria.

Johnson, W.F. 1983. Institutional, policy, and economic influences of the wheat development program in Tunisia. p. B1-B40. *In* W.F. Johnson, C.E. Ferguson, and M. Fikry (ed.) Tunisia: The wheat development program. USAID PN-AAL-329. Washington, DC.

Ketata, H., H. Halila, M. Deghaies, A. Maamourie, and M. Harrabi. 1979. La productione cerealiere en Tunisie. p. 53-59. *In* The gap between: Present farm yield and the potential. Vol. 1. Proc. Fifth Regional Cereals Workshop, Algiers, 5-9 May 1979. Ministry of Agriculture and Agrarian Revolution, Algeria; CIMMYT, Mexico; and ICARDA, Syria.

Ministry of Agriculture and Agrarian Revolution, ICARDA, and CIMMYT. 1979. The gap between: Present farm yield and the potential. Proc. Fifth Regional Cereals Workshop, Algiers, 5-9 May 1979. Ministry of Agriculture and Agrarian Revolution, Algeria; CIMMYT, Mexico; and ICARDA, Syria.

Miladi, S. 1983. The state of food and nutrition in the Middle East. p. 35-54. *In* S. Miladi, S. Mahgoub, and P. Neate (ed.) Interfaces between agriculture, food science and nutrition. ICARDA, Aleppo, Syria.

Mokbel, M.G. 1985. Evaluation of nutritionally relevant indicators in villages in Aleppo Province, Syria, and their relation to agricultural development. Ph.D. Thesis. Univ. Massachusetts, Amherst, MA.

Newberg, R., J. Sleeper, T. Eighmy, M. Kanafi, H. Ream, J. Segal, and J. Hyslop. 1982. Rainfed agriculture sub-sector strategy, technical appendices. USAID, Morocco CDSS. Washington, D.C.

Papachristodoulou, S. 1979. Socioeconomic aspects of rainfed agriculture in Cyprus. FAO Regional Seminar on Rainfed Agriculture in the Near East, Amman, 5-10 May 1979. FAO, Rome, Italy.

Photiades, T. 1979. Integration of livestock with rainfed agriculture in Cyprus. FAO Regional Seminar on Rainfed Agriculture in the Near East, Amman, 5-10 May 1979. FAO, Rome, Italy.

Rassam, A.M. 1984. Syrian farm households: Women's labor and impact of technologies. M.A. Thesis. University of Western Ontario. London, Ontario, Canada.

Rassam, A.M., and D. Tully. 1986a. Wheat production practices in northwestern Syria. *In* ICARDA Annual Report 1985. ICARDA, Aleppo, Syria.

Rassam A., and D. Tully. 1986b. Gender related aspects of agricultural labor in northwestern Syria. Conference on Gender Issues in Farming Systems Research and Extension. Gainesville, FL, 26 Feb-1 Mar 1986.

Saab, G., 1973. Lebanon. p. 350-360. *In* International Association of Agricultural Economists. World atlas of agriculture. Vol. 2: South and East Asia. Instituto Geografico de Agostini, Novara, Italy.

Samios, T. 1979. Constraints to cereal production and possible solutions in Cyprus. p. 21-26. *In* The gap between: Present farm yield and the potential. Vol. 1. Proc. Fifth Regional Cereals Workshop, Algiers, 5-9 May 1979. Ministry of Agriculture and Agrarian Revolution, Algeria; CIMMYT, Mexico; and ICARDA, Syria.

Somel, K. 1979. Technological change in dryland wheat production in Turkey. Food Research Studies 17:51-65.

Somel, K., A. Mazid, and M. Hallajian. 1984. Survey of barley producers in northern Syria 1981/1982. Vol. 3: Descriptive statistics. ICARDA Research Report No. 12-III. ICARDA, Aleppo, Syria.

Tully, D. 1984. Land use and farmer strategies in Al Bab: The feasibility of forage legumes in place of fallow. ICARDA Research Report No. 13. ICARDA, Aleppo, Syria.

Tully, D. 1985. The development of rainfed agriculture in Syria. 19th Annual Meeting of the Middle East Studies Association, New Orleans, 23-26 November 1985.

Tully, D., E.F. Thomson, R. Jaubert, and T.L. Nordblom. 1985. On-farm trials in northwestern Syria: Testing the feasibility of annual forage legumes as grazing and conserved feed. *In* T.L. Nordblom, A. El Karim Ahmed, and G.R. Potts (ed.) Research methodology for livestock on-farm trials: Proc. Workshop held at Aleppo, Syria, 25-28 March 1985. IDRC, Ottawa, Canada.

Ulusan, A. 1980. Public policy toward agriculture and its redistributive implications. p. 125-167. *In* E. Ozbudun and A. Ulusan (ed.) The political economy of income distribution in Turkey. Holmes and Meier, New York.

U.S. Department of Agriculture, Economic Research Service. 1985. Middle East and North Africa outlook and situation report. USDA, U.S. Gov. Print. Office, Washington, DC.

World Bank. 1984. World development report 1984. Oxford University Press, New York.

Youseff, N., M. Buvinic, and A. Kudat. 1979. Women in migration: A Third World focus. USAID. Women in Development Office, Washington, DC.

SECTION II

Jordanian Experience—Overview Reports on Soil, Water, and Crop Management Systems

Analysis of Agricultural Policy in the Jordan Drylands

M.H. El-Hurani
University of Jordan, Amman, Jordan

ABSTRACT. This paper addresses the problem of the Jordan dryland region from a macroeconomic view to measure the impact of poor production conditions in this rai :fed subsector on Jordan's food deficit and other macroeconomic indicators. Some important aspects of the production environment in the dryland region of Jordan such as small farm size and land fragmentation, conditions of dryland farmers, and availability of improved inputs are analyzed. Jordan's long experience with dryland agricultural research is reviewed and factors responsible for the low yields and the low rate of adoption of improved inputs are critically analyzed. The study concludes that the issue of profitability provides a meaningful explanation for poor cereal yields and the low adoption rate of modern and recommended inputs. Low profitability is caused by a high cost of production, and this high cost is a result of low yield, and this low yield is caused by a lack of improved inputs. Wheat farmers do not use these modern inputs because of their high cost. It is the responsibility of government to interrupt this vicious circle. The government needs to provide inputs and agricultural services at the right times and at reasonable prices, especially fertilizers, herbicides, and machinery. The subsidy of inputs is supported here rather than subsidizing the price of bread to consumers. Estimates of future food requirements stress the need for Jordan to work toward long-term solutions to satisfy a higher percentage of food self-sufficiency. Jordan needs to set up a more consistent national agricultural and food policy which identifies macroeconomic conditions in Jordan.

Introduction

The economic contribution of the agricultural dryland subsector in Jordan has been poor during the past 30 years, and the farmers who live in these dry areas receive the lowest income level in the country. The rainfed land resources are not producing their biological or economic potential. In defining the Jordan dryland subsector we may classify it as a traditional agricultural system because of the dominant use of old cultural practices over many years. For example, the national average wheat yield is considered very low, ranging between 8 and 10 bu acre^{-1}, or 0.6 to 0.8 t ha^{-1}. This simply means Jordan's yield is only one-fourth or less of that of the dry region in the northwest of the United States. Dryland wheat exhibits annual fluctuation in total production and has had a downward trend for the last 10-year period, 1975 to 1984. Because of this wide variation and low annual production, a gap (shortage) has existed between food demand and cereal production since the early 1950s with the exception of a few years. Since 1968 this gap has been widening, to reach a maximum in 1984.

Although most of the problems that Jordan's dry areas suffer are strongly related to the environment and production conditions, we believe that Jordan must take a comprehensive look at the whole operation of the dryland subsector which includes cereal production, marketing and processing, consumption, and food policy. The weak outcomes of previous projects should demonstrate the need for this approach. In order to make a full assessment of Jordan's dryland production we need to study the interrelationships and interactions between these major activities. Figure 1 shows the interrelationships among production environment, marketing, processing, and food policy. There is strong evidence to show that Jordan government policy impacts on domestic cereal production. Analyses of government intervention in the internal and external marketing of wheat, importing, processing, pricing, and even the study of the changing pattern of bread consumption show a strong influence on the Jordan wheat farmer's decision to cultivate his farm with wheat.

This paper will address several aspects of agricultural policies in the Jordan drylands. First it will take a macroeconomic view of the problems of the Jordan dryland region from a food policy approach in order to demonstrate the significance of this rainfed subsector to the Jordanian economy. Section 2 will focus more closely on the production environment in the dryland region of Jordan including the rainfed land area, its policy issues related to

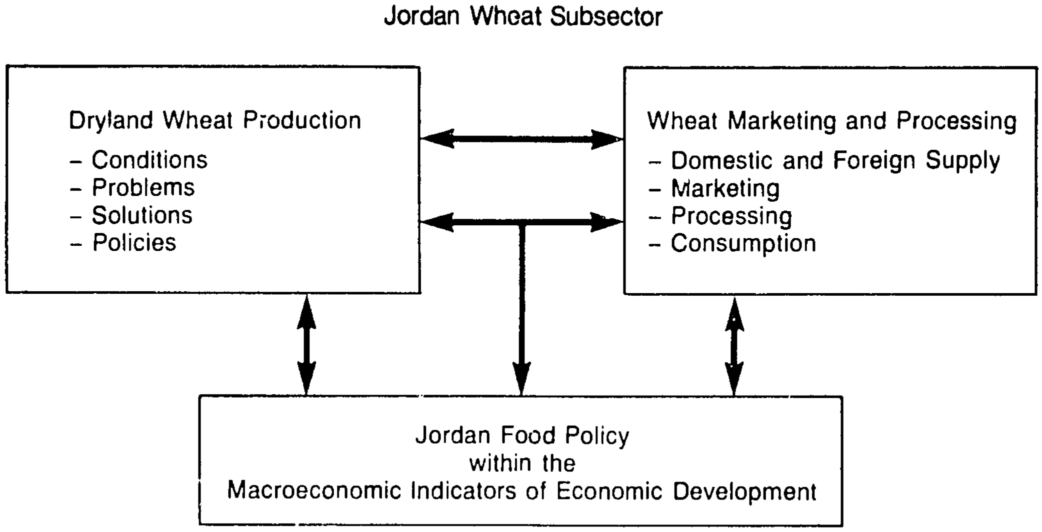


Figure 1. Interrelationships among Production Environment, Marketing, Processing, and Food Policy in the Jordan Wheat Subsector.

land fragmentation, economic conditions of farmers, and availability of inputs. In Section 3 Jordan historical experience with dryland agricultural research is analyzed and the issue of low rate of adoption of improved inputs by cereal farmers critically discussed. Previous efforts to develop the rainfed region of Jordan will also be assessed. A more specific analysis of agricultural policies in the Jordan drylands appears in Section 4 and finally, conclusions and recommendations for future projects and policy formulation for the development of Jordan's rainfed subsector in Section 5.

A Macroeconomic View of the Problem of the Jordan Dryland Region

To appreciate the significant role of developing better policies for the improvement of the Jordan rainfed subsector, and to recognize the importance of the dryland region in the Jordanian economy we must look at the problem of the dryland production from a macroeconomic view and food policy approach.

A 20-year performance record of the gross domestic product (GDP) (1960-1980) indicates that Jordan's economy has enjoyed a high real growth rate. For example, during the period 1960 to 1966, the average annual real growth rate of GDP was estimated at 7 percent (Mazur, 1979). During the period 1973 to 1981, it was estimated at 8.7 percent, and during the two-year period 1982 to 1983 Jordan's economy has witnessed a slowed growth rate reaching 5.7 and 5.4 percent, respectively (Central Bank of Jordan, 1983). However, despite this good performance, Jordan's economy suffers from major structural economic shortcomings which have their roots in the country's food and agricultural policies. A brief review of some of these macroeconomic indicators would help us to think more broadly when analyzing aspects of Jordan's food and agricultural policies in general, and dryland policies in particular. Also, these economic characteristics may shed light on the importance of increasing dryland production and may suggest some policy measures for supporting investment in agriculture. Agriculture's share in Jordan's gross fixed investment appears low in comparison with other LDCs (Mazur, 1979).

The structure of the economy has imbalances among producing sectors with the services sector maintaining a long standing high share of the GDP. Total commodity sectors contributed 39 percent of the GDP in 1983, while the services' share was 61 percent.

Table 1. The Relative Shares of the Commodity and Service Sector to the Gross Domestic Product (GDP) during 1964-1983 (Central Bank of Jordan, 1984).

Year	Agriculture		Total Commodity Sector		Total Service Sector		GDP	
	Million J.D.	*% of GDP*	*Million J.D.*	*% of GDP*	*Million J.D.*	*% of GDP*	*Million J.D.*	*%*
1964	34.1	25.2	52.9	39.0	82.6	61.0	135.5	100
1965	34.1	22.6	59.9	39.6	91.1	60.3	151.0	100
1966	27.6	18.4	56.2	37.6	93.4	62.4	149.6	100
1967	23.4	20.2	44.5	38.5	71.1	61.5	115.6	100
1968	16.2	11.7	43.6	31.5	94.6	68.5	138.2	100
1969	22.5	13.8	53.6	33.0	108.9	67.0	162.5	100
1970	15.6	10.0	41.1	26.5	113.6	73.4	154.7	100
1971	23.9	14.4	49.9	30.0	116.1	69.9	166.0	100
1972	26.6	14.5	56.8	31.0	126.0	68.9	182.8	100
1973	17.9	9.5	57.1	30.2	131.8	69.8	188.9	100
1974	30.3	12.5	90.6	37.4	151.8	62.7	242.4	100
1975	26.0	8.6	104.4	34.4	198.7	65.6	303.1	100
1976	37.3	9.8	135.6	35.8	242.8	64.2	378.4	100
1977	41.7	9.5	162.1	36.8	277.8	63.2	439.9	100
1978	58.6	10.6	211.1	38.3	340.1	61.7	551.2	100
1979	43.6	6.5	245.8	36.8	422.8	63.2	668.6	100
1980	64.6	7.3	346.3	39.0	542.1	61.0	888.4	100
1981	76.6	7.2	416.5	39.3	642.9	60.7	1059.4	100
1982	83.8	7.0	461.3	38.4	739.9	61.6	1201.2	100
1983	99.1	7.5	511.2	38.8	806.8	61.2	1318 0	100

Table 1 shows the relative shares of both sectors during the period 1964 to 1983. The relative share of the agriculture sector to the GDP is decreasing. In 1964, its share was 25.2 percent of the GDP and since then has continued to decrease to its lowest share in 1979, 6.5 percent. Table 1 also shows this share of agriculture to the GDP during 1964 to 1983.

Jordan's foreign trade has continued to show an increasing chronic deficit over a long period of years. Table 2 shows the balance of trade for the period of 1964 to 1983 when the deficit grew at 16 percent annually. Jordan also has a chronic food deficit. It is estimated that 25 to 30 percent of the total food requirements are produced domestically while 70 to 75 percent are imported. Table 3 shows the total food imports, exports, and the food trade balance for the period 1964 to 1983. The food deficit grew at 12.6 percent annually.

Generally speaking Jordan imports all food items. However, wheat import costs rank the largest among all imported food items. Imports of live animals and dairy products also are rising. An annual population growth rate of 3.4 percent, and a real improvement in per capita income have enhanced the demand for imported food. Table 4 shows a record of strategic food imports for the period 1964 to 1983. This table demonstrates the need for an integrated approach to the development of Jordan's dryland subsector to increase the volume of grains and animal production.

Table 2. Jordan's Foreign Trade (1964-1983) (Central Bank of Jordan, 1983, Tables 29 and 30).

Year	Imports	Exports	Trade Balance
	.... *Million J.D.*		
1964	50.35	7.01	-43.34
1965	56.05	7.75	-48.30
1966	68.21	8.76	-59.45
1967	55.05	9.98	-45.07
1968	57.49	12.17	-45.32
1969	67.75	11.92	-55.83
1970	65.88	9.32	-56.56
1971	76.63	8.82	-67.81
1972	95.31	12.61	-82.70
1973	108.20	14.01	-94.19
1974	156.51	39.44	-117.07
1975	234.01	40.08	-193.93
1976	339.54	49.55	-289.99
1977	454.42	60.25	-394.17
1978	458.83	64.13	-394.70
1979	589.52	82.56	-506.96
1980	715.98	120.11	-598.87
1981	1047.50	169.03	-878.47
1982	1142.49	185.58	-956.91
1983	1103.31	160.09	-943.22

Table 3. Jordan's Foreign Food Trade (1964-1983) (Central Bank of Jordan, 1983, Tables 27 and 28).

Year	Food Exports	Food Imports	Trade Balance
	.... *Million J.D.*		
1964	3.150	14.241	-11.091
1965	3.733	14.974	-11.241
1966	4.062	18.202	-14.140
1967	4.839	14.097	-9.258
1968	5.749	16.238	-10.489
1969	5.743	18.093	-12.350
1970	4.751	18.884	-14.133
1971	3.978	21.465	-17.487
1972	5.003	27.600	-22.597
1973	4.709	30.843	-26.134
1974	10.062	42.360	-32.298
1975	10.732	49.299	-38.567
1976	16.411	81.546	-65.135
1977	18.537	72.216	-53.679
1978	16.892	85.616	-68.724
1979	21.551	100.632	-79.081
1980	24.293	112.636	-88.343
1981	34.040	156.468	-122.428
1982	40.088	177.329	-137.241
1983	36.080	157.103	-121.023

Table 4. Jordan's Food Imports, 1964-1983 (Central Bank of Jordan, 1984, Table 30).

Year	Imports									
	Live Animals	Dairy Products & Eggs	Wheat & Wheat Flour	Rice	Sugar	Fruits, Vegetables & Nuts	Coffee, Tea & Spices	Total Food & Live Animals	Total Imports	Relative Share of Food Imports to Total imports in %
	Million J.D.									
1964	1.46	0.82	2.87	1.27	1.94	1.64	1.36	13.60	50.35	27.01
1965	1.22	1.06	2.28	1.47	2.04	2.19	1.57	14.20	56.05	25.22
1966	1.34	1.06	4.31	1.47	1.96	1.91	1.75	17.54	68.21	25.71
1967	1.15	1.20	2.51	1.34	1.52	1.74	1.58	13.64	55.05	24.77
1968	1.75	1.43	3.46	1.14	1.85	2.52	1.82	15.75	57.49	27.40
1969	3.13	1.88	1.78	1.26	2.29	2.52	2.00	17.84	67.75	25.80
1970	1.61	2.14	3.99	0.79	2.12	2.03	1.72	18.68	65.88	28.35
1971	0.78	2.45	3.84	1.31	2.19	3.96	2.08	20.13	76.63	26.26
1972	1.18	3.24	6.10	1.29	5.19	3.89	2.00	27.30	95.31	28.64
1973	2.96	3.31	7.04	1.39	1.78	6.44	2.52	30.81	108.20	28.47
1974	2.37	3.88	7.14	4.28	6.76	8.67	2.34	42.74	156.51	27.30
1975	3.19	4.82	6.82	1.87	11.53	9.57	2.93	49.42	234.01	21.11
1976	2.14	6.47	14.80	4.54	20.20	15.92	2.99	81.38	239.54	33.97
1977	2.56	7.43	13.87	2.75	6.56	15.69	5.30	75.92	454.42	16.70
1978	3.95	8.25	14.58	3.46	8.37	16.68	6.52	87.57	458.83	19.08
1979	3.89	10.54	19.57	4.92	9.94	21.40	6.12	108.28	589.52	18.36
1980	6.90	12.55	23.00	6.10	8.17	22.71	6.67	118.79	715.98	16.59
1981	8.64	10.74	23.43	5.41	21.39	25.52	7.08	167.93	1047.50	16.03
1982	12.61	13.85	31.15	8.36	19.11	31.82	4.13	191.92	1142.49	16.80
1983	21.56	15.46	32.84	4.42	6.51	32.27	5.64	180.37	1103.31	16.34

Table 5. Jordan Wheat Requirement, Actual Production, and Annual Shortage or Surplus, 1954-1984
(Ministry of Agriculture, Department of Statistics).

No.	Year	Population	Annual Wheat Requirement	Actual Production	Annual Shortage or Surplus
			.... *ton*	....	
1	1954	620,342	93,051	179,018	+85,967
2	1955	642,147	96,322	60,284	-36,038
3	1956	662,832	99,424	186,756	+87,332
4	1957	686,791	103,018	182,656	+79,638
5	1958	720,000	108,000	46,001	-61,999
6	1959	746,770	112,015	79,683	-32,332
7	1960	781,136	117,170	29,599	-87,571
8	1961	900,776	135,116	106,121	-28,995
9	1962	932,000	139,800	96,547	-43,253
10	1963	961,500	141,225	50,038	-94,187
11	1964	992,000	148,800	224,788	+75,988
12	1965	1,024,000	153,600	224,492	+70,892
13	1966	1,059,000	158,850	71,453	-87,397
14	1967	1,094,000	164,100	196,086	+31,986
15	1968	1,126,000	168,900	111,461	-57,439
16	1969	1,600,000	240,000	201,054	-38,946
17	1970	1,668,000	250,000	45,183	-205,017
18	1971	1,723,000	258,450	148,477	-109,973
19	1972	1,774,000	266,100	160,914	-105,186
20	1973	1,831,000	274,650	37,652	-236,998
21	1974	1,889,592	283,438	180,000	-103,438
22	1975	1,950,071	292,510	60,000	-232,510
23	1976	2,012,473	301,870	58,441	-243,429
24	1977	2,076,872	311,529	56,036	-255,493
25	1978	2,143,332	321,498	53,743	-267,755
26	1979	2,211,918	331,786	16,401	-315,385
27	1980	2,282,700	342,403	139 007	-203,396
28	1981	2,355,746	353,360	59,687	-293,673
29	1982	2,431,130	364,667	29,100	-335,567
30	1983	2,508,926	376,336	115,613	-251,723
31	1984	2,589,211	388,378	5,000	-383,378

With respect to the problem of cereal production, Jordan's major wheat requirements are met through imports. It is estimated that domestic wheat covers on average only one-fifth (20 percent) of the total requirements, and most of this domestic wheat is either consumed at the village level or stored for seed (ICARDA, 1981). Table 5 shows for the period 1954 to 1984 wheat production, estimated wheat requirements, and annual shortage. Figure 2 is a graphical presentation of Table 5 which illustrates the increase in the cereal gap since 1968. It is very important to reduce this food gap in order to raise food self-sufficiency and decrease the pressure on Jordan's foreign currency reserve. Jordan depends heavily on foreign currency sources such as loans, assistances, remittances, and exports resulting in the vulnerability of Jordan's economy to international climate. Table 6 depicts external public debts during the period 1964 to 1983 which grew at an annual rate of 18.8 percent.

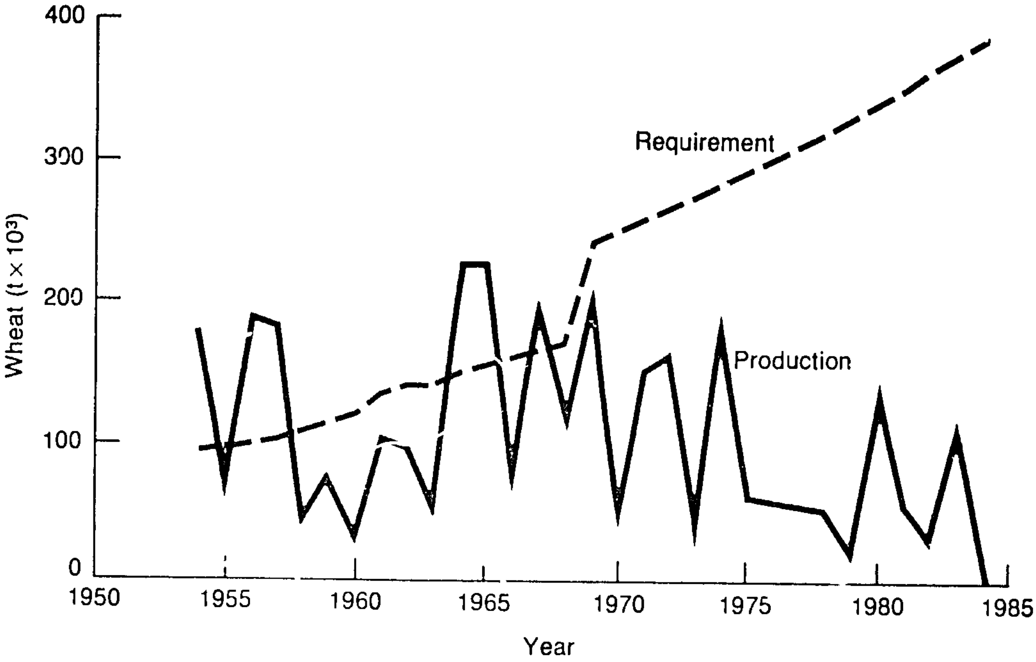


Figure 2. Jordan Wheat Requirement and Production.

Rainfed Agricultural Land in Jordan

Agricultural land suitable for year-round cultivation is scarce in Jordan. The major constraining factor is limited and variable rainfall. About 91 percent of total land area (92,600 km^2) receives less than 200 mm annually. The area is technically considered an arid desert and is utilized for natural grazing ground. The remaining 9 percent of total land area, which receives more than 200 mm of rainfall, is divided between three agroclimatic zones:

1) Marginal land receives from 200 to 350 mm and is estimated at 563,000 ha.
2) Semiarid land receives from 350 to 500 mm and is estimated at 136,000 ha.
3) Semihumid land receives from 500 to 600 mm and is estimated at 99,000 ha.

Due to limited precipitation, total cultivated area is about 4 percent of Jordan's total area or 400,000 ha. Ninety-four percent of this area is considered dryland and 7 percent is partially or completely irrigated. Field crops are the major agricultural commodities occupying 80 percent of the total cultivated dryland area; wheat and barley constitute 92 percent of the total rainfed field crops. Figures 3 and 4 show the relative importance of major crops in Jordan's dry areas. The actual cultivated area of field crops varies from year to year because of variable rainfall. Table 7 shows this wide fluctuation in the area of rainfed field crops for the period 1974 to 1982.

Production Environment in the Dryland Region of Jordan

Three major factors play a substantial role in the process of development of the rainfed subsector of Jordan. These factors are: small farm size and land fragmentation, conditions of dryland farmers, and availability of improved inputs in the dry areas of Jordan.

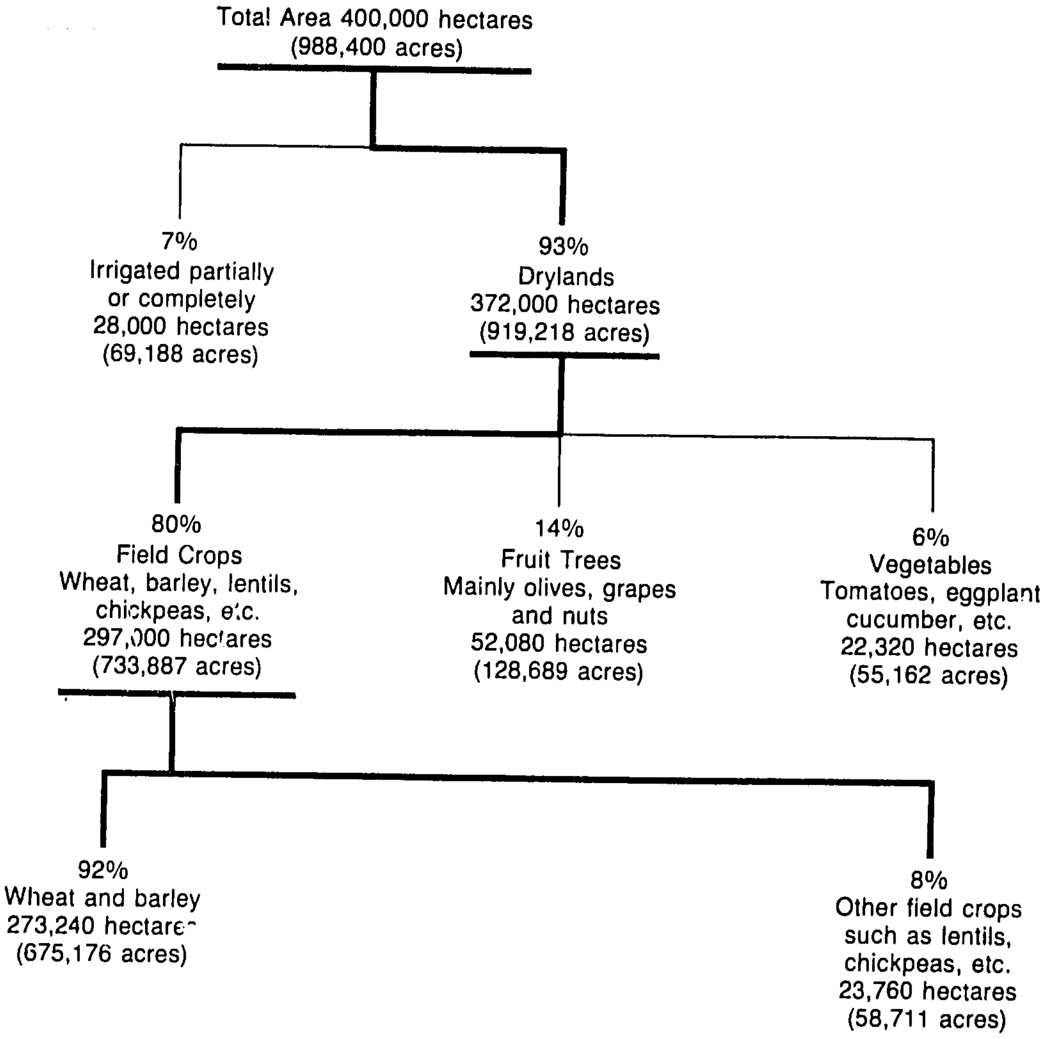
Small Farm Size and Land Fragmentation

Small farm size and land fragmentation exist very widely in the dry areas of Jordan. These phenomena have adversely affected the technical and economic feasibility of using modern inputs and services in the rainfed areas. They are believed to be the principal causes of

Table 6. Jordan's External Public Debts, 1964-1983
(Central Bank of Jordan, 1983, Table 40).

Year	External Public Debts
	Million J.D.
1964	21.287
1965	23.716
1966	26.886
1967	31.077
1968	35.856
1969	39.899
1970	41.784
1971	49.583
1972	61.228
1973	68.306
1974	79.842
1975	108.007
1976	132.582
1977	194.320
1978	244.449
1979	306.264
1980	382.742
1981	512.792
1982	616.592
1983	762.867

Jordan's low productivity and the major obstacles to the development of the rainfed subsector. Available data indicate that the average size of a landholding in the dry areas is 8 ha, and that this one landholding is divided into 2.5 pieces. This would reduce the farm size in one location to 3.3 ha. (The average size of a wheat farm in the dryland region of the Northwest of the United States is about 1000 ha.) Field crop production requires large-scale acreage for the use of improved inputs and services such as modern agricultural machinery. Existing laws give an individual the right to own land which can be as small as one dunum (0.1 ha). Another aspect of land fragmentation is the law which governs the partitioning of land into a single landholding with defined borders and location. The minimum size of a landholding which can be partitioned into a separate holding is 1 ha outside city or village limits. This law allows for common ownership of one single piece of land. Common ownership is a result of inheritance under Islamic law or purchase. Land owned by an individual passes to his heirs after his death. In 1975 the agricultural census reported the distribution of landholdings by size, summarized in Table 8. The situation since 1975 has worsened. The annual reports of the Department of Land and Survey indicate that as many as 8830 partitioning transactions took place during the period from 1976 to 1981. Table 9 shows the number of landholdings before and after partitioning for 1976 to 1981, illustrating clearly the trend toward land fragmentation in Jordan. On the average each landholding was divided into 3.34 new landholdings during the 6-year period (59,070/17,668 = 3.34). The majority of these transactions were the result of land sales to new owners. Another study reported that the number of landholdings with an area of less than 20 dunums (less than 2 ha) was 18,000 in 1975, and increased to 23,000 landholdings in 1983. This means a 28 percent increase in small infeasible landholdings during 8 years (El-Hurani and Duwayri, 1986).



CONCLUSION: Wheat and barley occupy ⅔ of total agricultural land and ¾ of total dryland.

Figure 3. Jordan's Agricultural Land.

The expansion of urban areas, construction of new municipalities in the heart of fertile land, and the establishment of more infrastructure for these emerging municipalities have led to the loss of the best quality land from field crop production to other urban uses. Available data indicate that about 20,000 ha of high quality agricultural land have been transferred into urban uses. The rise of land prices around villages and towns since 1973 has reflected this impact on the utilization of Jordan's dryland, and made the economic returns from rainfed cultivation unattractive. Moreover, farmers now use their fertile, level land for the production of fruits and vegetables instead of field crops.

In conclusion, the present laws allow the creation of new landholdings which are not economically feasible. These laws treat all drylands the same regardless of availability of water resources, agroclimatic zone, or degree of slope. Undoubtedly, these factors affect productivity and should be taken into consideration when determining the minimum size of a landholding (El-Hurani and Duwayri, 1986). Qasem estimated the minimum farm sizes which could generate enough income to keep families on the farm. For example, he suggests in zones where annual rainfall is 300 to 400 mm, 200 dunums should be

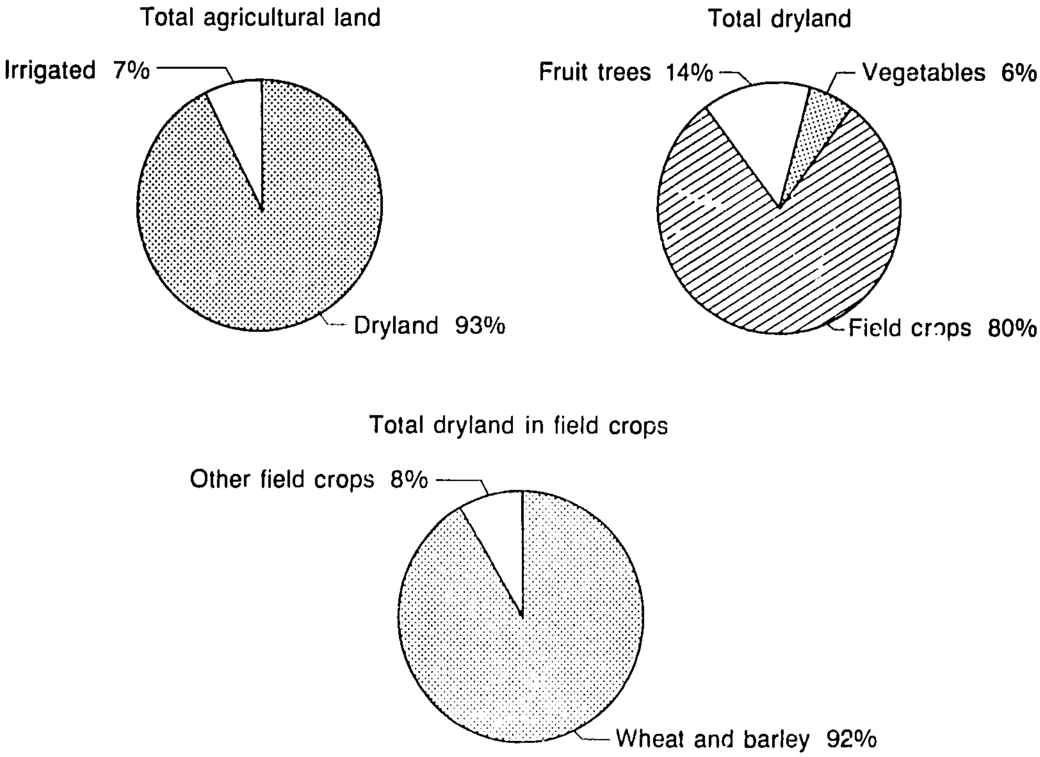


Figure 4. The Use of Jordan's Agricultural Lands.

Table 7. Total Cultivated Area of Dryland Field Crops for 1974-1982 (Department of Statistics, 1974-1982).

Field Crops	Year								
	1974	1975	1976	1977	1978	1979	1980	1981	1982
					10^3 dunum				
Wheat	2,355	1,111	1,307	1,212	1,303	961	1,301	970	995
Barley	623	512	515	446	506	445	502	467	479
Lentils	216	148	229	133	143	73	86	105	108
Chickpeas	—	36	16	14	13	26	29	20	20
Total	3,194	1,807	2,067	1,805	1,965	1,505	1,918	1,567	1,602

Table 8. Distribution of Landholdings by Size in Jordan, 1975 (Qasem, 1985).

Size of Landholding	Number of Landholdings	% of Total
dunum		
Less than 10	12,374	24
10-29	12,226	24
30-49	7,634	15
50-199	14,123	28
200-499	3,359	7
500+	1,075	2
Total number	50,791	100
Total area (ha)	3,904,031	
Average size of a landholding (dunum)	77	

considered a minimal farm size if the farmer uses improved inputs. In zones with less than 300 mm rainfall, 600 dunums is seen as a minimal farm size that can support a family (Qasem, 1986). Qasem's analysis and estimation of a feasible farm unit confirms the need to stop any further fragmentation and strongly suggests that the government should issue an agricultural law which will prohibit the sale or misuse of designated agricultural land. To overcome the problem of fragmentation would require comprehensive investigation and assessment of all available alternatives. One suggestion is to reaggregate landholdings on a sound farming basis without changing legal ownership, such as forming better organized cooperatives which lead to a system of farm size restructuring and a better decision-making mechanism.

Another option is sharecropping on a large scale, such as leasing a number of adjacent farms to a custom farmer who grows field crops on a large scale and uses better inputs. Previous experience indicates that custom farming operations might not create a better production environment for the application of improved technology because the lease arrangements usually run for only short terms such as one or two seasons and, consequently, do not motivate custom farmers to employ modern inputs. Therefore, leasing arrangements must be contracted for a longer period to encourage custom farmers to develop these dryland farms and improve cereal yields. The development of adequate contract farming practices and marketing activities would also make it possible for abandoned farm land to be put back into productive use. There is evidence that 34 percent of agricultural drylands have been left each year without cultivation. Part of this area is fallowed while a larger part located in higher rainfall zones is simply not utilized because of absentee owners and small landholdings.

Conditions of Dryland Farmers

In investigating the dryland production environment, one must inquire about conditions of Jordanian growers, their attitudes toward dryland production, and their standard of living. Dryland farmers are essentially the ultimate decision-makers when it comes to production and adoption of improved inputs. One interesting comment made by the head of the government agricultural department in Irbid might explain the present farmer's conditions. He simply said, "There are no longer wheat growers in Jordan." What he meant was there are no professional or full-time wheat farme. in Jordan. Because of the low returns on dryland farming, farmers seek other job opportunities in the urban areas. It is reported that the population of the Jordan drylands region is the poorest class of Jordan's total

Table 9. Number of Landholdings before and after Partitioning during 1976-81 (Qasem, 1985).

Year	Number of Landholdings before Partitioning	Number of Landholdings after Partitioning
1976	2,657	7,033
1977	2,445	8,313
1978	2,898	9,853
1979	3,028	10,295
1980	3,160	10,744
1981	3,480	11,832
Total	17,668	59,070

population. This poor standard of living within the dryland areas in developing countries is a general phenomenon, especially in the Middle East and North Africa (Gotsch, 1980). Apparently, the farmers' financial ability to invest in improving their land is very low. The outstanding expansion of education in the rural areas led to the emergence of a young, educated generation who sought employment in urban areas. This has created a situation where elderly people have the responsibility of farming. Furthermore, the availability of good job opportunities in off-farm employment has reduced the supply of labor in these dry areas.

The economic returns from field crop production are also considered very low. This is basically due to the low yield per planted ha of wheat. It is estimated that the cash operating cost for planting 1 ha of wheat by traditional methods is $152. Based on the assumption that the average yield is 1 t ha^{-1}, if the price received by a farmer is $275 t^{-1}, the gross profit margin would be $123 ha^{-1} or about JD 4.92 dunum^{-1} (Watkins *et al.*, 1983). A rough comparison with cost of production in the dryland region of the Northwest United States (Eastern Oregon) shows that the cash operating cost per planted acre is $56.10 or $136.60 ha^{-1} (Cook *et al.*, 1984).

The highest yields for a dryland farm are estimated at 34 bu acre^{-1} or 2.3 t ha^{-1} reducing the average cost of producing 1 t of wheat to $60. Low yield conditions in Jordan's dry areas reflect negatively on the cost of production, making farmers hesitant decision-makers with respect to using modern inputs. Due to low economic returns from wheat cultivation, farmers have been shifting increasingly toward planting trees, especially olives and grapes. It is reported that farmers' attitudes toward new dryland cultivation techniques are positive and that they appreciate the benefits obtained from these modern inputs. Also, they are aware of the effectiveness of the recommended techniques, but do not adopt them due to many factors, among which is the profitability of these inputs. This issue will be discussed later in the analysis of Jordan's experience with dryland agricultural research.

Availability of Improved Inputs

One of the main requirements for improving dryland agriculture is that inputs and agricultural services be available in the rural areas where farmers can easily obtain them. These inputs include improved seeds, herbicides, fertilizers, and proper machinery. Unfortunately, private agribusiness was not as motivated to serve the dry areas as it was the irrigated sector. Reports indicate that the tractor operators are very traditional and run old equipment. Private agribusiness in the rainfed areas did not show any interest in providing proper machinery such as grain drills and plows. The Jordan Cooperative

Organization (JCO) runs three machinery stations and provides seed drilling and tillage services to field crop farmers. However, the magnitude of efforts provided by JCO is still small. Therefore, shortages of proper agricultural equipment, as well as the technical sufficiency of how to use and maintain them, still exist in Jordan dry areas. The use of chemical fertilizer is still very modest. It is estimated that only 8 percent of farmers applied nitrogen and 5 percent of farmers applied phosphate to their fields. The total area fertilized annually is estimated to be only 300 ha. The present fertilizer production plants in Jordan operate for export rather than to fulfill the needs of the dry areas of Jordan. The Jordan Fertilizer Industry Company (JFI) produces diammonium phosphate fertilizer. Fertilizer requirements for wheat growing were estimated by Duwayri *et al.* (1984). It is interesting to note that locally manufactured fertilizer does not provide the required mix of nitrogen and phosphorus so fertilizer must be imported. The adoption of herbicide use is also very low in the dry area. It is reported that more research is required to determine the best and most effective weed control.

In general it is the high cost of improved inputs to dryland farmers that forestalls their use. It is believed that cooperatives are more capable of providing improved inputs, especially fertilizer and herbicides, to farmers at lower costs.

An Assessment of Agricultural Dryland Research in Jordan

Jordan has good experience in technically improving dryland farming, especially with respect to the production of wheat and barley. This is due to a long history of research which has been conducted since the inception of the State of Jordan.

The first research efforts to improve cereal production were initiated in 1951 and 1952 when varietal testing and fertilizer experiments were conducted by the Jordan Ministry of Agriculture (MOA) in cooperation with FAO (ICARDA, 1981). The variability of results over sites made interpretation difficult. However, responses to nitrogen application and nitrogen/phosphorus interaction were reported at some sites. In 1964, a breeding program was undertaken at the Deir Alla station in the Jordan Valley with the assistance of the Ford Foundation and CIMMYT.

More intensive efforts to increase wheat production were begun in 1967 when the MOA started a comprehensive project with Oregon State University and funded by USAID. The basic elements of this project were to increase wheat yield through the adoption of a package of better cultural practices, namely, soil moisture, conservation, proper tillage, weed control, fertilizer, improved seeds, and seed drilling. Most of the activities of this project were concentrated on conducting agricultural demonstrations throughout the dryland areas to show, teach, and encourage wheat farmers to use better inputs and improved farming methods in order to obtain higher wheat yields (El-Hurani, 1975). The project was in operation until 1975.

In 1974, the Faculty of Agriculture of the University of Jordan launched a research program in cooperation with FAO. Its purpose was to provide a format for training scientists as well as to supply materials for varietal improvement. This program has dealt primarily with varietal testing, fertilizers, and other cultural experiments.

In 1976, the Ministry of Agriculture launched an integrated dryland farming development project in cooperation with FAO. The goal of this project was to increase productivity in the principal crop area of northern Irbid to be implemented in the five-year period from 1976 to 1980. This project focused on soil and moisture conservation practices ranging from simple contouring to rock terracing, and a package of improved technology (Dabb, 1967). This project showed that it is difficult to store moisture under Jordanian conditions in the fallow year, and that the suggested technology package would be profitable on large farms about 50 to 75 percent of the time in the long run.

In 1978, ICARDA cooperated with the Faculty of Agriculture and the MOA to conduct the Jordan Cooperative Cereal Improvement Project. This project was funded by the Ford Foundation for a period of 5 years, 1978 to 1983. The purpose was to define with greater certainty, in a variable environment, those combinations of options which offer the farmer the best chance of making the most effective use of his limited resources of land, labor, and capital. More specifically, the project was designed to develop and demonstrate a package of agronomic technologies. ICARDA reported that the project developed a set of recommended best-bet production practices with respect to variety, seed rate, fertilizer, method and date of sowing, and weed control for wheat and barley in the different rainfall zones of Jordan. This project has demonstrated that an increase in yield of 20 to 30 percent can be achieved even in relatively dry environments. But this yield increase can be achieved only if the lessons of this project are extended to the farming community, and provided that the necessary capital and supplies of inputs (seeds, fertilizers, and chemicals) are made available. This project made clear recommendations for future research on tillage practices, conservation of moisture, choice of variety, use of fertilizer, control of weeds, the establishment and management of pasture, and the study of farming systems that integrate the production of cereal crops and livestock (ICARDA, 1984).

Research on food legume production started late in Jordan. In 1978, the Faculty of Agriculture launched a research program to develop better cultural practices. The program has focused on developing means for mechanical harvesting of lentils. In 1980, a Jordanian-Australian dryland project commenced operation until 1984. The basic objective of this project was to improve the productivity of the cereal growing areas of Jordan by the introduction of fodder legumes into the cropping rotation and by the extension of improved crop management techniques (Jordan-Australia Dryland Farming Project, 1984). The project utilized on-farm trials of improved cereal and forage production.

Other projects to increase cereal production include one funded by International Funds for Agricultural Development (IFAD) in cooperation with the JCO. The objective of this project is to increase agricultural production and farm incomes. It provides medium-size seasonal loans to farmers, marketing services, supply of inputs, new agricultural machinery, and technical assistance. Another project is supervised by the Arab Center for Studies in the Arid Zones and Drylands (ACSAD) for the production of improved wheat seeds. It provides all the requirements for the production and distribution of improved seeds.

It can be concluded that there has been an accumulation of agronomic information, technical experience, and research to improve Jordanian cereal production, but the results so far have been somewhat disappointing. Jordan wheat yield did not show any significant improvement, and total production has been decreasing for the past ten years. The most comprehensive project Jordan had a few years ago was the USAID/Oregon State University Project from 1967 to 1975. This project focused on demonstrations to teach, inform, and encourage farmers to use these improved inputs. Unfortunately, farmers' adoption of these recommended inputs was minimal. Other comprehensive research indicated that farmers do know that better tillage, fertilizer, weed control, and all other recommended inputs will increase wheat yield. Furthermore, this study reported that farmers could express their knowledge in clear terms, since they could formulate quantitative rates of return which they perceived from each input (El-Hurani, 1975). So basically farmers did not lack knowledge concerning the benefits expected from the technologies in the package but still decided not to invest in these improved inputs. Another inquiry addressed the issue of low adoption rate and found that a logical interpretation lay in the issue of profitability (El-Hurani, 1980). A detailed calculation of benefit/cost ratios for these inputs showed that farmers are rational, in the sense that the economic returns from using these inputs were not attractive enough to cause farmers to apply improved inputs. The issue of profitability provided a meaningful explanation of the behavior of Jordanian wheat farmers. The profitability of wheat production is basically determined by the prices of these inputs (cost side), by the wheat yield (technical side), and by the price of wheat output (determined by market or government price policy).

The real issue that needs to be tackled is how to get farmers interested and motivated to use these inputs. A long list of research results and reports indicates clearly that farmers' readiness to use the inputs depends on the availability of these recommended inputs at the right time, place, and prices. The issue of availability of inputs in the dryland areas is discussed in Section 2.

Farmers' financial ability is another constraint. As indicated earlier, farmers in the traditionally rural areas are the poorest class in Jordan. Any amount of capital investment requires some kind of support, such as a short-term seasonal credit, and these loans should be provided in kind to guarantee a proper use of the loan.

Review of Agricultural Dryland Policies

The government recognizes the important role of the agricultural rainfed subsector to the Jordanian economy since 93 percent of the total agricultural lands are considered rainfed land resources. As Section 3 has shown, the government has a long history of efforts to improve the productivity of these drylands through the implementation of several research projects.

The first five-year economic development plan (1976 to 1980) specifically set the following national goals to improve production conditions and to increase food production:

1) Increasing the production of the principal dryland crops by 1980 as follows: wheat, 36 percent; barley, 25 percent; lentils, 25 percent; olives, 115 percent; grapes, 110 percent; and vegetables which are partly produced in rainfed areas by 50 percent.
2) Increasing fodder and forage crop production.
3) Developing agricultural methods, supporting services, and extension.
4) Changing the pattern of utilizing rainfed lands by relating the crops planted to the agroclimatic conditions. Reducing the grain-growing area from 340,000 ha to 240,000 ha, shifting about 90,000 ha from wheat to barley, and increasing tree plantings.
5) Promoting the establishment of agricultural cooperatives in the rainfed areas.
6) Increasing livestock production, beef by 100 percent and mutton by 20 percent.

However, this five-year plan did not allocate enough capital resources to improve the production environment in the rainfed subsector. It is reported that the largest proportion of agricultural investment (about three-fourths of total agricultural investment) was spent on irrigation projects. The second five-year economic development plan (1981 to 1985) has almost repeated the same national goals of the first five-year plan for the rainfed subsector. For example, it stated the following national goals:

1) To increase productivity of the dryland sector and speed up the introduction of farm mechanization.
2) To increase average production of the main field crops (wheat, barley, lentils) by 30 percent during the period 1981-1985.
3) To limit the production of these field crops to areas most suitable for them.
4) To plant 245,000 dunum with fruit trees, giving priority to land with more than 9 percent slope.

With respect to field crops, this plan expected to increase total production from 109,000 t in 1980 to 142,000 t in 1985, achieving a total production growth rate of 30 percent for this period. However, actual production averaged 90,000 t during 1981 to 1985, which indicates a decrease of 18 percent from previous production. This simply means that total production of field crops has deteriorated over the past 10-year period. To obtain a better understanding of the presently stagnating dryland sector, we need to review the prevailing agricultural dryland and food policies in Jordan. There are three significant policies: agricultural input price subsidies, wheat output price support policy, and finally, consumption subsidies on wheat and bread prices. A brief discussion of these policies follows.

Agricultural Input Price Subsidies

The Jordan government provides some general subsidies to the agricultural sector in the form of duty-free importation of agricultural inputs and machinery. However, all agricultural inputs are sold by private firms who import directly from international companies, so the prices of all these inputs reflect the international supply and demand conditions. Some specific government projects promote planting fruit trees in hilly rainfed areas with a slope of 9 to 25 percent. For example, the government in cooperation with FAO/UNDP provides farmers with subsidized fruit tree seedlings and food material assistance for terrace building. Also JCO provides some inputs to dryland farmers at subsidized prices. But this support is very limited with respect to the scope of the Jordanian rainfed sector. Fertilizers, herbicides, and machinery are sold to the dryland farmers at high prices. A serious concern was raised by an important study in 1980 (Gotsch, 1980). It was concluded that output-input relative prices were moving against purchased modern inputs. Gotsch calculated the ratios of wheat-fertilizer prices for the period 1967 to 1976 and found that these relative prices were preventing farmers from using fertilizers. The diffusion of the improved package could be accelerated by applying a subsidy directly to the input itself. We believe the government of Jordan might be well advised to subsidize fertilizer if the alternative is to subsidize large-scale wheat purchases from abroad. There must be an emphasis on the provision of inputs and services at prices which guarantee a reasonable profit margin to dryland farmers. Input price policy for the dry areas must receive more attention by decision-makers, since the slow adoption rate of recommended inputs is the result of factors such as the high prices of inputs.

What Output Price Support Policy?

The Jordan government encourages dryland farmers to produce wheat in rainfall zones of 300 mm and above, and in areas with a slope of 0 to 8 percent. The goal of this is to increase wheat production in order to reduce the size of imported wheat annually. For many years the government adopted wheat price support policy by offering to purchase the domestically produced wheat at higher prices than the international price. Although this price support program has been practiced by the government over many years, it has never achieved its desired purpose due to the inefficiency and poor timing of its implementation. Farmers usually have the freedom to sell either to the local merchants or the government. Over many years, this support price has not been attractive to farmers nor effective in motivating farmers to increase their wheat acreage.

Previous studies asserted that farmers prefer selling to local merchants rather than to the government because:

1) The difference between the government support price and local market is negligible.

2) The government has requirements for quality, procedures of procurement, and routine of payment. These strictures do not motivate farmers to sell to the government.

3) The local wholesale merchants usually pay cash to farmers, and carry the purchased wheat from the farm.

Table 10. Size of Government Purchases of Domestic Wheat from 1980-1983 (Records of Ministry of Supply, Amman, Jordan.)

Year	Size of Local Wheat Purchased by Government	Size of Total Wheat Production	Percent of Purchase to Local Production
	.... ton	....	
1980	25.508	139,007	18.4
1981	20,188	59,687	33.8
1982	3,871	29,100	13.3
1983	34,947	115,613	30.2

Table 10 shows the percent of government purchases of domestic wheat during the period 1980 to 1983 and the ratio of these purchases to total domestic production. The Ministry of Supply bought only a small proportion of Jordanian wheat, ranging from 13 to 34 percent of total domestic production. Apparently, the government did not work hard in purchasing local wheat simply because it costs much more than imported wheat. Since the government bought only a small proportion (13 to 34 percent), the logical question is what happened to the rest of the domestic wheat. About 50 percent of domestic wheat is retained on the farm for household consumption, seed requirements, and feed for animals. It is believed that a high percentage of the remaining domestic wheat is marketed through private channels as animal and poultry feeds. If this is true, it means that Jordan will have to import more wheat as the availability of local wheat diminishes. The total area of wheat cultivation has decreased during the last several years reaching its lowest level to date in 1984, 700,000 dunums.

It is strongly argued that lack of rainfall is not responsible for this decrease. Qasem provides good examples on this matter. For instance, the year 1974 was considered an excellent rainfall season and the wheat area was 2.3 million dunum. In 1980, however, the cultivated wheat area was only 1.3 million dunum, a 43 percent decrease from 1974, although it was an equally excellent rainfall season. Also, 1976 was considered an average rainfall season, with the cultivated wheat area at 1.3 million dunum, but in 1984, an equivalent rainfall season, the cultivated wheat area was 700,000 dunum, a 46 percent decrease from 1976.

This simply means that wheat cultivation has become a low priority for farmers. Because wheat is usually cultivated in high to medium rainfall areas (300 mm annual rainfall) these areas are also suitable for fruit trees and vegetable production. If farmers have the financial resources they might as well establish fruit orchards which have a higher net income and less financial risk (Qasem, in press).

Consumption Subsidies on Wheat and Bread Prices

The Jordanian government provides sizable subsidies for the wheat consumed by Jordanians. This policy has been practiced by the government for many years. The purpose of this market intervention is to provide bread to Jordanians living in urban areas, at low cost. The government imports most of the needed wheat from the world market and sells it to mills at a reduced price to control the price of flour, and consequently, to stabilize the price of bread.

Table 11. Government Consumption Subsidy on Imported Wheat for the Period 1981-83
(ACSAD, 1984, Table 14.)

Item	Year		
	1981	1982	1983
	.... *J.D.*		
Price of imported wheat CIF Agaba	67.25	64.63	62.43
Total cost of handling	10.37	10.34	9.46
Total cost of imported wheat	77.62	74.97	71.89
Government subsidized sales price to millers	40.00	38.40	37.40
Government subsidy per imported ton of wheat	37.62	36.54	34.49
Amount of imported wheat (10^3 ton)	199.1	249.9	290.6
Total government subsidy for imported wheat (million J.D.)	7.490	9.139	10.023

It is noteworthy that during the 1950s and 1960s about half of Jordan's total wheat requirements were met by domestic production. Foreign donations of wheat fulfilled 25 percent of the need. This means that Jordan imported around 25 percent of its requirements. However, since the 1970s, Jordan's direct imports of wheat have risen to 70 percent of total annual needs because the relative share of local production has fallen to only 20 percent and wheat donations have decreased to 10 to 12 percent of the total wheat demand. The consequences of such a trend are a greater burden on the government budget and more foreign currency allocated to purchase an increasing amount of wheat.

In 1983, more money was spent to import wheat than any other food item, J.D. 32 million, or about $95 million. In 1984, the estimated cost for imported wheat was $30 million while in 1973 it was only $9 million. To attain a better understanding of the Jordanian consumption subsidy, Table 11 shows calculations of the budgeted cost of imported wheat for 1981 to 1983. Government budgetary support increased from J.D. 7.5 million in 1981 to 10 million in 1983, a 33% percent increase in budget support during three years.

In addition to support for imported wheat, the government of Jordan buys domestic wheat. Although this purchase is small, it represents a very interesting case as the government supports two groups of Jordanians: dryland wheat farmers and urban consumers. The government buys wheat from farmers at a price perceived to support farmers since the government could buy wheat abroad at a much lower cost. Table 12 shows the budget for purchases of domestic wheat from 1981 to 1983.

Government support rose from J.D. 1.5 million in 1981 to J.D. 2.6 million in 1983. To evaluate the government efforts to buy domestic wheat, Table 13 shows wheat prices, both imported and domestic, and the price differential from 1981 to 1983.

The world market price was lower than the local price over all years and increased with time. For example, the government paid more than 41.5 percent of the imported price in 1981 for local wheat, increasing to 50 percent in 1982, and 74 percent in 1983.

Table 12. Government Consumption Subsidy on Locally Purchased Wheat (ACSAD, 1984).

Item	Year		
	1981	1982	1983
	.... *J.D.*		
Price of a ton of purchased domestic wheat	95.20	96.45	108.45
Total cost of handling	4.27	4.36	4.21
Total cost of purchased wheat	99.47	100.81	112.68
Government subsidized sales price to millers	40.00	38.40	37.40
Government subsidy per ton	59.47	62.41	75.28
Amount of purchased wheat (ton)	25,510	19,410	37,760
Total government subsidy and support for local wheat (million J.D.)	1.517	1.212	2.624

Table 13. A Price Differential between Imported and Domestic Wheat (ACSAD, Table 11 and Table 12).

Item	Year		
	1981	1982	1983
	.... *J.D.*		
Price of domestic wheat per ton	95.20	96.45	108.45
Price of imported wheat per ton	67.25	64.63	62.43
Price differential per ton	27.95	31.82	46.04
Percentage price differential over imported price (%)	41.5	49.2	73.8

An Assessment of Jordan Agricultural Dryland Policies: Conclusions and Recommendations

All Jordan development plans have placed emphasis on the importance of the developing agricultural sector. Although actual farming is done by the private sector, the government of Jordan assumed the responsibility of providing infrastructure as well as basic services to facilitate and accelerate agricultural growth. As mentioned previously, the government grants full exemption of import duties on all agricultural materials obtained from international markets. For the purpose of protecting farmers from the use of low quality imported inputs or potential health hazards, the government instituted measures for regulating and controlling the import of pesticides and other chemical materials. The government also provides a number of public sources of credit on easy terms to encourage the private sector to enter the farming business.

Despite these efforts, the performance of the agricultural sector is still weak, and more efforts are apparently needed to bring about more positive responses in production, particularly in the rainfed subsector. As reported earlier, agriculture's share of Jordan's gross fixed investment appears low, and most of this investment is channeled into the irrigated sector. The rationale of previous government policy was to concentrate development efforts more on irrigated agriculture and this is quite understandable. After experiencing several years of drought which adversely affected dryland agriculture, Jordan's solution has been to turn its efforts to the Jordan Valley, a unique irrigable area of high potential. Also, it is in irrigated agriculture that the international community offers the best opportunities for financial support and assistance.

The present food and agriculture conditions demonstrate the necessity to reactivate efforts for the development of the rainfed sector. There will be an even greater need to develop the dryland subsector as the demands for food grains and meat increase at higher rates in the future.

The dryland subsector has been showing signs of deterioration over the years. The general assessment is that the government has made only minimal efforts to improve the production conditions in the dry regions. Previous efforts were primarily research and technology transfers. Dryland agriculture appears to be a low priority for resource allocation. I believe the Jordan rainfed subsector requires more public investment, as well as the devotion and dedication of Jordan's higher officials. What is required now is to develop more specific projects in actual agricultural production such as the Jordan Highlands Agricultural Development Project (JHADP). The proposed JHADP utilizes a fresh approach in dealing with the issues of production in rainfed agriculture, especially for inputs and services.

Research efforts have been directed toward the improvement of the drylands since 1952. However, all these years of research did not bring prosperity to the rainfed subsector. The farmers plant wheat with minimum inputs. The adoption rate of modern technology is very low, and the area cultivated with field crops is decreasing. I believe that significant progress in the dryland subsector of Jordan will be a real challenge, along with formulating a strategy to increase production. Increasing the cereal yield is not impossible, because it is a result of using proper inputs such as fertilizer, herbicides, and proper machinery. As illustrated in Section 3, the issue of profitability would provide a meaningful reason for the low adoption rate behavior of Jordan wheat farmers.

The high cost of production of 1 t of domestic wheat is due to the low yield per dunum of Jordan's drylands. This low yield is caused by the lack of application of improved inputs. Farmers do not use improved inputs because of high prices and the unavailability of these inputs. This seems like a vicious circle where low profitability is caused by the high cost of production. This high cost of production is caused by low yield, and this low yield is caused by lack of use of improved inputs, and wheat farmers do not use these modern inputs because of high cost. To break this vicious circle is the responsibility of the government. I believe the most important task of the government is to provide inputs and agricultural services to dryland farmers at the right time, and at reasonable prices, especially with regard to fertilizers, herbicides, and machinery. We stress subsidized inputs rather than the subsidized price of bread to consumers. Generally, it is recognized that the expenditure which food subsidies may require in LDCs is often immense and may come at the expense of investment in food production, which provides the lower income people with even more food than the subsidies themselves (Knutson *et al.*, 1982). In Jordan, it is realized that providing cheap bread through strong government intervention in marketing, processing, and pricing of wheat, flour, and bread undoubtedly has adversely affected domestic wheat production. Therefore, in addition to improving the conditions of Jordan's production environment, the government must recognize all the factors which influence the farmers' decision to produce field crops, including marketing, processing, pricing of inputs and outputs, and food policy.

From the available data, it seems there are clear separations between Jordan agricultural policy and food policy. A study of Jordan food policy reveals a purely consumer-oriented policy that stresses the desire of the government to provide cheap food prices, whereas the major goal of providing an adequate supply of food would require programs designed primarily to expand production. There is some evidence that Jordan food policy is contrary to agricultural policy. Examples are: the government freezes the prices of local agricultural commodities, squeezing farmers' profit margins; and the government imports large amounts of food from the world market and sells it at low prices to consumers. Estimates of Jordan's future food requirements stress the need for Jordan to work for long-term solutions for satisfying a higher percentage of food self-sufficiency. It seems that Jordan, as many other countries, did not explicitly recognize the interrelationships among food policy, farm policy, resource policy, and economic development policy, or between agriculture and the rest of the economy. One final remark to end this paper, I believe we need to set up a more consistent national agricultural and food policy which identifies the macroeconomic conditions of Jordan.

References

Australian Development Assistance Bureau. 1984. Annual report of Jordan-Australian Dryland Farming Project, No. 4, June 1984.

ACSAD. 1984. A report on Improved Seeds Project. Damascus, Syria, February 1984.

Babb, E.N. 1967. A report on integrated agricultural development of the rainfed areas, FAO/UNDP, Amman, Jor .an, August 1967.

Central Bank of Jordan. 1983. Twentieth annual report, Amman, Jordan.

Cook, G. *et al.* 1984. Dryland wheat production and marketing cost in Oregon's Columbia Plateau. Oregon State University, Corvallis, OR.

Department of Statistics. 1974-1982. Agricultural statistical yearbook and agricultural sample survey. Amman, Jordan.

El-Hurani, M.H. 1975. Economic analysis of the wheat subsector of Jordan. Ph.D. Thesis. Iowa State Univ., Ames, IA.

El-Hurani, M.H. 1980. Jordanian farmers' perceptions of improved wheat technology. *In* Improving dryland agriculture in the Middle East and North Africa. Food Research Institute, Stanford Univ., Palo Alto, CA.

El-Hurani, M.H. and M. Duwayri. 1986. Rainfed agriculture in Jordan. Abdul Hameed Shoman Foundation, Amman, Jordan.

Gotsch, C. 1980. Wheat price policy and the demand for technology in Jordan's rainfed agriculture. *In* Improving dryland agriculture in the Middle East and North Africa. Food Research Institute, Stanford Univ., Palo Alto, CA.

ICARDA. 1981. A report on Cooperative Winter Cereal Research Project. Aleppo, Syria.

ICARDA. 1984. A report on Jordan Cooperative Cereal Improvement Project. Aleppo, Syria.

Knutson, R. *et al.* 1982. Agricultural and food prices. Prentice-Hall, Englewood Cliffs, NJ.

Mazur, M.P. 1979. Economic growth and development in Jordan. Westview Press, Boulder, CO.

Ministry of Supply. 1984. Records on government purchase of domestic wheat. Amman, Jordan.

Qasem, S. 1985 Agricultural policy formulation and administration in the agricultural section of Jordan. Ithaca Press, London, UK.

Qasem, S. 1986. Analysis of issues of agricultural sector in Jordan. A. H. Shoman Foundation, Amman, Jordan.

Watkins, Grierson, and Harvey. 1983. Land use capability planning study. Jordan National Planning Council and Australian Development Assistance Bureau.

Jordan/Australia Dryland Farming Project Background, Aims and Some Early Results

C.S. Heysen and P. Tow
Jordan/Australia Dryland Farming Project, Amman, Jordan

ABSTRACT. The ley farming system, in which the fallow in the cereal/fallow rotation is replaced with a self-perpetuating annual legume pasture, may be a good method of increasing production in Jordan's rainfed farming sector. The Jordan/Australia Dryland Farming Project is doing research to adapt ley farming to Jordanian conditions, and extension to encourage adoption of new, productive agronomic practices. The Project has identified a number of annual medics which fix nitrogen and are self-seeding. Research on their potential for inclusion in the Jordanian cereal-based farming system will continue.

Introduction

The Jordan/Australia Dryland Farming Project is designed to improve the productivity and profitability of rainfed farming in the 200 to 300 mm rainfall zone of Jordan through the closer integration of cereal and livestock production utilizing methods adapted from the southern Australian ley farming system.

The essential feature of this system is the replacement of fallow in the cereal/fallow rotation with a self-regenerating annual legume pasture. Benefits include improved livestock production, increased soil nitrogen, and organic matter with a consequent beneficial effect on fertility and soil structure.

Research and Extension

The project has two main programs:

1) Research, and

2) Extension and training.

The goal of the research program is to define the optimum production system given the existing physical and social environment of Jordan. It comprises agronomic and livestock research, a sociological survey, and economic evaluation. The objective of the extension program is to educate the rural community in the means of achieving the production possibilities defined by the research program. Since the research process is dynamic the two programs are run concurrently with research results incorporated into the extension program as they are obtained.

Achievement of these goals will rely on the development of a cohesive farm system approach. The framework described in this paper is used to define each aspect of the work. The basis of the framework is for activity to be centered on the farm; the program is designed to support the implementation of project goals at the farm level. Where necessary, specialist support is employed from outside the participating organizations of the project. However, essential ingredients for long-term success of the program are the participation of local agriculturists in all stages of the work and cooperation among Jordanian institutions involved in agriculture.

Ley Farming Research

Because large cereal improvement programs are in progress in Jordan, the project is concentrating its efforts on the incorporation of an annual legume phase in cereal-based farm rotations. The following results from the first three years of the work support the view that such a pasture phase will be feasible:

1) A mixture of commercial annual medic cultivars has yielded as much dry matter as cereal-vetch mixtures in small plots. *M. scutellata* is the most productive commercial cultivar.

2) Other, noncommercial medics, particularly *M. rotata*, have been more productive in small plots than many commercial cultivars.

3) Annual medics have repeatedly responded to inoculation with commercial Rhizobium cultures, demonstrating reasonable nitrogen fixation.

4) Several medics have given good seed yields in small plots, particuiarly *M. rotata*, *M. scutellata*, *M. aculeata*, and *M. blacheata*.

5) Medics regenerate in subsequent years, provided pods are not plowed in, taken by rodents or ants, or eaten by sheep.

The current pasture research program is designed to continue the evaluation of a range of annual legumes in terms of their adaptation to climate and soil, their utilization for livestock production, and their compatibility with Jordanian cereal-based farming systems. Farm demonstrations are continuing but extension and education programs will be expanded as practical information becomes available. This program and these plans will be guided by the results of a sociological survey now being undertaken.

SECTION III

Regional Experience—Overview Reports on Soil, Water, and Crop Management Systems

Soil Management, Water Conservation, and Crop Production in the Dryland Regions of Turkey

N. Durutan, M. Pala, M. Karaca and M.S. Yesilsoy
Central Anatolian Agricultural Research Institute, Ankara, and University of Cukurova, Adana, Turkey

ABSTRACT. In order to stabilize cereal production against unpredictable precipitation in the Central Anatolia, Turkey, available soil water must be increased during the fallow period through improved soil and water management. Four tillage systems were compared to determine their effects on soil properties, moisture conservation, and weed control. The soil mulch system had the highest water infiltration, the most effective weed control, and the highest fallow efficiency. It was superior to the stubble mulch, modified soil mulch, and modified stubble mulch systems. A package of agronomic practices based on these studies has been recommended for adoption by farmers in the wheat/fallow areas.

Introduction

In Turkey, although semiarid areas are mostly concentrated in the Central Anatolia there are a number of small areas scattered outside of the major zones (Figure 1) (Basbakanlik Devlet Meteoroloji Isleri Genel Mudurlugu, 1984). The semiarid regions are approximately 40 percent of the total area; nearly 60 percent of the total semiarid area exists in the Central Plateau. The major dry-farmed cropland is bounded by longitudes 30.5° and 38° E and latitudes 37° and 40.6° N.

It should be emphasized that any management system that will increase production in an area will be closely linked to the ecology of that area. In other words, the ecological conditions of a given region determine the agricultural system for that part of the country.

Climate

The inner areas of the country, particularly the Central Anatolian Plateau, are dryland in nature. However, due to the topography of the region, climatic conditions vary. Figure 2 shows four types of climate occurring in the Central Plateau. Although there is some variation among the provinces in annual precipitation, scarcity of rainfall and seasonal distribution of rainfall are the most important characteristics of the region.

The average annual precipitation ranges from 250 mm to 450 mm depending on the region. There are also great differences among the years. For instance, in one location the annual rainfall was 195 mm one year, and in another year it was 557 mm. This unpredictability always carries the threat of drought.

The seasonal distribution of precipitation is given in Figure 3. Nearly 70 percent of precipitation occurs in winter and spring. The dry season begins around mid-June and continues until the end of October. This period is the most important for cereal production from the point of view of water storage. It has very limited total rainfall accompanied by high temperatures and low humidity.

Soils

Soils of the Central Plateau belong to the Brown great soil group. Fifty-six percent of the Central drylands have clay and clay loam soils (Tables 1 and 2). Approximately 40 percent of the soils are loam soils; only 4 percent are coarse-textured soils.

Most soils are limited in their water holding capacity since the soil depth is just a meter over the calcareous parent material. These soils have a low water infiltration rate with very slow downward movement into the subsoil but considerable upward movement occurs when evaporation takes place at the soil surface.

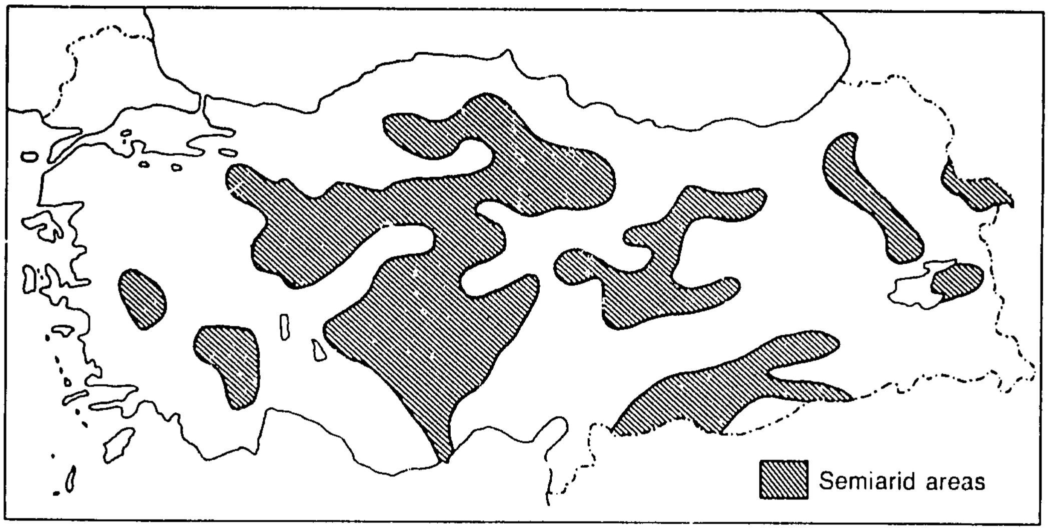


Figure 1. Semiarid Areas of Turkey (Basbakanlik Devlet Meteoroloji Isleri Genel Müdürlügü, 1984).

Generally, the soils are poor in organic matter content; 75 percent of the soil contains only 1 to 2 percent organic matter. Since nearly 70 percent of the soils are poor in P_2O_5, phosphorus and nitrogen fertilizer applications are standard practice in most areas. Most soils are rich in $CaCO_3$ and K_2O (Ulgen and Yurtsever, 1984).

Soil salinity and alkalinity are not serious problems in the Central Plateau. According to the latest statistics, only 3.5 percent of the total arable land is saline or alkaline.

Cropping Systems

In winter-dominant, low rainfall areas (250-400 mm), cropping is based on a fallow-cereal rotation using a 14-month fallow period. Wheat and barley are the most important cereals. According to the latest statistics almost 60 percent of the total wheat yield is produced in this area by dryfarming.

In the transitional zones high annual precipitation allows more intensive cropping. Legumes are usually grown in rotation with cereals.

Major Problems and Main Approaches

The main factor limiting yield in the Plateau is insufficient moisture. If moisture is the most important factor limiting yield in a region, the efficient use of water should be the guiding principle in selecting the package of crop and soil management practices (Bolton and Booster, 1977). Crop management practices under dryland conditions are:

1) Good soil management to conserve the maximum amount of water in the soil profile and to provide optimum seedbed conditions during the fallow period.
2) O·timum date and rate of seeding that enable the plant to efficiently utilize the available moisture for maximum yields.
3) In relating moisture supply in the soil to crop demand, careful fertilization must be practiced (in addition to phosphorus fertilizer, nitrogenous fertilizer is also required).
4) High-yielding cultivars (well-adapted to drought and cold, and disease and insect resistant) are needed.
5) Control of weeds, both in the fallow and crop year, is essential to conserve moisture in the fallow and make more water available to the crop in the crop year.

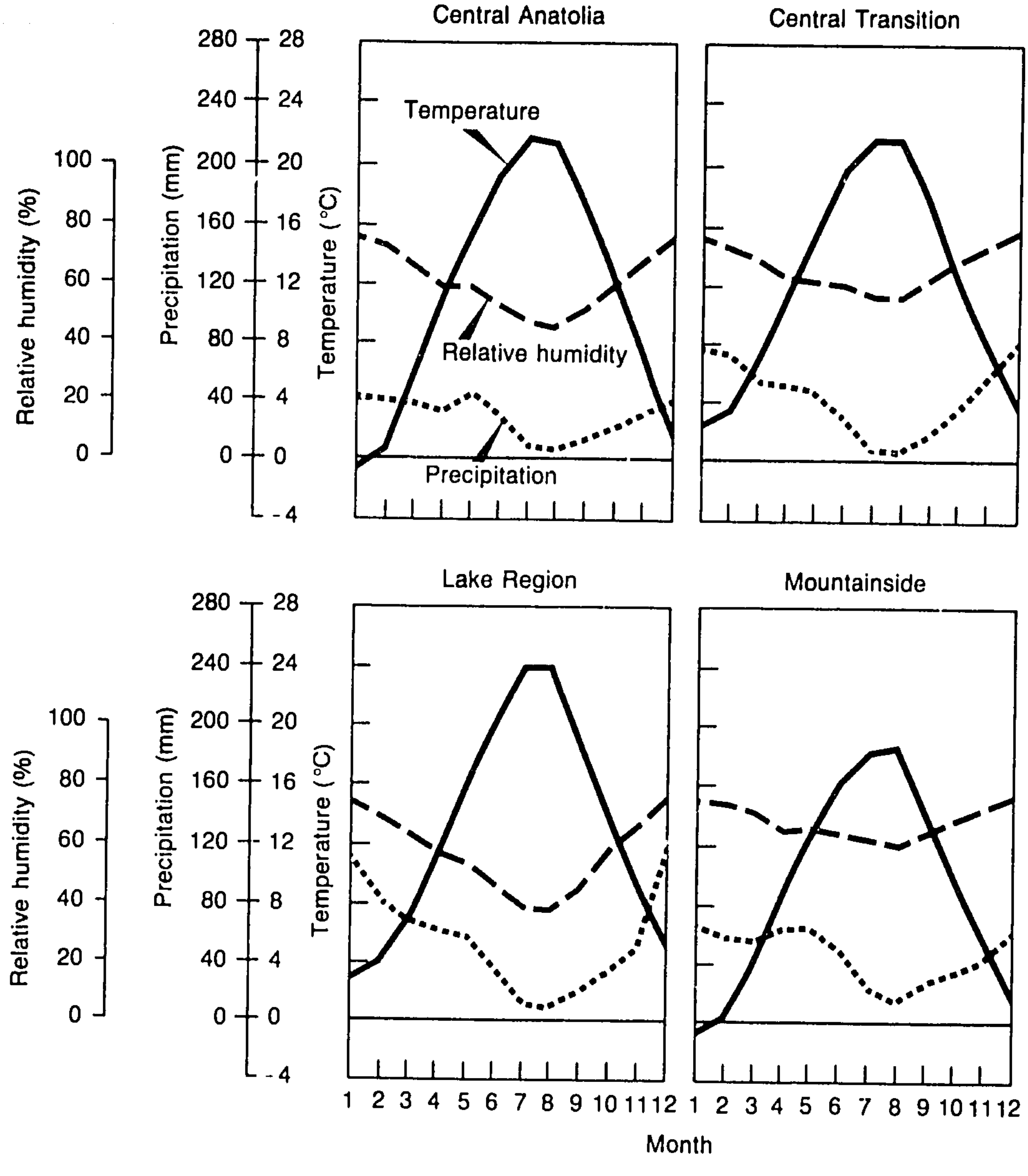


Figure 2. Fou·· Types of Climates Occurring in the Central Plateau (Mizrak, 1983).

In order to stabilize cereal production against unpredictable precipitation, available soil water must be increased during the fallow period through improved soil management. Primary emphasis should be directed toward increasing infiltration and preventing evapotranspiration. Since the water infiltration rate is slow in the Plateau and the downward movement into the subsoil is very slow, soil must be tilled so that the infiltration rate is enhanced during the intensive rainfall period. Intensive rainfall occurs during spring, particularly in April and May. After this humid period, the drought period begins with the onset of dry and hot weather. Water loss by transpiration and evaporation also increases at this time.

Weed growth on fallow land is the primary cause of water loss by transpiration. Consequently, fields must be kept clean throughout the fallow period, from the beginning of spring until planting time. This can be done by tillage or use of herbicides.

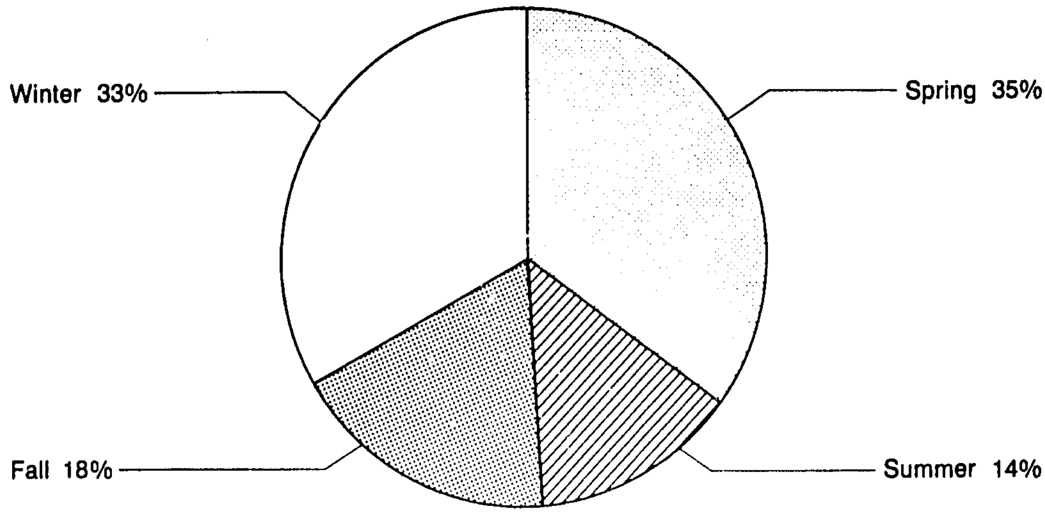


Figure 3. Yearly Precipitation Distribution in Main Dryland Area from 1930 to 1980 (Basbakanlik Devlet Meteoroloji Isleri Genel Müdürlügü, 1974).

During long, dry periods, capillary continuity causes evaporative moisture loss. Therefore, evaporation rate may be reduced by disrupting capillary continuity with the deeper soil layers. Since the upward flow of water is high in the fine-textured soils of the region, a layer must be formed on the surface to increase the resistance to upward movement. This layer must also thermally insulate the deeper soil layers during the dry season.

Water Erosion

Water runoff is an erosive agent. In soils having low infiltration rates soil losses can occur during high intensity rainfall.

In order to decrease runoff from high intensity rains on slowly permeable soils, the water retention period on the soil surface must be extended. Second, the water intake rate must be improved. Both can be accomplished through increasing surface roughness and total porosity. Soil management practices that have these results are part of the proper management system for soils of the Central Plateau. The frequency of erosive rainfall, however, is somewhat low in this region (Figure 4).

Soil losses caused by runoff are also closely related to the percent of slope. In the Plateau, cereal production is recommended for areas with slopes of less than 8 percent. Perennial forage-crop production is encouraged for steeper areas.

A 5-year runoff study was conducted on a clay loam soil with 10 percent slope in the transitional zone and an annual precipitation of 450 mm. During experimentation years, 19 percent of the annual precipitation was found to be erosive. Under these conditions, tilling up and down hill caused 3.5 percent runoff while only 1.9 percent runoff occurred with contour tillage (Köse and Sayin, 1978).

Wind Erosion

With the practice of fallow, soil is left without vegetative cover and is exposed to the wind. The hazard is greatest during the dry season when the soil surface is dry and high winds are common. According to Ask (1977), wind speed higher than 5.5 m s^{-1} is accepted as erosive. In the Central Plateau, only 3.4 percent of the total crop land is

Table 1. Some Physical and Chemical Properties of Central Anatolian Soils, Altinova State Farm (Yesilsoy, 1974).

Soil Depth	Particle Size Distribution				pH	Bulk Density	Field Cap.	Wilting Point	Organic Matter	Total Soluble Salts	Lime	Available	
	Sand	Silt	Clay	Texture†								P_2O_5	K_2O
cm	.... %					*g cm*$^{-3}$	..... *mm*		.... %			.. *kg da*$^{-1}$ ..	
0-5	30.2	30.0	39.8	CL	7.40	—	16.6	10.6	2.27	0.054	9.97	6.61	193
5-10	30.6	29.3	40.0	C	7.40	—	16.9	11.2	2.20	0.060	9.29	2.13	148
10-30	27.9	26.7	45.4	C	7.28	1.15	69.5	47.8	2.12	0.059	10.5	0.77	99.3
30-60	25.2	23.2	51.5	C	7.35	1.07	100.1	69.9	1.51	0.054	16.2	0.77	45.6
60-90	23.0	25.3	53.0	C	7.47	1.20	111.7	67.5	0.93	0.044	32.7	0.77	31.6
90-120	37.8	28.4	35.8	CL	7.61	1.16	108.6	54.7	0.47	0.033	51.3	0.77	17.3
120-150	43.5	30.2	26.2	L	7.88	1.12	99.6	55.3	0.31	0.059	39.4	0.77	18.4

† C, clay; CL, clay loam; L, loam.

Table 2. Some Physical and Chemical Properties of Central Anatolian Soils, Karapinar, Konya (Abali, 1980).

Soil Depth	Particle Size Distribution				pH	Bulk Density	Field Cap.	Organic Matter	EC 25°C	Lime
	Sand	Silt	Clay	Texture†						
cm	.... %					*g cm*$^{-3}$	*mm*	%	*mmhos cm*$^{-1}$	%
0-15	68.1	15.3	16.6	SL	8.1	1.10	23.3	1.9	0.62	44.7
15-30	57.2	22.7	20.1	SCL	8.1	1.09	32.9	1.6	0.45	48.6
30-60	31.0	26.0	43.0	C	8.2	1.01	79.6	1.5	0.45	53.5
60-90	16.0	24.4	59.6	C	8.3	1.06	88.6	1.3	0.85	54.6
90-120	12.5	42.3	45.2	SIC	8.0	1.18	85.7	1.2	1.10	55.3

† C, clay; SCL, sandy clay loam; SIC, silty clay; SL, sandy loam.

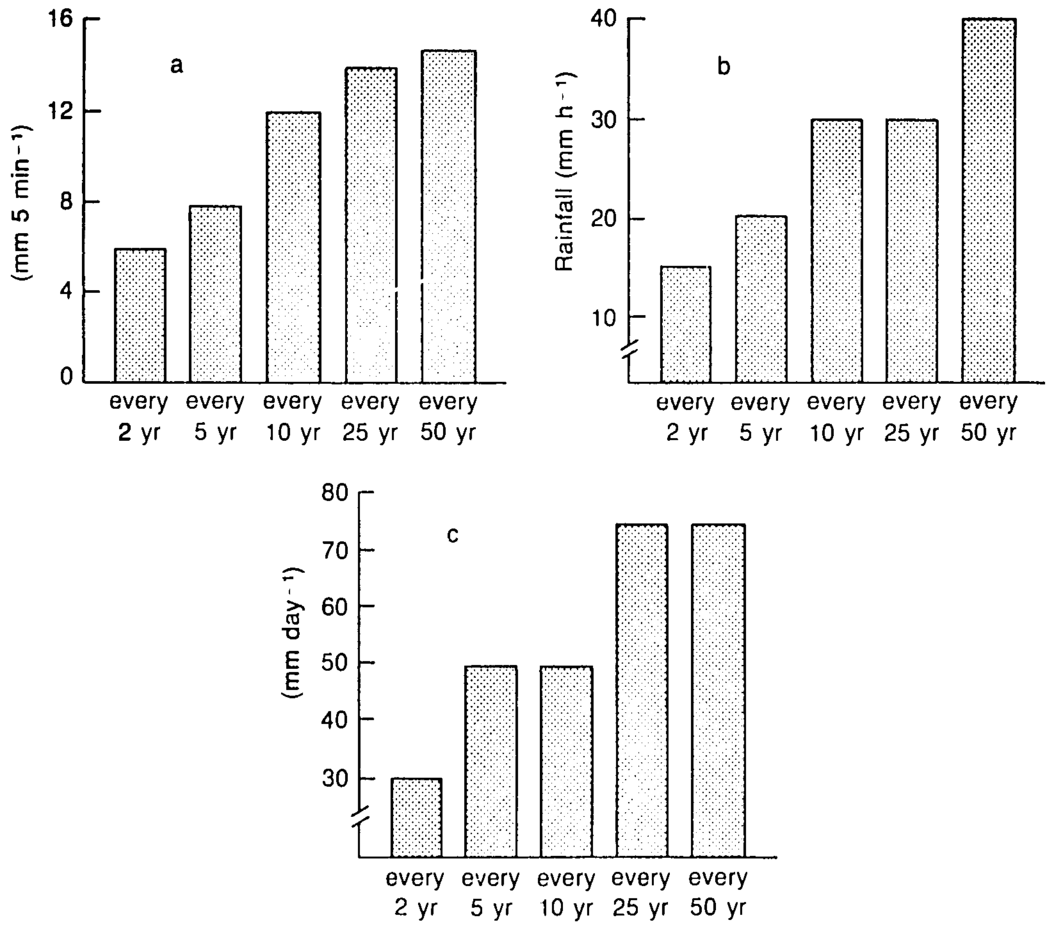


Figure 4. Maximum Rainfall in Central Anatolia (Cölasan, 1969).

affected by wind erosion (Topraksu, 1980). Within this area the monthly average wind speed is less than the limit accepted as erosive. Therefore, wind erosion is not a problem except in specific areas.

To prevent wind erosion, soil should be protected during the fallow months, particularly in dry periods, by either a residue cover or a soil layer of erosion-resistant clods. Soil clods 1 to 8 cm in diameter on the soil surface improve erosion control (Greb *et al.*, 1979).

A soil management system that meets these requirements can reduce wind erosion in the dryfarmed croplands of the Plateau.

Research for Fallow-Wheat Areas of Central Anatolia

Much research on the fallow-wheat areas of Central Anatolia has been conducted since the 1930s with valuable results. With the initiation of the National Wheat Research Project in 1969 special emphasis was placed on soil moisture conservation in the dryland areas of Turkey, paralleling the soil tillage research carried out in other dryland areas of the world. Research since 1969 has been based on experimental findings of the work from 1930 to 1968 (Berkmen, 1961; Gerek, 1968).

Time and depth of tillage and implements for initial and succeeding tillages were determined by a series of experiments conducted at research farms, State Farms, and on farmers' fields in various locations.

In the first phase, research was directed toward determination of various components of the soil management system such as time, depth, and type of implement. The recommended system was established and named the soil mulch system. This system was determined through basic and adaptive research trials carried out in various locations of the Central Plateau.

In the second phase, the recommended system was tested against some other systems and its effects on yield and on various soil properties were investigated in detail.

The soil mulch system for dryland areas of the Central Plateau is summarized below.

1) The effect of fall tillage by chisel or moldboard plow versus no tillage on wheat yield is not significant. Initial tillage can be practiced in the fall in areas where heavy spring rains do not allow plowing in the early spring.

2) To get the maximum benefit from spring rains, initial tillage must be practiced in early spring as soon as the soil reaches the proper condition for tillage. Early tillage also provides lower weed density in the crop year, 20 and 84 weeds m^{-2} for early and late initial tillage, respectively. Early tillage results in a 75 percent greater yield than late tillage.

3) The moldboard plow is the best initial tillage implement, resulting in higher total soil porosity, higher random soil roughness, better infiltration, lower weed density, and higher grain yields than the sweep, chisel plow, or no tillage, in that order.

   Plowing is the first step in creating a soil mulch layer on the soil surface to prevent moisture losses during dry periods. When soil is in the proper condition, plowing facilitates good aggregation and granulation which work as barriers to wind erosion.

4) The moldboard plow, used at a depth of 18 to 20 cm, provides higher random soil roughness, higher total soil porosity, higher infiltration rates, lower weed density, and better yields than shallow plowing.

5) A sweep and harrow combination at a soil depth of 8 to 10 cm at the beginning of the dry period is required to prevent evapotranspiration. Depending on weed density and crust formation, several summer tillages should be practiced. This can result in an 86 percent yield increase over the control (no summer tillage). In order to keep the conserved moisture closer to the surface of the seedbed, the depth of tillages subsequent to the second tillage should be decreased to 6 to 8 cm.

The soil management system devised for the Central Plateau has been tested for five years at different locations of the region. The experimental yields were compared with that of adjacent farmer's fields (Figures 5 and 6). The five-year average of the recommended practices for five provinces was 88 percent greater than the average farmers' yield.

A series of detailed experiments was conducted at one location for six years to evaluate various soil management systems. The treatments were:

1) Stubble mulch system: Initial tillage and succeeding tillages with a large sweep at a depth of 5 to 8 cm (Figure 7).

2) Modified stubble mulch system: Initial tillage with a common sweep at a depth of 18 to 20 cm and succeeding tillages with a sweep and harrow combination at a depth of 8 to 10 cm (Figure 8).

3) Soil mulch system: Initial tillage with a moldboard plow at a depth of 18 to 20 cm and succeeding tillages with a sweep and harrow combination at a depth of 8 to 10 cm (Figure 9 and 10).

4) Modified soil mulch system: Initial tillage with a reduced surface moldboard plow at a depth of 18 to 20 cm and succeeding tillages with a sweep and harrow combination at a depth of 8 to 10 cm (Figure 11).

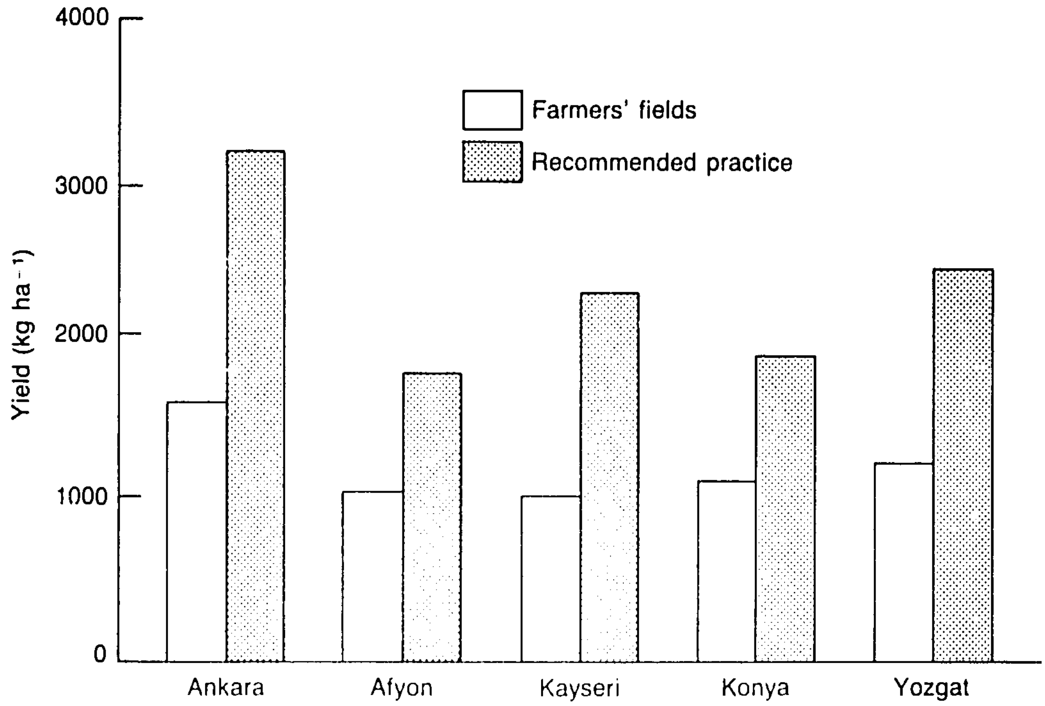


Figure 5. Five-Year Average Wheat Yields of Farmers' Fields and Demonstration Plots Using Recommended Cultural Practices in Five Provinces in the Central Plateau from 1973 to 1977.

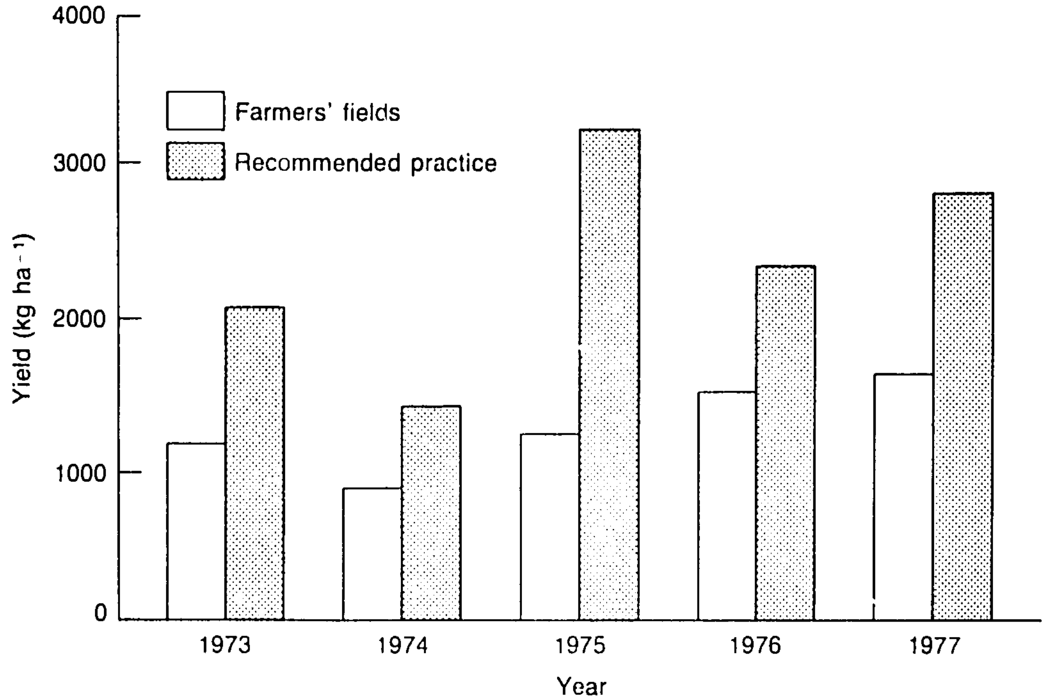


Figure 6. Average Annual Wheat Yields on Farmers' Fields and Demonstration Plots Using Recommended Cultural Practices.

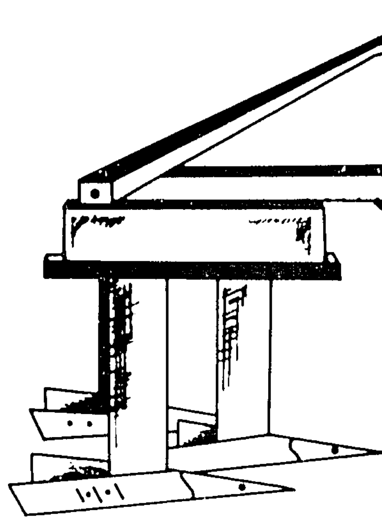


Figure 7. Large Sweep Which Is Used as the Initial Tillage Implement and for Succeeding Tillages (Dogan *et al.*, 1977).

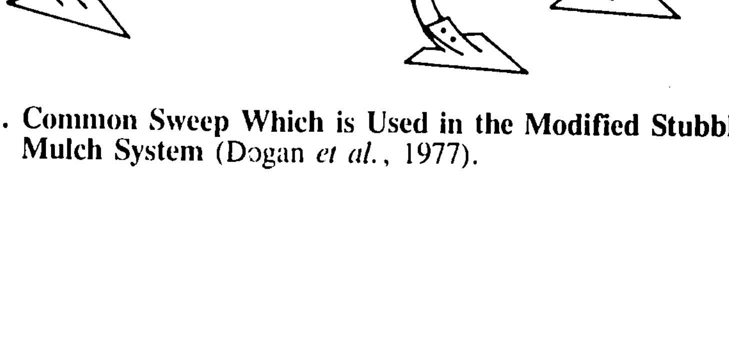


Figure 8. Common Sweep Which is Used in the Modified Stubble Mulch System (Dogan *et al.*, 1977).

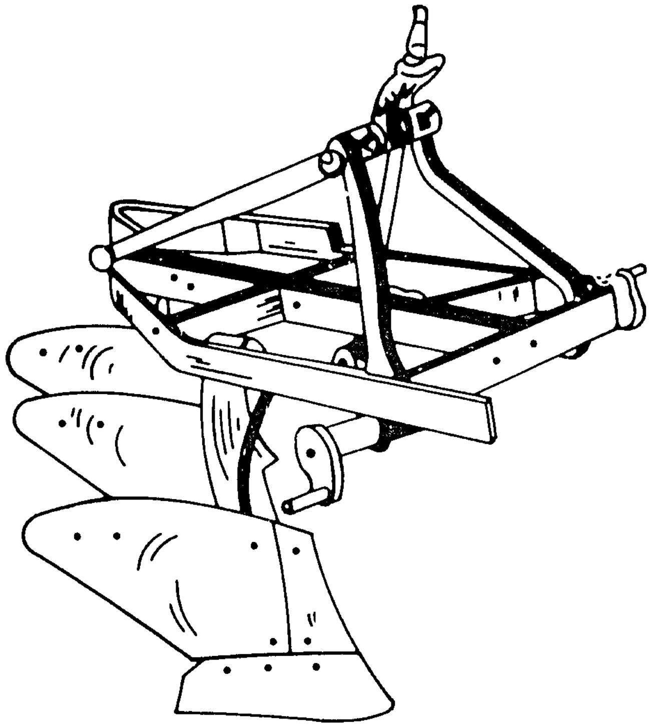


Figure 9. Moldboard Plow Which Is Used as the Initial Tillage Implement in the Soil Mulch System (Dogan *et al.*, 1977).

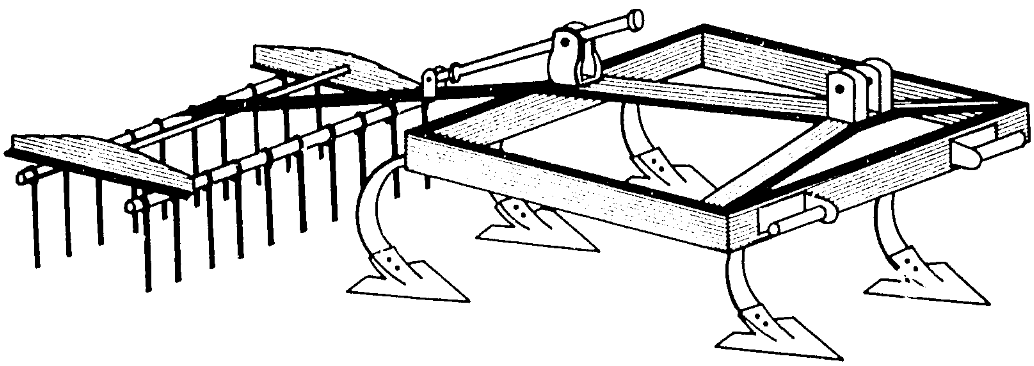


Figure 10. Sweep and Harrow Combination Which Is Used as the Summer Tillage Implement for the Soil Mulch, the Modified Soil Mulch, and the Modified Stubble Mulch Systems (Dogan *et al.*, 1977).

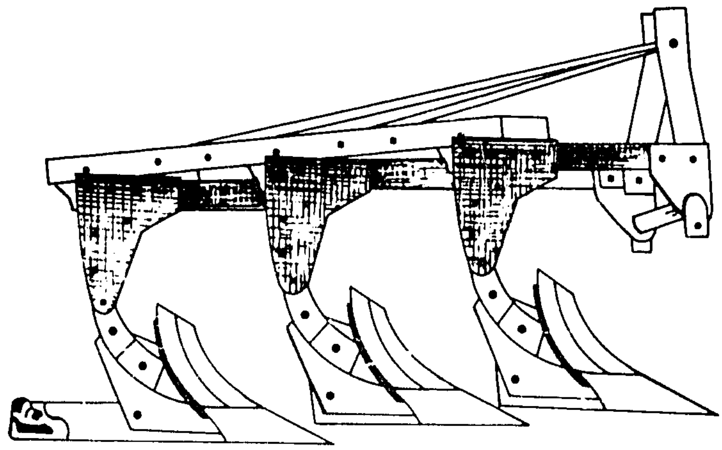


Figure 11. Reduced Surface Moldboard Plow Which Is Used as the Initial Tillage Implement for the Modified Soil Mulch System (Dogan *et al.*, 1977).

Physical and chemical properties of the experimental field are given in Table 3.

The soil mulch system was found to be the most effective soil management system resulting in the highest infiltration rate after both initial tillage and the second operation. The modified soil mulch and modified stubble mulch systems, respectively, ranked second and third in effectiveness. The stubble mulch system was the least effective system in increasing the infiltration rate (Figure 12).

The cumulative infiltration at the end of 3 hours for no-till soil was found to be 551 mm in an experiment conducted in the same year at a neighboring field. The stubble mulch system remained below that level with a cumulative infiltration of 249 mm. The soil mulch system reached to a level of 1090 mm.

A soil management system which provides moisture accumulation above the wilting point in the seed germination zone at seeding time gives an advantage to the crop through the vegetative period. This is reflected in higher yields. Data obtained from the soil management system studies indicated that the soil mulch system provided these advantages. As seen in Figure 13, this system helped to accumulate moisture above the wilting point particularly in the seedbed zone. This is important for early fall establishment of winter wheat. The stubble mulch system was the least effective system for moisture conservation. At seeding time the moisture conserved by this system was above the wilting point at depths of 23 cm and below. The soil mulch system also provided the highest fallow efficiency (Figure 14).

Water stable aggregates were measured at the end of the research period of year 6 just before the initial tillage (Özkan *et al.*, 1984). The data in Figure 15 indicate that the stubble mulch system keeps the percent of water stable aggregates about the same at depths of 0 to 10 cm and 10 to 20 cm. In the soil mulch system, however, the percentage of water stable aggregates is the lowest at 0 to 10 cm and the highest at 10 to 20 cm depth. This system brings stable aggregates to the surface layer later due to the turnover function of plowing.

Stubble mulch encouraged weed growth, particularly the grassy weed population (*B. tectorum* and *Aegilops spp.*). The moldboard plow is the most effective initial tillage implement in decreasing weed population compared to sweep type implements. Therefore, the soil mulch system is recommended to control the grassy weeds.

Table 3. Physical and Chemical Properties of the Soils of the Research Farm at Haymana.

Soil Depth	Particle Size Distribution				pH	Bulk Density	Field Cap.	Wilting Point	Organic Matter	Total Soluble Salts	Lime	Available	
	Sand	Silt	Clay	Texture†								P_2O_5	K_2O
cm	.... %					*g* cm^{-3}	..... *mm*		.... %			.. *kg* da^{-1} ..	
0-10	20.8	30.2	49.0	C	7.50	1.08	38	22	2.10	0.053	23.1	3.74	137
10-30	19.7	24.6	55.7	C	7.50	1.08	79	49	1.79	0.057	22.9	1.55	88
30-60	17.1	20.9	61.0	C	7.60	1.11	123	72	1.10	0.053	30.2	0.73	49
60-90	16.9	19.7	63.4	C	7.65	1.12	127	74	0.87	0.052	32.2	0.87	55
90-120	16.9	18.5	64.9	C	7.75	1.14	131	72	0.43	0.050	38.0	0.61	43

† C, clay.

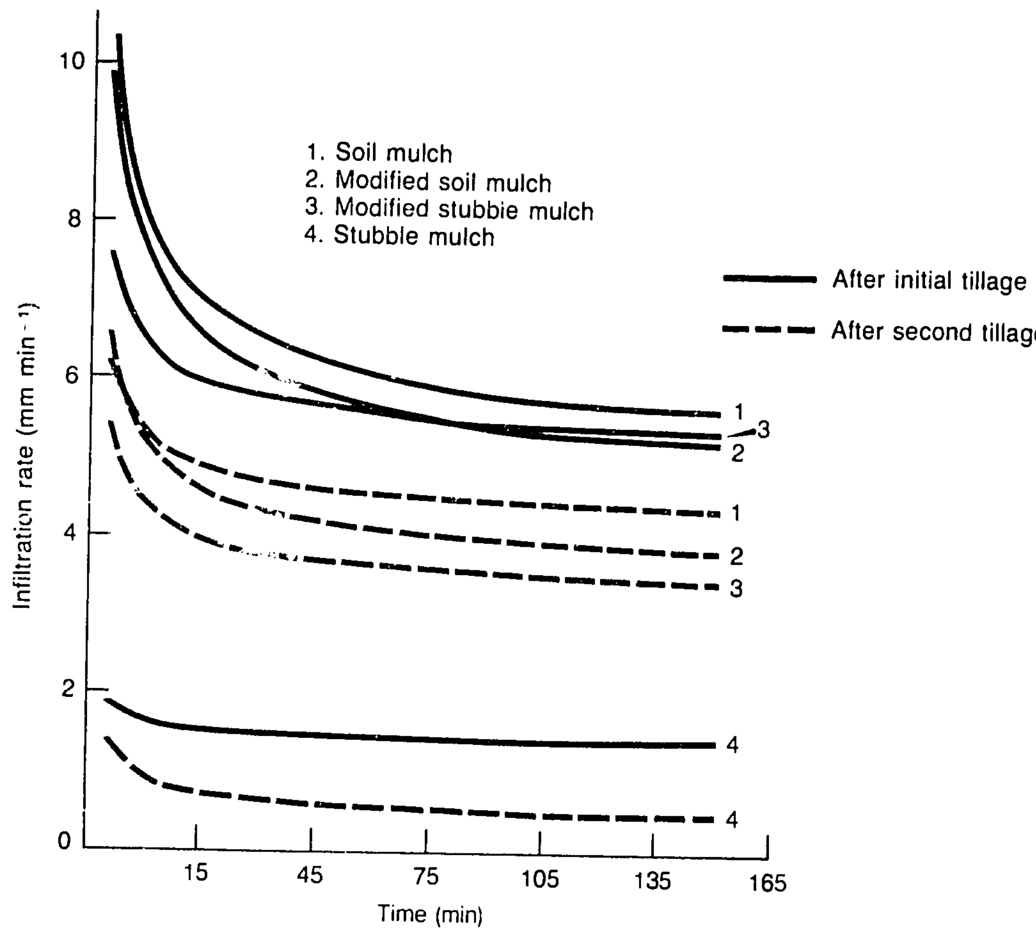


Figure 12. The Effects of Different Soil Management Systems on Infiltration Rate.

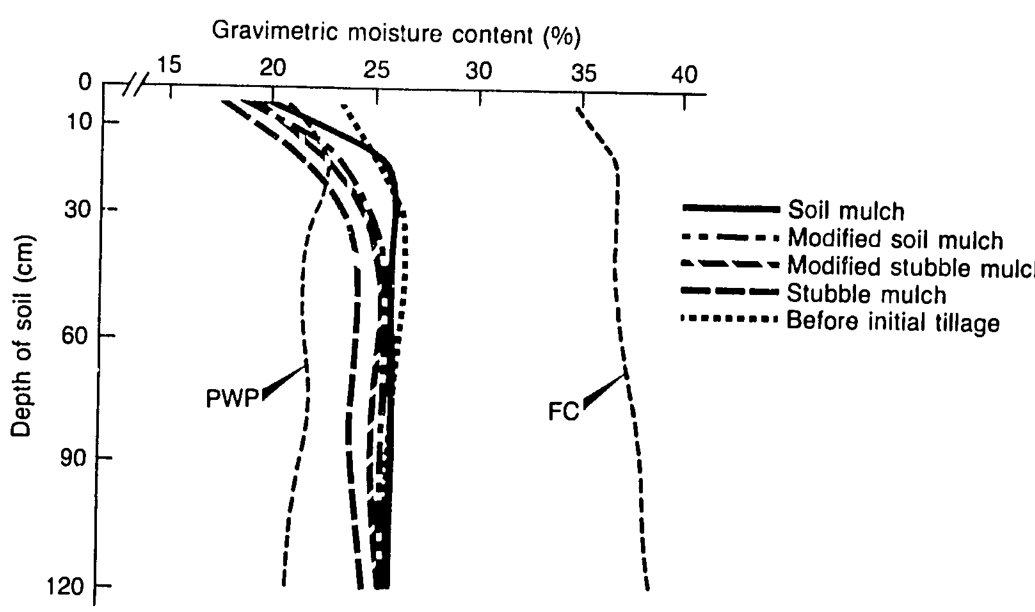


Figure 13. Average Moisture Content of the Soil Profile for Different Soil Management Systems at Seeding Time.

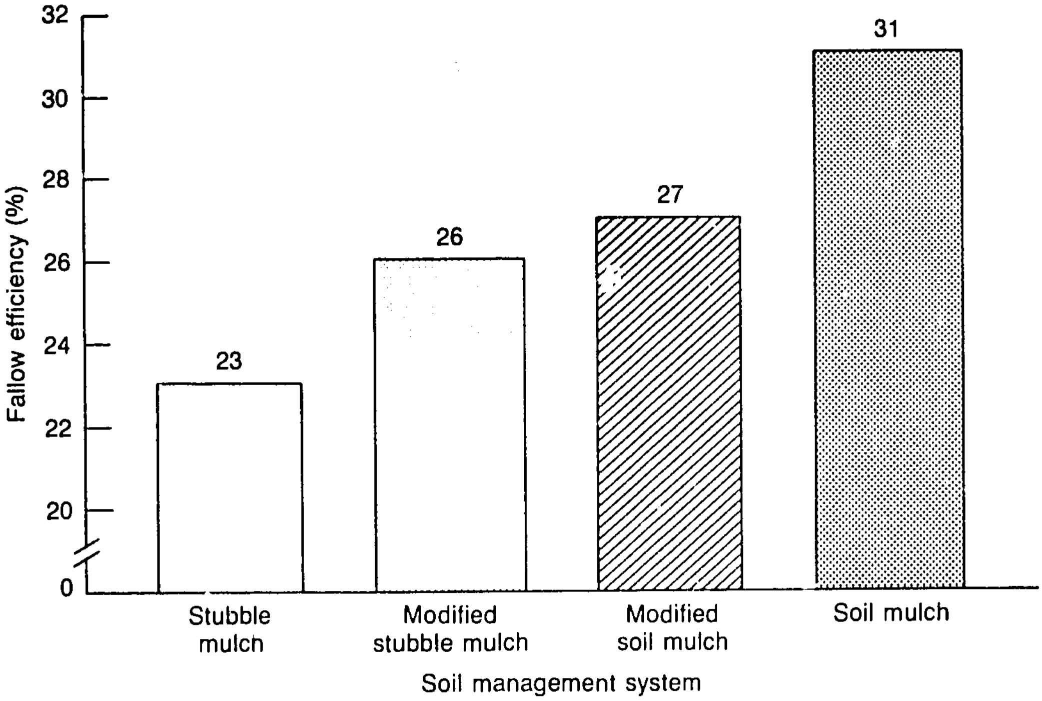


Figure 14. The Effect of Soil Management System on Average Fallow Efficiency from 1976 to 1980.

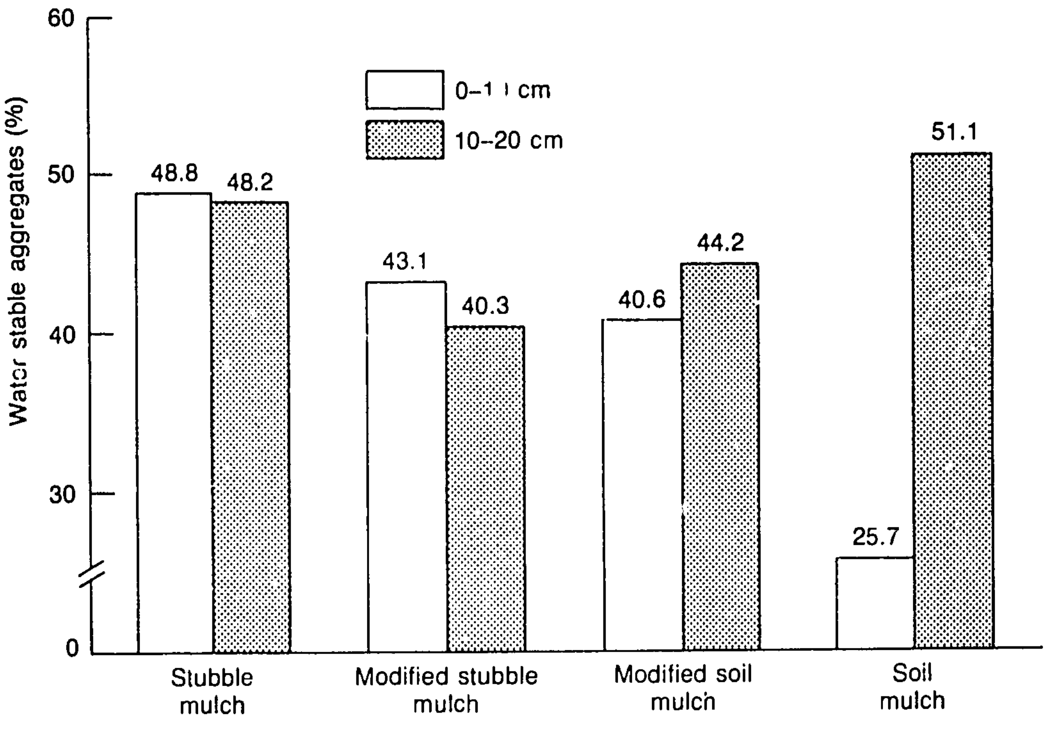


Figure 15. The Effect of Soil Management System on Water Stable Aggregates from 1975 to 1980.

Due to improved soil properties, effective moisture conservation, and weed control, the soil mulch system produced remarkable yield increases compared to the stubble mulch system. The modified soil mulch and modified stubble mulch systems produced intermediate yields. Results were strongly dependent on the year.

In the crop year efforts are made to provide efficient use of previously stored moisture. For this purpose experiments have been conducted to determine optimum seeding time and method, proper seed and fertilizer rates, optimum time and method of efficient weed control, and optimum varieties.

With these trials, a proper package of practices was developed for the fallow-wheat areas of the Central Plateau. Information was transferred to the farmers through demonstrations in farmers' fields. Figure 16 shows the effects of high-yielding varieties and the recommended management system on farmers' yields in various locations.

This work is continuing in all provinces of the Plateau. Since different components of the improved package are missing in different management locations, demonstrations are being carried out to complete the packages.

Research for Annually Cropped Areas of the Central Plateau

In 1980, a research and extension project was organized by the Ministry of Agriculture, Forestry, and Rural Affairs to utilize the fallow areas. The Central Anatolian Regional Agricultural Research Institute carried out work to determine the possible boundaries of fallow areas. For this purpose, meteorological data from a large number of locations were used to calculate an index for each location. The results of this work were (Güler *et al.*, 1981):

1) In the Central Plateau it is possible to give up the fallow practice where annual precipitation is higher than 410 mm.
2) In shallow soils annual cropping appears to be more economical.
3) The Aydeniz Aridity Index (Aydeniz, 1973) can be used to determine boundaries of fallow areas. According to this index, fallow should be practiced when its value is above 0.90.

The areas suitable for annual cropping and fallow-cereal rotation according to calculated indices are shown in Figure 17.

With the initiation of the project, research and extension for annual cropping areas has been improved. At present, lentils, chickpeas, vetch, sunflower, and cumin are grown in rotation with cereals, mainly wheat. Several institutions are conducting research to determine the most profitable crop rotations and suitable growing techniques for the crops in the rotation.

References

Abali, I. 1980. Karapinar Yöresinde Nadas-Hububat Tarim Yönteminde Uygulanacak Toprak Isleme ve Ekim Aletleri. Konya Bölge Topraksu Arastirma Enstitüsü Yayinlari.

Ask, K. 1977. Erozyonla Savas El Kitabi. Gürsoy Matbaacilik Sanayi, Ankara, Turkey.

Aydeniz, A. 1973. Tarimda verimliligin saglanmasinda önemli bir etken olan su ve sulama durumumuz. Verimlilik Dergisi Cilt 3, Sayi 1.

Basbakanlik devlet Meteoroloji Isleri Genel Müdürlügü. 1974. Meteoroloji Bülteni, Basbakanlik Basimevi, Ankara, Turkey.

Basbakanlik Devlet Meteoroloji Isleri Genel Müdürlügü. 1984. Ortalama, Ekstrem Sicaklik ve Yagis Degerleri Bülteni (Günlük-Aylik), Ankara, Turkey.

Berkmen, N. 1961. Ankara Zirai Arastirma Enstitüsü Calismalari, 1931-60. Tarim Bakanligi Ankara Zirai Arastirma Enst. Calismalari No. 4, Ankara, Turkey.

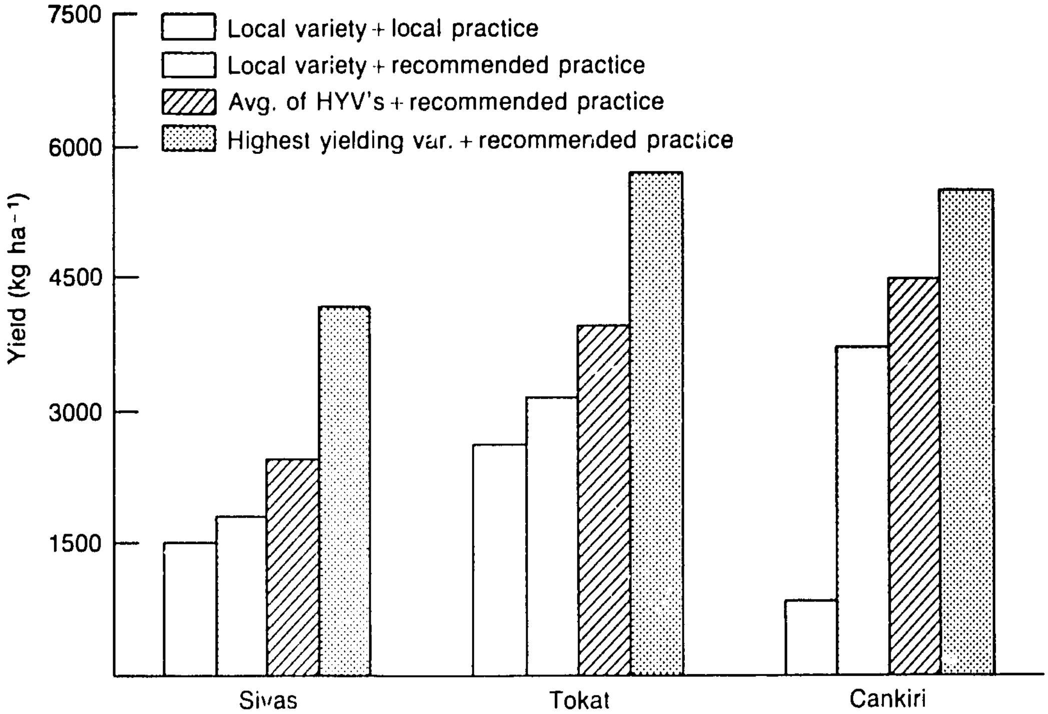


Figure 16. The Effect of Variety and Recommended Practice on Wheat Yield in Farmers' Fields.

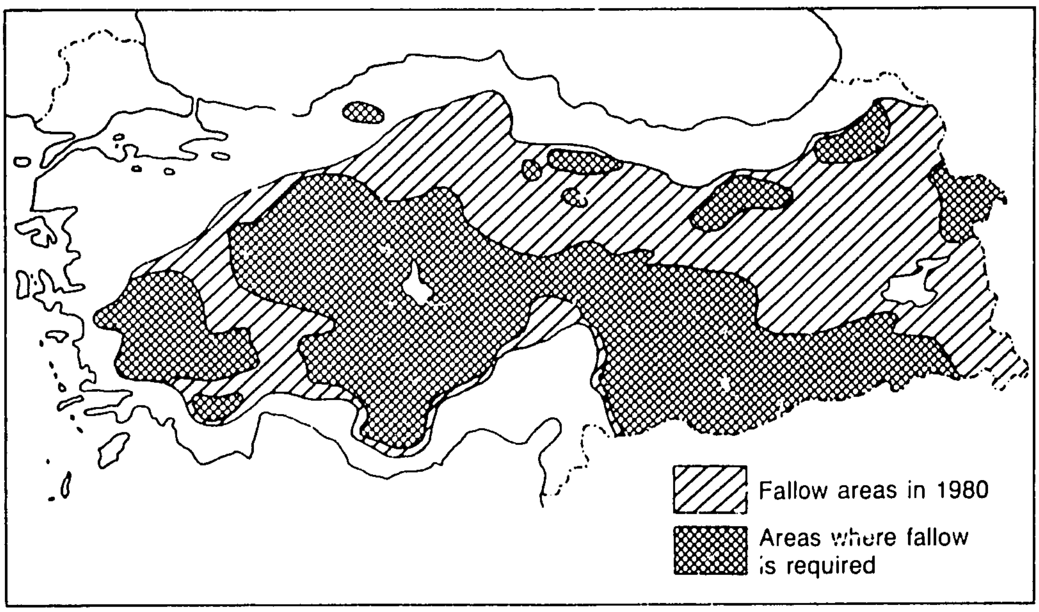


Figure 17. Areas Suitable for Annual Cropping and Fallow-Cereal Rotation.

Bolton, F., 1974. Tillage and cultural practices for wheat under low rainfall conditions. Proceedings of 2nd Regional Wheat Workshop, May 6-11, Ankara, Turkey.

Bolton, F., and D.E. Booster. 1977. Tillage, moisture conservation and water use efficiency for dryland cereal production in winter rainfall regions. Proceedings of an Int. Symposium on Rainfed Agriculture in Semi-arid Regions, April 17-22, Riverside, CA.

Cölasan, E. 1969. Türkiye'nin Yagis-Siddet-Süre Tekerrür Haritalari. Devlet Meteoroloji Isleri Genel Müdürlügü, Ankara, Turkey.

Dogan, O., B. Cimilli, and C. Güeer. 1977. Orta Anadolu Iklim Kosullarinda Nadas-Bugday Tarim Yönteminin Uygulandigi Yörelerde En Uygun Sonbahar Islemi, Aniz Bozma Aletleri, Yaz Islemleri ve Bu Aletlerle Uyusabilen Mibzer Cesitlerinin Saptanmasi Uzerinde Arastirmalar. Merkez Topraksu Arastirma Enst. Mdl. Yayinlari, Genel Yay. No. 45, Ankara, Turkey.

Durutan, N. 1982. Orta Anadolu Bugday Ekim Alanlarinda Brom (Bromus Tectorum L.)'un Yayilisi, Biyoekolojisi ve Mücadele Olanaklarinin Arastirilmasi, A.Ü. Ziraat Fakültesi, Doktora tezi, Ankara, Turkey.

Gerek, R. 1968. Dryfarming Istasyonu Tarafindan Yapilmis olan Nadas Hazirlama ve Toprak Verimliligi Denemeleri. Eskisehir Tohum Islah ve Deneme Istasyonu Nesriyat No. 6, Eskisehir.

Greb, B.W., D.E. Smika, and J.R. Welsh. 1979. Technology and wheat yields in the Central Great Plains. J. Soil Water Conserv. 34:264-268.

Güler, M., I. Unver, M. Pala, N. Durutan, and M. Karaca. 1978. Orta Anadolu'da 1972-1977 Nadas Toprak Hazirligi ve Bugday Yetistirme Arastirmalari. Orta Anadolu Bölge Zir. Aras. Enst. Mdl. Yayinlari, No. 78-1, Agron. Rap. No. 2.

Güler, M., M. Pala, N. Durutan, M. Karaca, A. Avcin, and M. Avci. 1981. Nadas alani sinirlarinin belirlenmesinde yararlanilabicek ölcütler. TÜBITAK Kuru Tarim Bölgelerinde Nadas Alanlarindan Yararlanma Simpozyumu Bildirileri, TOAG Seri No. 119, Ankara, Turkey.

Güler, M., M. Pala, N. Durutan, M. Karaca, and I. Ünver. 1983. Orta Anadolu Bölgesinde Nadas Toprak Isleme Yöntemlerinin Bugday Verimine Etkileri. Orta Anadolu Bölge Zir. Aras. Enst. Tarla Bitkileri Yet. Taknigi Sonuc Raporu, Ankara, Turkey.

Karaca, M. 1980. Nadas Toprak Islemesi Derinlik ve Yöntemlerinin Infiltrasyona Etkileri. A.Ü. Ziraat Fakültesi, Doktora tezi, Ankara, Turkey.

Köse, C., and S. Sayin. 1978. Tokat Yöresinde Egime Dik Sürüm ve Ekimin Toprak ve Su Korunumuna Etkisi. Tokat Bölge Topraksu Arastirma Enst. Mdl. Yayinlari, Rapor Yayin No. 17, Tokat.

Mizrak, G. 1983. Türkiye Iklim Bölgeleri ve Haritasi. Orta Anadolu Bölge Zirai Aras. Enst. Mdl. Teknik Yayin No. 2, Genel Yayin No. 52.

ORZA, 1984. Ciftci Sartlarinda Deneme ve Demonstrasyon Calismalari 1983-84 Gelisme Raporu. Orta Anadolu Bölge Zirai Aras. Enst., Ankara, Turkey.

Özkan, I., I. Ünver, M. Pala, N. Durutan, and M. Karaca. 1984. Cesitli Toprak Isleme Sistemlerinin Topraktaki Suya Dayanikli Agregatlarin Miktari Üzerine Etkileri. A.Ü. Ziraat Fakültesi Yilli i 1983, Cilt 33, Fasikül 1,2,3,4 (Ayri basim).

Pala, M., M. Göler, I. Ünver, N. Durutan, and M. Karaca. 1980. Orta Anadolu'da Nadas Dönemi Ilkbahar Toprak Isleme Zamaninin Bugday Verimine Etkisi. Tarimsal Arastirma Dergisi, Cilt 2, Sayi 2.

Pala, M. 1982. Yaz Toprak Isleme Derinliklerinin ve Kullanilan Araclarin Toprakta Nem ve Sicaklik Degisimine Etkileri Üzerinde Bir Arastirma. A.Ü. Ziraat Fakültesi, Doktora tezi, Ankara, Turkey.

Pehlivantürk, A., C.N. Izgin, M. Güler, I. Ünver, and M. Pala. 1977. Orta Anadolu'da 1970-76 Nadas Toprak Hazirligi ve Bugday Yetistirme Teknigi Arastirmalari. Orta Anadolu Bölge Zirai Aras. Enst. Mdl. Yayinlari, No. 77-2, Agron. Rap. No. 1.

Prime Ministry State Institute of Statistics. 1985. Statistical yearbook of Turkey. Ankara, Turkey.

Topcu, H., and I. Abali. 1979. Karapinar Rüzgar Erozyonu Alanlarinda Uygun Nadas Zamani ve Derinliginin Nem Korunumu ve Bugday Verimine Etkisi. Konya Bölge Topraksu Arastirma Enstitüsü Mdl. Yayinlari, No. 68, Konya.

Topraksu, 1980. Istatistik Bülteni Topraksu Genel Müdürlügü Program ve Planlama Dairesi Baskanligi, 1981, Ankara, Turkey.

Tüzüner, A., and M. Yörük. 1978. Orta Anadolu Kosullarinda Bugday Üretiminde Gelistirilmis Tarim Teknigi ile Geleneksel Ciftci Uygulamalarinin Karsilastirilmasi. Toprak ve Gübre Arastirma Enst. Mdl. Yayinlari, Rapor Yayin No. 14, Ankara, Turkey.

Ülgen, N., and N. Yurtsever. 1984. Türkiye Gübre ve Gübreleme Rehberi. Topraksu Genel Müdürlügü, Arastirma Dairesi Baskanligi, Yayin No. 47, Rehber No. 8, Ankara, Turkey.

Ünver, I. 1978. Nadas Toprak Islemesinde Zaman, Derinlik ve Yöntemlerinin Topragin Rutubet ve Sicaklik Degisimine Etkileri. A.Ü. Ziraat Fakültesi, Doktora tezi. Ankara, Turkey.

Yesilsoy, S. 1974. The influence of tillage practices on moisture conservation and the wheat yield in Central Anatolia. Proceedings of 2nd Regional Wheat Workshop, May 6-11, Ankara, Turkey.

A Summary of Adaptive Research and Demonstrations in the Central Anatolian Plateau of Turkey

N. Durutan, M. Karaca, M. Avci, H. Eyuboglu
Central Anatolian Regional Agricultural Research Institute, Ankara, Turkey

ABSTRACT. Since wheat is produced in Turkey primarily under dryland conditions, research priority has been assigned to dryland agriculture. The National Wheat Research Project emphasizes developing a package of suitable agronomic practices for dryland wheat and an effective extension and farmer education program to encourage its adoption. Adaptive research has resulted in recommended practices which differ with location, but generally include early tillage, early planting, and the use of herbicides. Demonstrations by county agents show that yields can be increased as much as threefold by recommended agronomic practices and fivefold with improved wheat cultivars and cultural practices.

Introduction

In Turkey wheat has been the primary crop for years, particularly in dryfarmed cropland. In order to increase the country's yields, agronomic research was started in 1926, after the establishment of the Republic. Many experiments were conducted and valuable results were obtained.

With the initiation of the National Wheat Research Project in 1969, primary emphasis was given to developing a package of practices suitable for each region and an effective extension and farmer education program.

Since most wheat is produced under dryland conditions, research priority has been given to dryland agriculture. Due to variation in annual precipitation among years and locations, drought poses a constant threat to production. In order to stabilize cereal production against unpredictable precipitation, sufficient moisture must be accumulated during the fallow period. Consequently, in the early 1970s research focused on the development of techniques for moisture conservation.

The National Wheat Research Project

The National Project brought the concept of a package of practices which comprised cultural operations from initial tillage to harvest. The achievement of increased production required the application of the entire combination of practices rather than the application of any individual practice.

Basic research was carried out at the Central Anatolian Regional Agricultural Research Institute to determine the package proper for the dryland areas of the Central Plateau. In order to hasten the transfer of newly obtained information to the farmers, special emphasis was given to adaptive research trials and demonstrations. The objectives were:

1) To test the adaptation of the results obtained from experiments conducted at the Research Institute in various locations of the Central Plateau;
2) To strengthen the communication link between research and extension;
3) To demonstrate the improved package of practices to the extension staff and to the farmers;
4) To demonstrate the wheat production potential of the Central Plateau by comparing the yields obtained from the trials with that of adjacent farmers' fields; and
5) To determine the problems responsible for low yields in the Central Plateau through cooperation with the extension service.

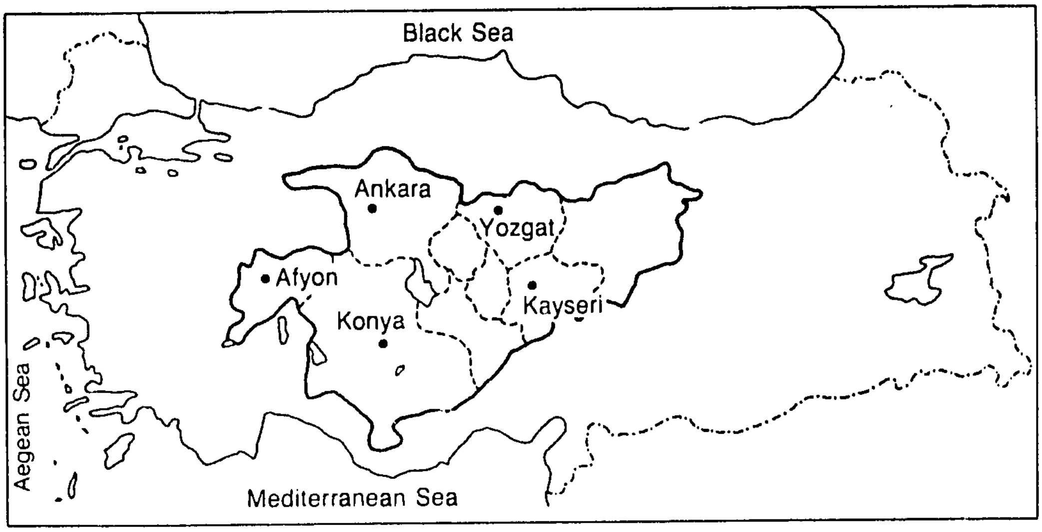


Figure 1. Central Anatolian Plateau of Turkey and the Locations Where Adaptive Research Trials Were Carried Out During 1973 to 1977.

Adaptive Research

In 1972 adaptive research trials involving various improved techniques found promising in basic research were established on farmers' fields in five provinces of the Central Plateau, Ankara, Afyon, Kayseri, Konya, Yozgat (Figure 1). In the trials, primary emphasis was given to tillage practices. The effects of the spring tillage implement and succeeding tillage implement on wheat yield were tested. After the completion of the studies, proper tillage implements were determined for each location. In these experiments, the remainder of the components of the package applied as blanket applications were the recommended practices determined through basic research.

During the period from 1973 to 1977, the highest yielding treatment determined as the recommendable system in the adaptive research trials was compared with the yields of the adjacent farmers' fields. This was done for 5 years in five provinces of the Central Plateau. The results are given in Figures 2 and 3.

As seen in Figure 2, although yield levels changed over the years, the recommended system always yielded higher than the farmers' practices. It was interesting to observe that there was a gradual increase in farmers' yield over years. The main reason for this was the adoption of the new techniques by the local farmers.

Figure 3 indicates that the recommended system always yielded more despite locational differences. The overall average yield over 5 years and five provinces was 88 percent greater with the recommended system than with the farmers' traditional practices. The data showed that with the application of the recommended system and the currently available variety it was possible to almost double yields in the Central Plateau.

Beginning in 1977, the adaptive research trials were carried out with a different approach. In the areas where a particular component of the package was misapplied, the recommended technique for that particular component was tested against the local common practice. In addition to data collection, the experimental plots were also utilized for demonstrative purposes (Figures 4, 5, and 6).

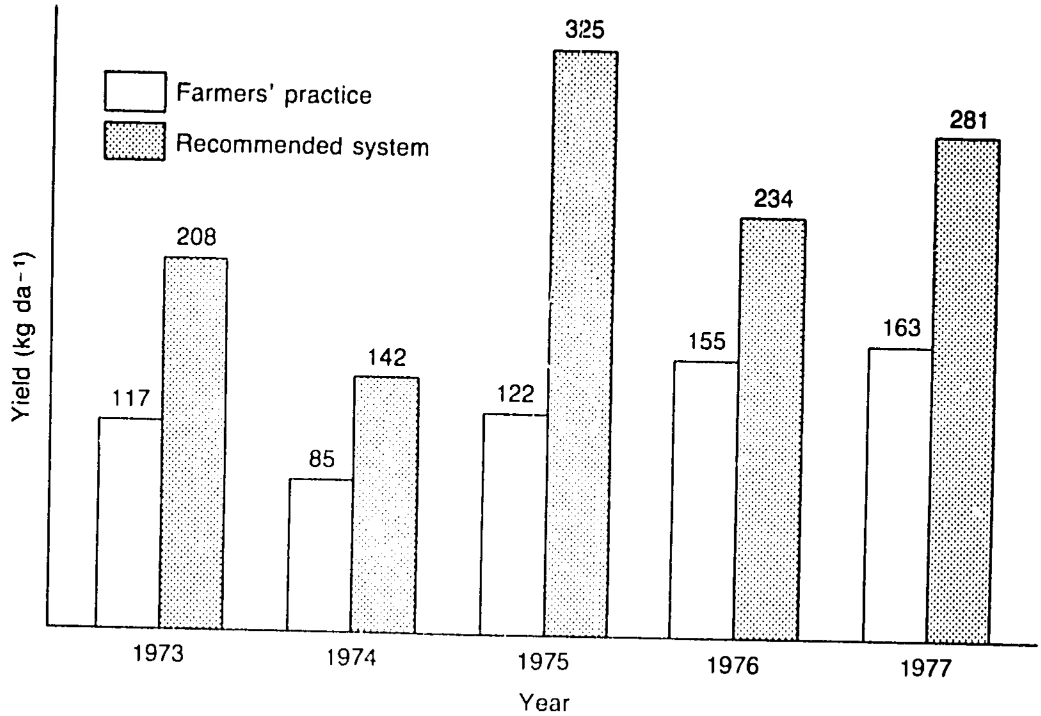


Figure 2. Annual Average of Wheat Yields on Farmers' Fields and Demonstration Plots Using the Recommended System (Average of Five Provinces).

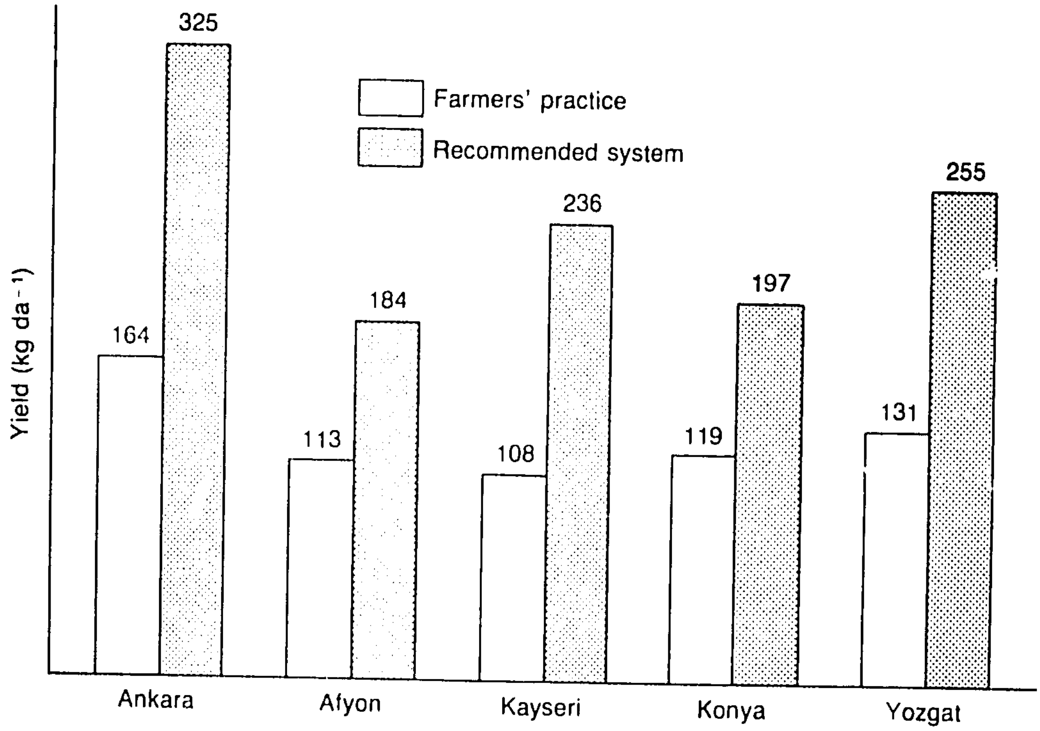


Figure 3. Five-Year Average Wheat Yields of Farmers' Fields and Demonstration Plots Using the Recommended System.

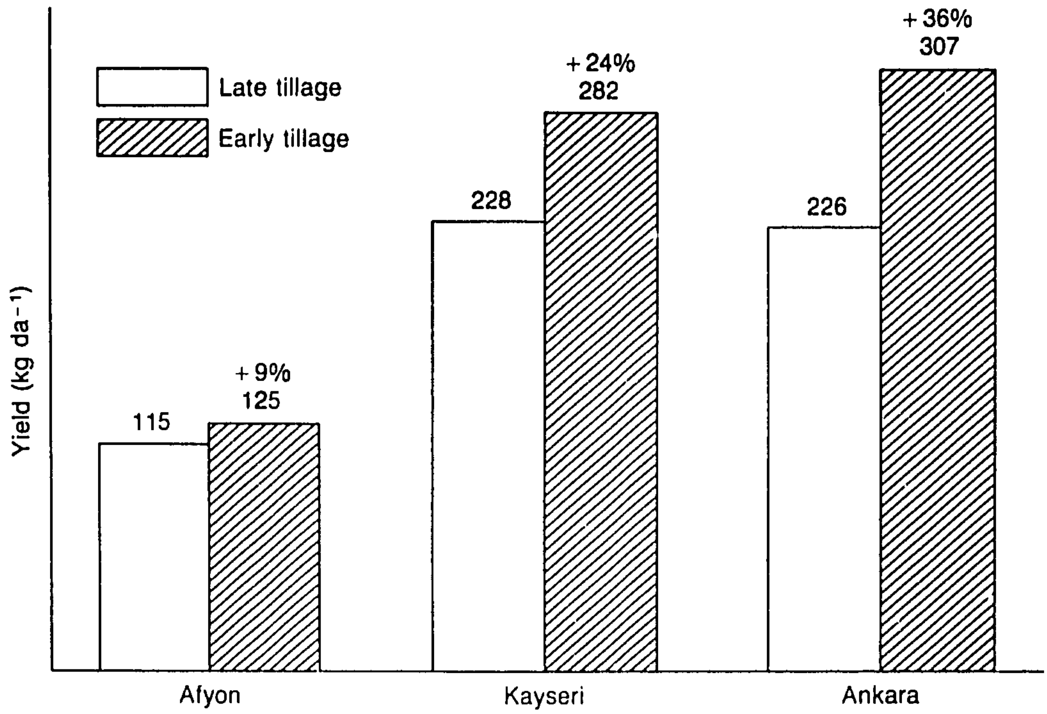


Figure 4. The Effect of Initial Tillage Time on Wheat Yield in Different Locations of the Central Plateau, 1978.

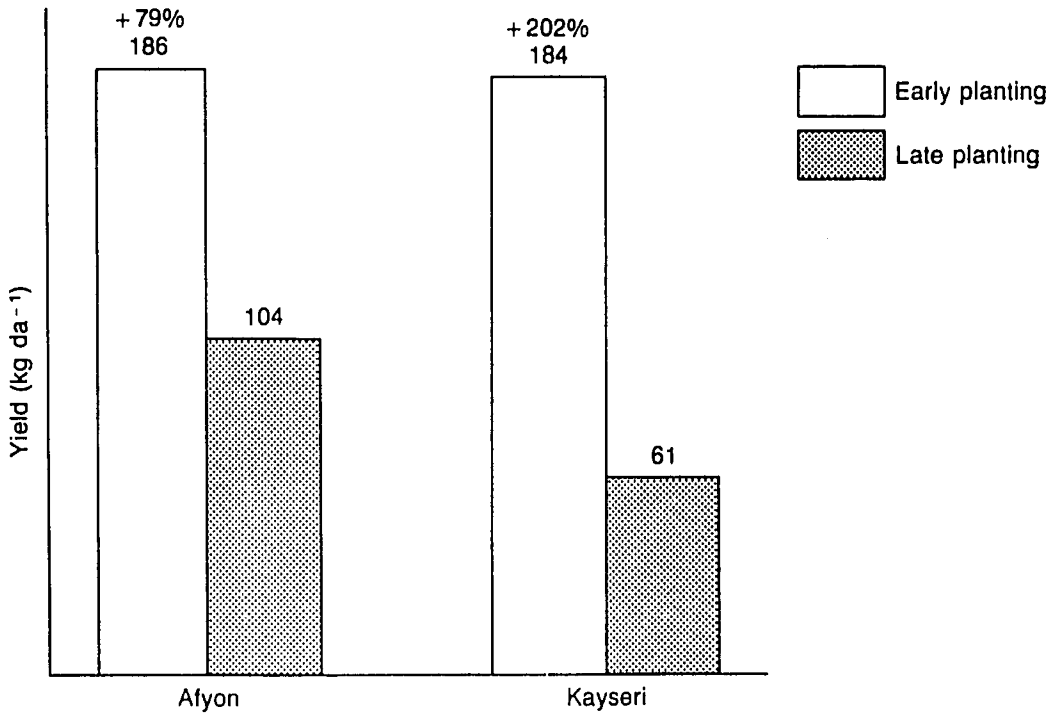


Figure 5. The Effect of Planting Time on Wheat Yield in Two Locations of the Central Plateau, 1978.

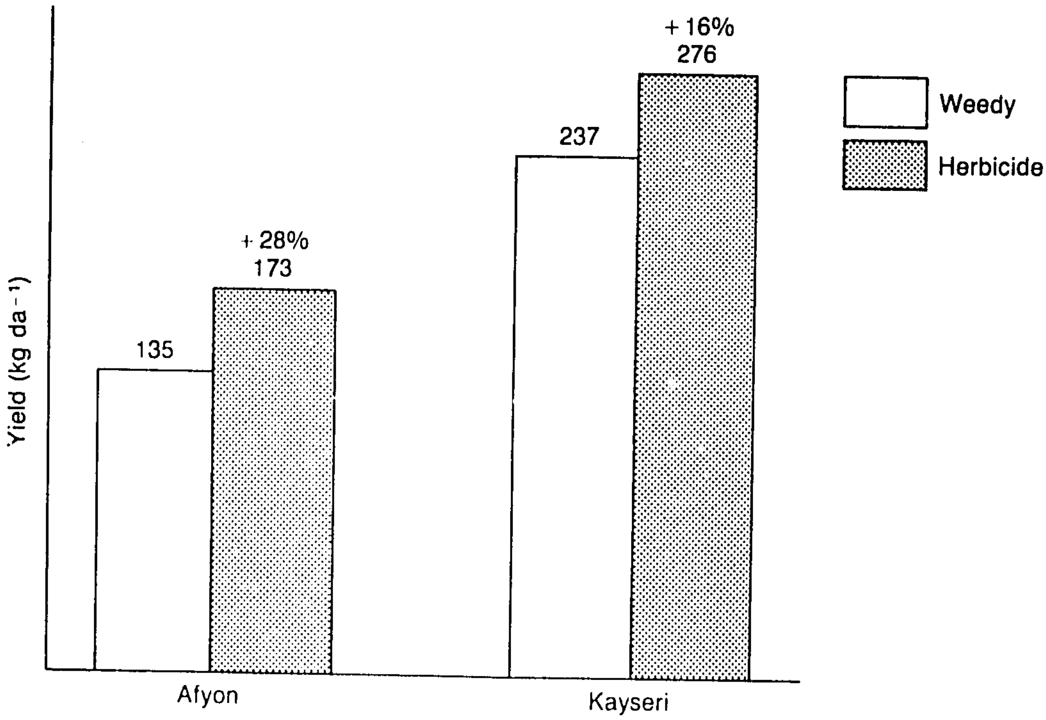


Figure 6. The Effect of Herbicide Application on Wheat Yield in Different Locations of the Central Plateau, 1978.

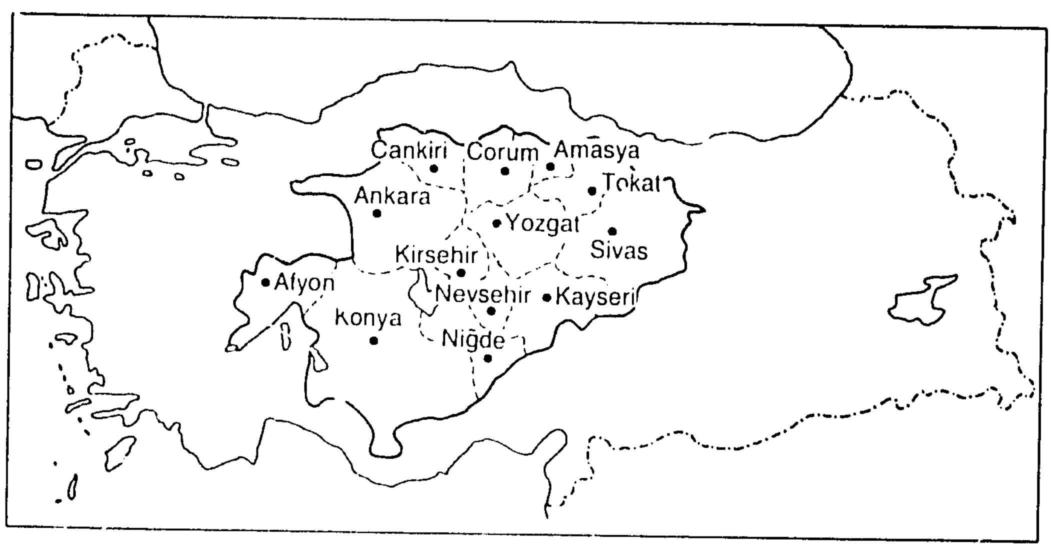


Figure 7. Provinces Where Adaptive Research Trials and Demonstrations Have Been Conducted Since 1983.

The trials for determination of optimum initial tillage time resulted in favor of early tillage. Timing was found to be important in initial tillage. Although the yield increase due to early tillage differed widely among the locations, the data showed that it could be as high as 36 percent (Figure 4).

Planting time experiments indicated the advantage of early planting (early October) compared to late planting (mid-November), a common practice among the farmers in the region. Early planting provided a yield increase of more than 100 percent (Figure 5).

Chemical weed control trials demonstrated the benefit of herbicide application. As seen in Figure 6, the average yield increase was about 22 percent. If fallow practices had not been applied properly, the yield increase due to herbicide usage would be even higher since success of the weed control in the fallow year strongly influences the weed density in the crop year. The effect of herbicide application on yield is more pronounced as the weed density increases in wheat fields.

In 1983, the study area was extended throughout the Central Anatolian Plateau (Figure 7). The adaptive research and demonstration program was carried out in 13 provinces with the inclusion of eight new ones.

Extension and Farmer Education

In the spring of 1983, meetings were organized in 13 provinces by the Research Institute. In these meetings, yield limiting factors were determined by consultation with county agents.

In order to determine the current agronomic practices in the Central Plateau, survey forms were prepared by the research specialists for the county agents. Based on the information gathered in these meetings, plus observations, several maps were prepared indicating the extent of application of various components of the package of practices. Some examples from that work are given in Figures 8 and 9.

In the meetings the need for field training of the extension staff was noted. It was agreed that to improve the practical skills of the extension personnel one demonstration would be conducted by research specialists in each province, and at every operation the county agents would attend and work with the specialists. The program was implemented smoothly.

During the spring, a one-week training program was organized at the Central Anatolian Agricultural Research Institute for the extension specialists in which recommended practices and practical clues for conducting demonstrations were given.

In the fall of 1983, demonstration plans were prepared by agronomists and sent to the provinces. Varieties used in these demonstrations were cultivars newly developed by the Research Institutes in the region. Seeds were provided by these institutes. Some results are shown in Figure 10.

As seen in Figure 10, the yield potentials of the agriculturally less developed provinces are much higher than the level indicated by the actual average yield of the provinces. It is possible to reach the potential yield levels by changing the local growing practices and the local varieties grown. First, farmers' yield levels can be increased by growing the local variety with the recommended system. The yield increase achieved in this way varied from 11 to 33 percent, depending on the yields of the particular farmer. As the agricultural level of the farmer decreases, the yield increase provided by just the change in cultural practices increases. In the case of Cankiri, the yield increase was 335 percent (Figure 10).

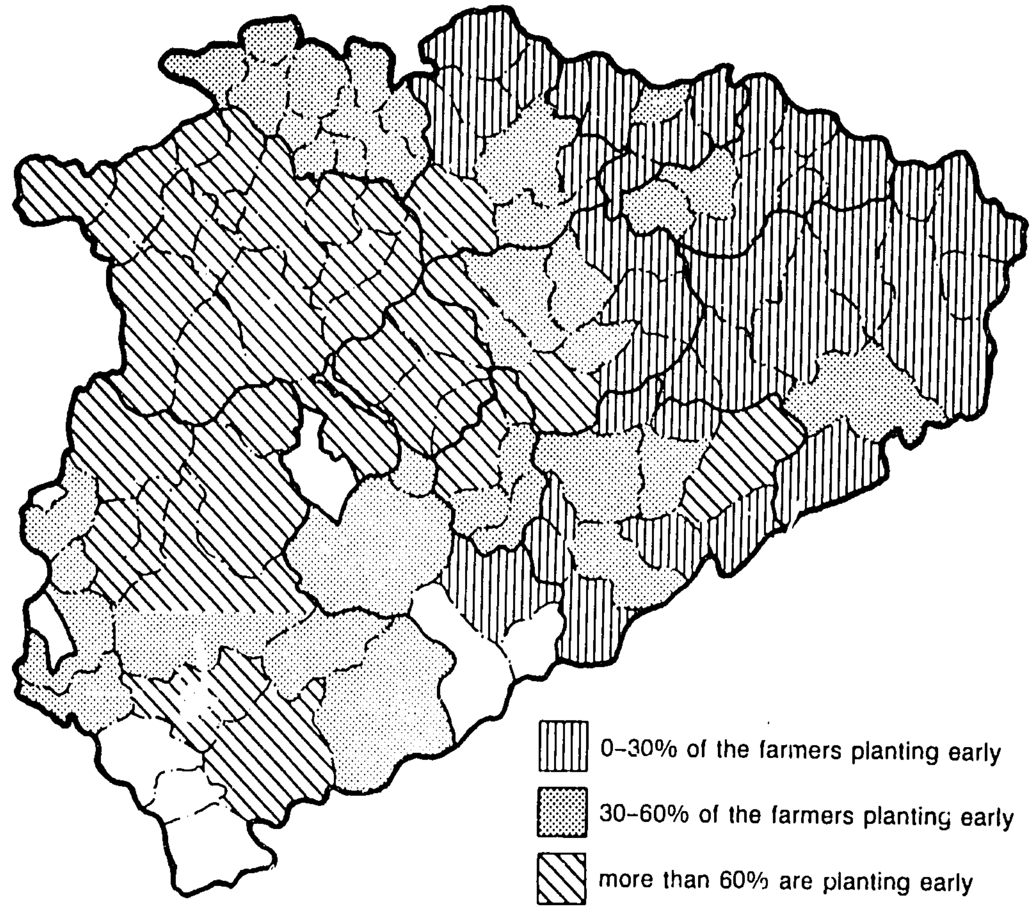


Figure 8. Early Planting Habits of Wheat Farmers at the County Level in the Central Anatolian Plateau, 1983.

As the level of the farmer increases, a significant yield increase shouldn't be expected since slight changes in the practices provide small increases. This was the case in Kayseri (Figure 10).

Second, the growing technique plus the variety can be changed. All of the high-yielding varieties (HYVs) improved for dryland conditions can provide yield increases. In the case of growing a HYV best adapted to a particular environment with the recommended agronomic system, the yield increase can be as high as 547 percent. Data showed that in agriculturally less developed areas, tremendous yield increases could be obtained by introducing the recommended system and a proper variety for that environment.

After examining the 1984 data, it was decided that in order to reach the potential yield levels in certain areas demonstration activities should be intensified. For this purpose nine types of demonstrations were planned:

1) Fallow operations: Recommended system vs. traditional practice;
2) Seeding time: Early vs. late;
3) Seeding methods: Drilling vs. broadcasting;
4) Seeding rate: Recommended rate vs. higher rate;
5) Phosphorus rate: Recommended rate vs. higher rate;

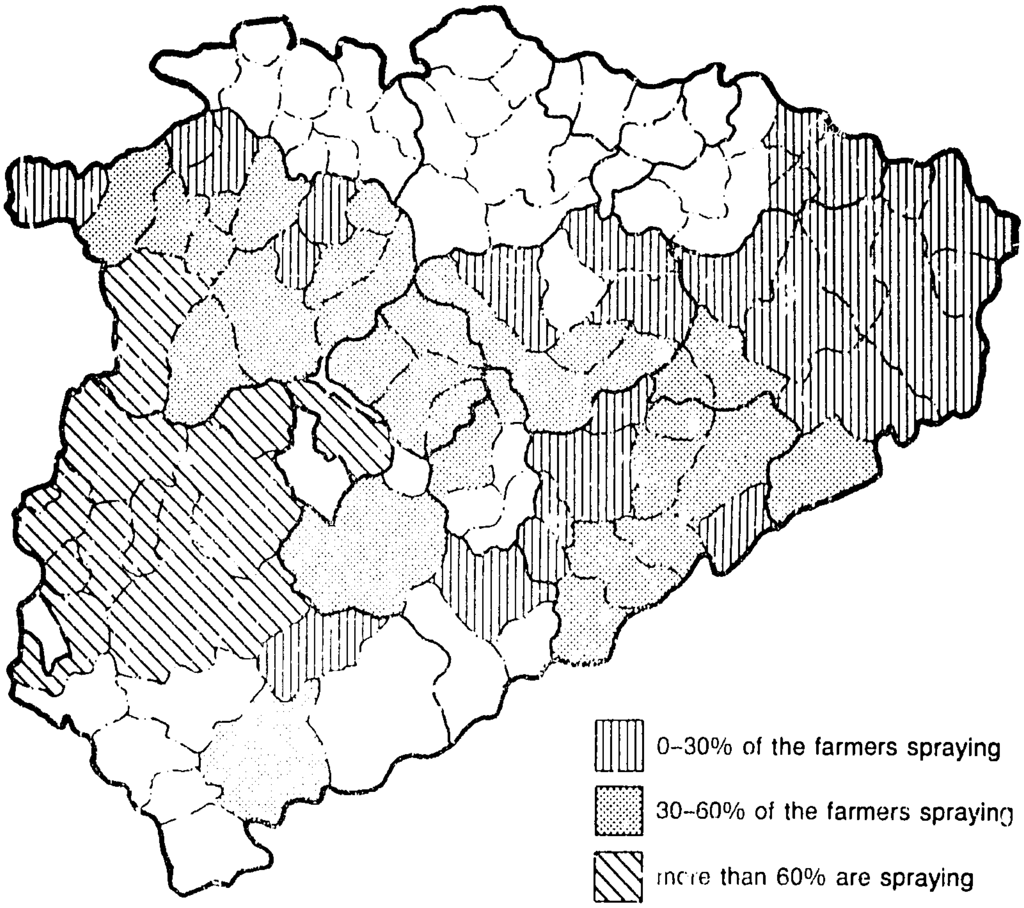


Figure 9. Herbicide Spraying Habits of Wheat Farmers at the County Level in the Central Anatolian Plateau, 1983.

6) Nitrogen rate: Recommended rate vs. lower rate;

7) Application of herbicide: Weedy vs. clean;

8) Different sources of P: DAP vs. TSP vs. 20:20; and

9) Different sources of N: Ammonium nitrate vs. ammonium sulphates vs. urea.

All of the demonstration types were planted at six locations by the Research Institute and certain types selected on the basis of local needs were carried out by county agents at various villages. The results were demonstrated to local farmers at field days.

Conclusions

The average yields of demonstrations and the farmers' fields are presented in Figure 11. This data indicated that extension activities should be intensified in these areas. However, it has to be emphasized that the yields were very low due to a severe drought in 1985.

In 1984 there was no fall emergence due to a 65 percent reduction in fall rain compared to long-term averages. In the period from June to July, the rainfall was also very low, 45 percent less than the long-term average.

It is interesting to see that the farmers' average yields were almost the same, even slightly higher than that from 1973 to 1977, despite very limited rainfall in 1984/85 crop year

(Figure 12). The comparison indicates that in recent years the farmers improved their practices to such a point that the negative weather conditions did not significantly affect the yield levels. It can also be seen in Figure 12 that the yield level of the recommended system was also higher compared to the level from 1973 to 1977. This was mainly due to the improved cultivars of the National Research Project with higher yield potential.

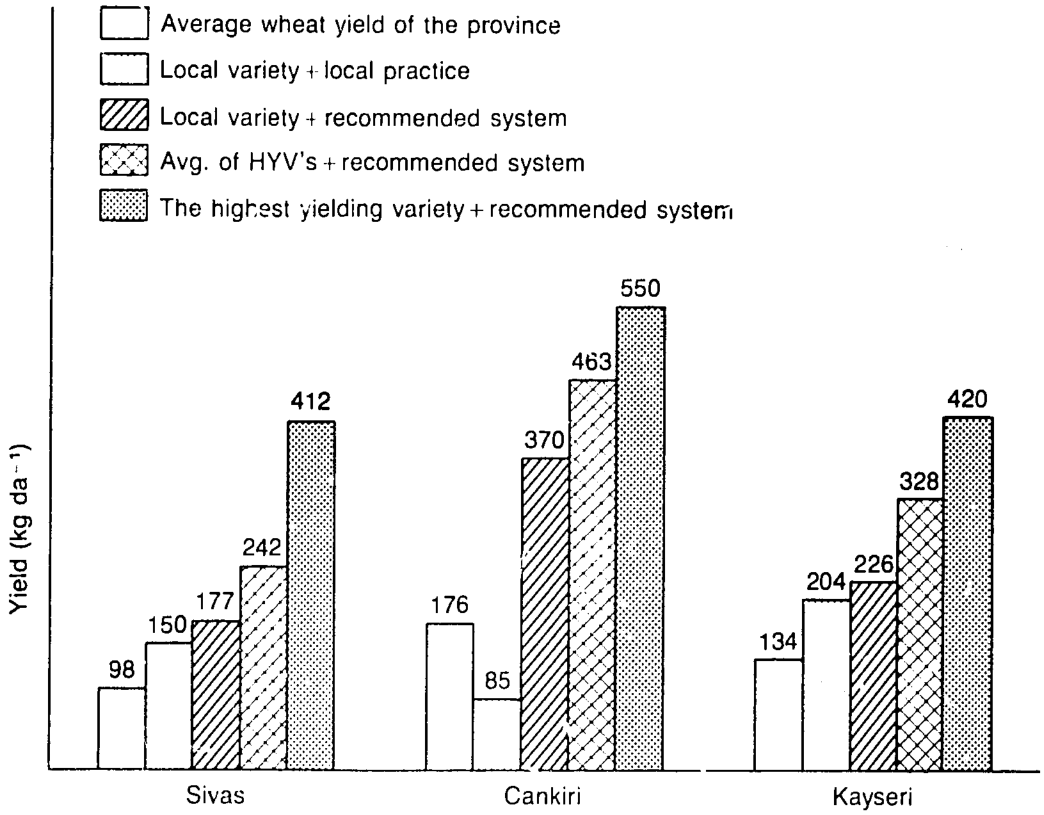


Figure 10. The Effect of Variety and Growing Techniques on Wheat Grain Yield in Sivas, Kayseri, and Cankiri, 1984.

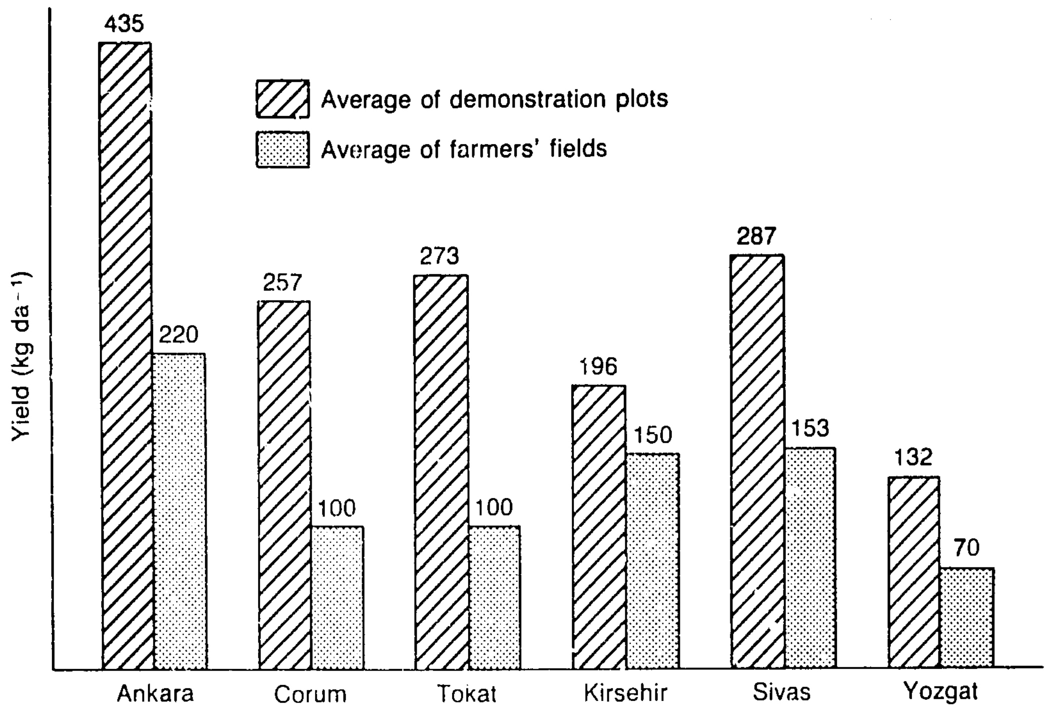


Figure 11. Yield Levels of Farmers' Fields and Demonstration Plots at Selected Sites, 1985.

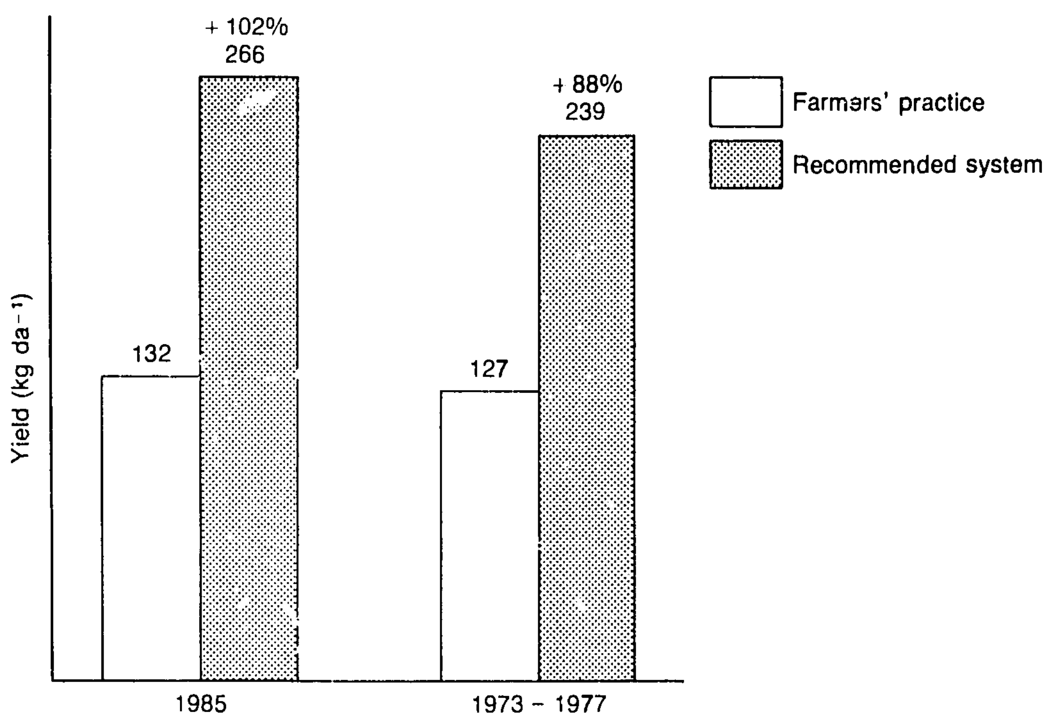


Figure 12. Comparison of Farmers' Yield Levels with the Recommended System in Two Different Periods.

A Country Paper on Soil, Water and Crop Management Systems for Dryland Agriculture in Pakistan

A.R. Khan, A. Qayyum and G.A. Chaudhary
BARD Project, Pakistan Agricultural Research Council, Islamabad, and Barani Agricultural Research Institute, Chakwal, Pakistan

ABSTRACT. Pakistan is predominantly an agricultural country. There are 4.9 million ha of cultivated agricultural land that depend on rainfall. In addition, there are another 10 to 12 million ha of arid range land. Some 14 to 15 million people eke out a subsistence living in these rainfed (barani) lands. There is no doubt that by improving management of these areas and employing appropriate technology productivity can be greatly increased.

It has been established that yield increases of 2 to 4 times that normally obtained with traditional methods can be obtained for wheat, groundnuts, pulses, maize, and other crops by adopting an improved package of technology. This would include: 1) better varieties of crops adapted to rainfed conditions; 2) better and timely cultivation for moisture conservation; and 3) the use of balanced fertilizers at the right times.

More sophisticated agronomic practices, as well as agricultural machinery, are needed to improve moisture conservation. In addition, a shift in cropping patterns may be desirable in order to bring about significant improvements in agricultural production.

Land and water are great natural resources in Pakistan. The projects undertaken have helped to manipulate these resources for greater productivity. Useful information has been gathered on the use of macro- and micronutrients to improve soil fertility, moisture conservation, and cropping systems for dryland areas of Pakistan.

Introduction

Pakistan is situated between latitudes 24° and 37° N and longitudes 62° and 75° E. It stretches over 1600 km from north to south and 885 km from east to west with a total area of 796,000 km^2 and has a subtropical, semiarid climate.

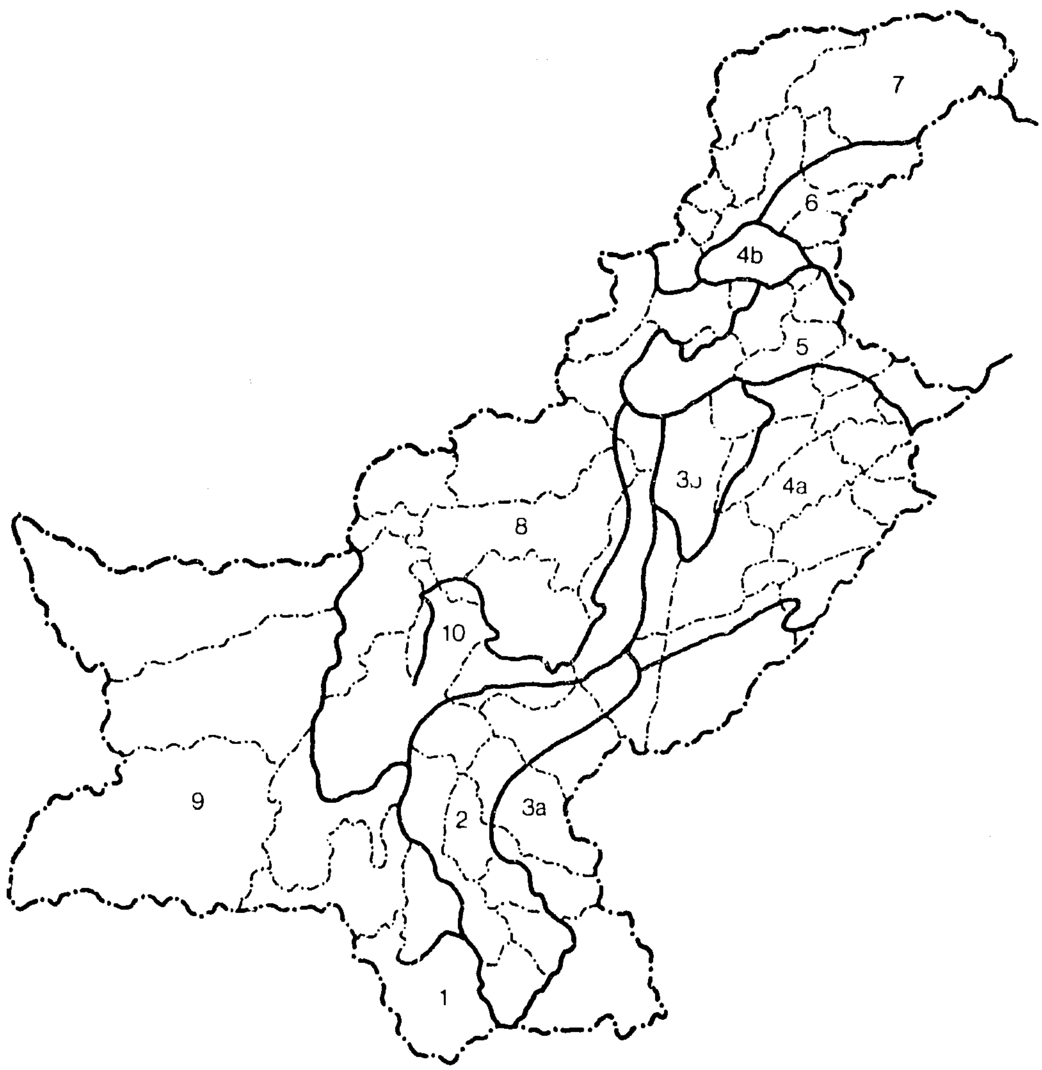
Agriculture is the predominant economic activity of the people of Pakistan. It accounts for 29 percent of the Gross Domestic Product (GDP), provides jobs for 55 percent of the labor force and supports 70 percent of the population directly or indirectly. Its share in the foreign exchange earnings from the export of agricultural raw materials and processed goods from the agro-based industries is 80 percent.

Agriculture in Pakistan is complex and diversified in terms of climatic conditions, soil heterogeneity, farming systems, and production patterns. Agricultural activities are influenced by an alpine-type climate at high elevations, extreme weather in the plains, and milder subtropical conditions in the South. Agriculture varies from irrigated to arid farming and is further characterized by great diversity in the size of holdings, ranging from very small farms to fairly large size acreages and ranches. Suitable climatic conditions, vast areas of deep soils, favorable topography and water resources allow production of wheat, cotton, rice, sugarcane, oilseeds, maize, millets, pulses, tobacco, fruits and vegetables, and many minor crops (Chaudhri, 1985).

Agroecological Zones

Only 25 percent of the total area of 79.6 million ha is cultivated (20.4 million ha). Irrigated and barani (rainfed) areas constitute 76 percent (15.5 million ha) and 24 percent (4.9 million ha) of the total, respectively. The average farm size is 5.3 ha. In addition there are another 10 to 12 million ha of arid range lands.

Pakistan is divided into ten ecological zones on the basis of physiography, geology, climate, agricultural land use and water availability, research infrastructure, and population (Figure 1).



1	Indus delta	6	Wet mountains
2	Southern irrigated plain	7	Northern dry mountains
3	Sandy desert (a & b)	8	Western dry mountains
4	Northern irrigated plain (a & b)	9	Dry western plateau
5	Barani lands	10	Staiman piedmont

Figure 1. Agroecological Regions of Pakistan (PARC, 1980).

Rainfall and Temperature

Annual rainfall ranges from 125 mm in the extreme southern plains to 500 to 875 mm in submountainous areas and the northern plains. Seventy percent of the total rain falls as heavy downpours in summer from July to September and 30 percent falls in winter. Except in the mountainous areas, the summers are very hot with a maximum temperature of more than 40 °C, and the winters are mild with a maximum temperature around 20 °C and the minimum a few degrees above freezing (Government of Pakistan, 1979).

Soil Conditions

The Soil Survey of Pakistan has done excellent work in Pakistan. Valuable information was collected and made available to researchers, extension workers, and planners in the form of reports, maps, bulletins, and other publications. This information can be the scientific base for improving agricultural practices. The Soil Survey of Pakistan has identified seven categories of land, determined by soil characteristics and moisture

Table 1. Land Capability Classes in Pakistan (NFDC, 1982).

Land Capability Class	Area	Soil Type
	million ha	
Very good agricultural land	5.0	Loam and silt loam irrigated soils.
Good agricultural land	6.5	75% clay loam to clay; 75% sandy/saline.
Moderate agricultural land	4.3	One million ha irrigated; salinity with minor problem of sodicity. About 2 million ha under dry farming. Rest uncultivated.
Poor agricultural land	1.7	Sandy and salinity problem.
Good grazing land	0.4	
Poor grazing land	4.7	Half mountains and sandy deserts and other half problem of erosion.
Agriculturally unproductive land	6.1	Sand dunes, strong saline, sodic soils.

availability, and has classified them as to land capability (NFDC, 1982). These land capability classes are shown in Table 1.

Soil Fertility

The soils are alkaline, with pH ranging from 7.8 to 8.1, and calcareous (8 percent free $CaCO_3$ content). They are poor in nitrogen. The organic matter content is usually less than 1 percent and about 90 percent of the soils are deficient in phosphorus. There is information available in the country on the response of field crops to nitrogen and phosphorus.

The concentrations of the macro- and micronutrients measured frequently in Pakistan soils appear in Table 2.

Problems and Constraints

The dryland area is presently being managed at extremely primitive levels of technology. But there are bright possibilities of securing manifold increases in agricultural production by the application of more productive and appropriate technologies. There are many constraints to progress in dryland agriculture which will be mentioned under specific topics. However, a few of the most important soil, water, and crop management problems/constraints follow.

Table 2. Concentrations of Nutrients Frequently Measured in Pakistani Soils (NFDC, 1985).

Nutrient	Concentration	Limit	Extractant†
N	0.08%	Lowest	
P	6 mg l^{-1}‡	Lowest	$NaHCO_3$
K	225 mg l^{-1}	Medium	CH_3COONH_4
Ca	4000 mg l^{-1}	Sufficient	-do-
Mg	4000 mg l^{-1}	Medium	-do-
Mo	0.2 mg l^{-1}	Medium	NH_3-Oxalate
	0.6 mg l^{-1}	Highest	Oxalic acid (pH corrected)
B	0.7 mg l^{-1}	Medium	Hot water
Cu	5 mg l^{-1}	Medium	AO-OA + EDTA
Fe	110 mg l^{-1}		-do-
Mn	10 mg l^{-1}	Low	DTPA
Zn	2 mg l^{-1}	Low	AAAc + EDTA
	0.8 mg l^{-1}	Low	DTPA
	2 mg l^{-1}	Low	-do- (pH corrected)

† AAAc, Acid Ammonium Acetate; EDTA, Ethylene diaminetetraacetic acid; AO-OA, Ammonium acetate-oxalic acid; DTPA, Diethylene triamine pentacetic acid.
‡ For conversion of mg l^{-1} into ppm multiply by 1000.

Soil Management

Erosion. Wind and water erosion constitute two of the major problems of the land. Estimates of losses of land from erosion in Punjab province vary from 4800 to 12,000 ha per year. Wind erosion, has led to desertification of vast areas in the country where rainfall is low, summer temperatures are high, and the soil is loose and sandy. Dust storms and shifting sands damage crops, choke waterways, and leave behind infertile, sandy wastes. Water erosion is also severe. Millions of tons of fertile topsoil get washed away to the sea and silt rivers and irrigation structures. The barani tract presents a stunning picture of sheet and gully erosion.

The basic problem is one of restoring the ecological balance and involves numerous adjustments which only an enlightened and informed approach can bring about. In fact, there is great danger in disturbing such lands by mechanical means without simultaneously implementing carefully planned land use and water management schemes. The gullied land in its natural state is more or less stable, but when disturbed by land-leveling, is subjected to active erosion (Government of Pakistan, 1979).

Low Soil Fertility. Low soil fertility is the most important problem of the barani tract. It is the cause of low crop yields, resulting in food deficits and prevailing poverty. On the basis of 8,000 soil samples, 95 percent showed deficiencies in nitrogen, 75 percent in phosphorus, and 10 percent in potassium. Thus, all soils are short of essential nutrients, particularly nitrogen. In areas where groundnut is cultivated, a rapid depletion of phosphorus from the soil takes place; unless phosphatic fertilizers are used, crop yields decrease significantly. The soils are low in organic matter because of deforestation, overgrazing, and removal of most of the manure for fuel. No part of a crop is returned to the soil. Even the stubble is grazed by the livestock and an exhausting cropping pattern emphasizing cereals is practiced. Almost 50 percent of the land is fallow and the lack of ground cover permits erosion of the soil. The hardpan created by the continued use of the inefficient country plow exacerbates runoff and results in low fertility levels. The proportion of leguminous species in the crop rotations is very small, although the potential for growing soybeans, pulses, groundnuts, and other soil-enriching leguminous crops is great. The adoption of more suitable cropping patterns which would include leguminous fodders such as the ley-farming system practiced in Australia, could add 60 to 80 kg of nitrogen ha^{-1} annually to the soil by nitrogen fixation.

Most of the dung and droppings from livestock, an excellent source of soil nutrition, are presently wasted or burned for fuel. The recycling of manure and other organic matter could provide the major part of fertilizer needed in the area. Very cheap bio-gas plants, both farm and village community size, have successfully evolved for the fermentation and conversion of farmyard manure and other biological materials into methane gas and residual sludge, an excellent fertilizer. Hundreds of thousands of these bio-gas plants are in operation in India, China, and the Philippines.

Salinity and Waterlogging. Large areas in Pakistan have severe salinity and waterlogging problems. Salinity ranks high among a multitude of problems with which agriculture in Pakistan is confronted. Of 15.5 million ha of irrigated land, 25 percent is salinized to varying degrees on the surface. Salinity and sodicity affect 38 percent of arable land. Even the best agricultural land is being rendered unfit for cultivation at a rapid pace every year due to salinity and waterlogging.

The main cause of salinity and sodicity is the shallow, saline groundwater table. About 6.6 million ha are affected by waterlogging and 55 percent of the total area in the country has water tables within 3.05 m of ground surface. Fourteen percent of this area is poorly drained with water tables ranging from 0 to 1.52 m (Zia and Khan, 1985).

Water Management—Water Losses

Water is one of the major constraints to agricultural production in the barani lands and effective water management is perhaps the biggest challenge in producing rapid yield increases. Although total rainfall in many areas is adequate for crop production, the seasonal pattern of precipitation often does not coincide with plant growth requirements. Great difficulties arise from the variability of the rainy season, causing uncertain and intermittent water supplies to crops. Periodic droughts result in the reduction of grazing and losses to livestock. Much of the rainfall is lost through runoff, estimated to be as much as 50 percent. If the loss is assumed to be 25 percent of the average precipitation, it approximates 1.2 million ha ft of water when extended to all of the barani crop land. Extremely effective water harvesting techniques have been developed in Australia, the United States, and a number of other countries. Such technology needs to be adapted to conditions in the various ecological zones of the barani lands.

Crop Management

The factors which determine crop production are area and yield per unit area. The cultivated area is determined by overall economic considerations, whereas the yield is affected primarily by irrigation, crop variety, and agronomic practices.

Three yield levels are recognized: experiment station yields, potential farm yields, and actual farm yields or farmer's average yields (Figure 2). The yield gap between the experiment stations and the potential farm yields is due to physical factors (environmental change), whereas the gap between the farmers potential and their average yield is due to biological and socioeconomic constraints. Biological constraints contribute 60 percent to the yield gap and socioeconomic constraints, 40 percent (Biggs, 1981). The results of a

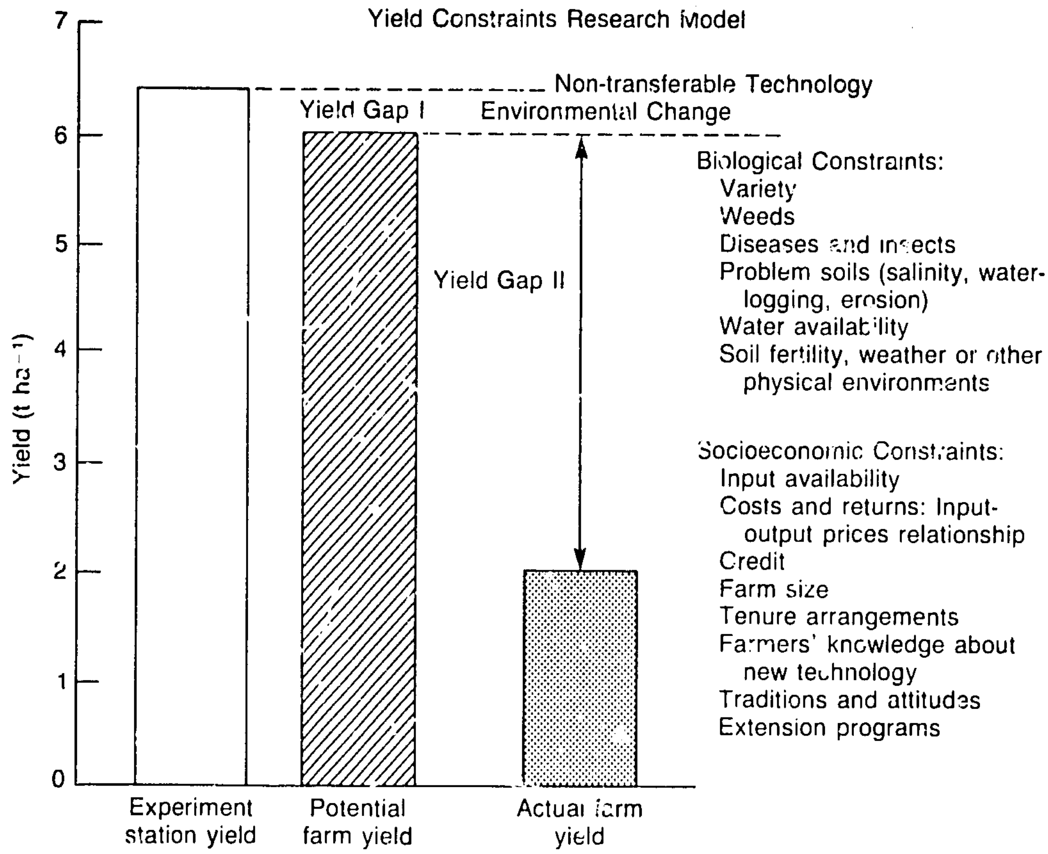


Figure 2. Wheat Yields from On-Farm Experiments (NARC, 1985).

research study on constraints to agricultural production in Pakistan, presented in Table 3, indicate that fertilizer, weeding, and variety greatly influenced crop yields in Pakistan (Malik, 1981). There are considerable yield gaps between the yields obtained with the recommended inputs and the farmers' inputs.

The yield gap between the average yield and the yield obtained by the progressive farmers caused the Pakistan Agricultural Research Council (PARC) to try to transfer technology at the farm level. They selected a district and ensured joint collaboration of all the related agencies within that area, i.e., research, extension, irrigation, credit, fertilizer distribution, district administration, etc. In one model district, an average rice (cv. IR-6) yield of 6.8 t ha^{-1} was obtained in the villages during the 1979-80 season; the highest yield was 9.0 t ha^{-1} in contrast to an average yield of 3.4 t ha^{-1} in the project area for the previous year (Amir, 1979). A similar approach was followed in Gujranwala district during kharif 1980 with success. This approach is also desirable for barani areas.

This approach has highlighted the fact that it is not the alleviation of biological constraints alone which can increase crop productivity, but the management of the technology at the farm level is also limiting. The yield gap between the average yield and the yield obtained with improved crop production technology is obviously high and can be bridged by the application of improved technology and management at the farm level. The biological constraints can be overcome with the package of improved technology. It is, however, the physical and management constraints such as availability of inputs at the right time and place, credit facilities, supply of electricity, dissemination of knowledge, etc., which do not allow the entire production system to function properly.

Table 3. The Yield Gap between Recommended Technology Inputs and Farmers' Inputs (Soil Fertility and Soil Testing Institute, 1981).

Conditions	Yield		Yield Gap	Yield Contribution			
	Recommended Inputs†	Farmer's Inputs‡		Fertilizer	Variety	Weed Control	Residual
	....	....	....	*kg ha⁻¹*	....	....	....
Irrigated (30)§	4010	2790	1250	703 (56%)	201 (16%)	260 (21%)	86
Barani (5)	2280	1010	1270	644 (51%)	462 (36%)	160 (13%)	0

† Recommended inputs included the use of the recommended variety (PARI-73), fertilizers 114:84:0 ($N:P_2O_5:K_2O$) kg ha^{-1}, and and complete weeding.
‡ Farmer's own variety, fertilizer, and weeding practices.
§ No. of trials conducted in farmers' fields

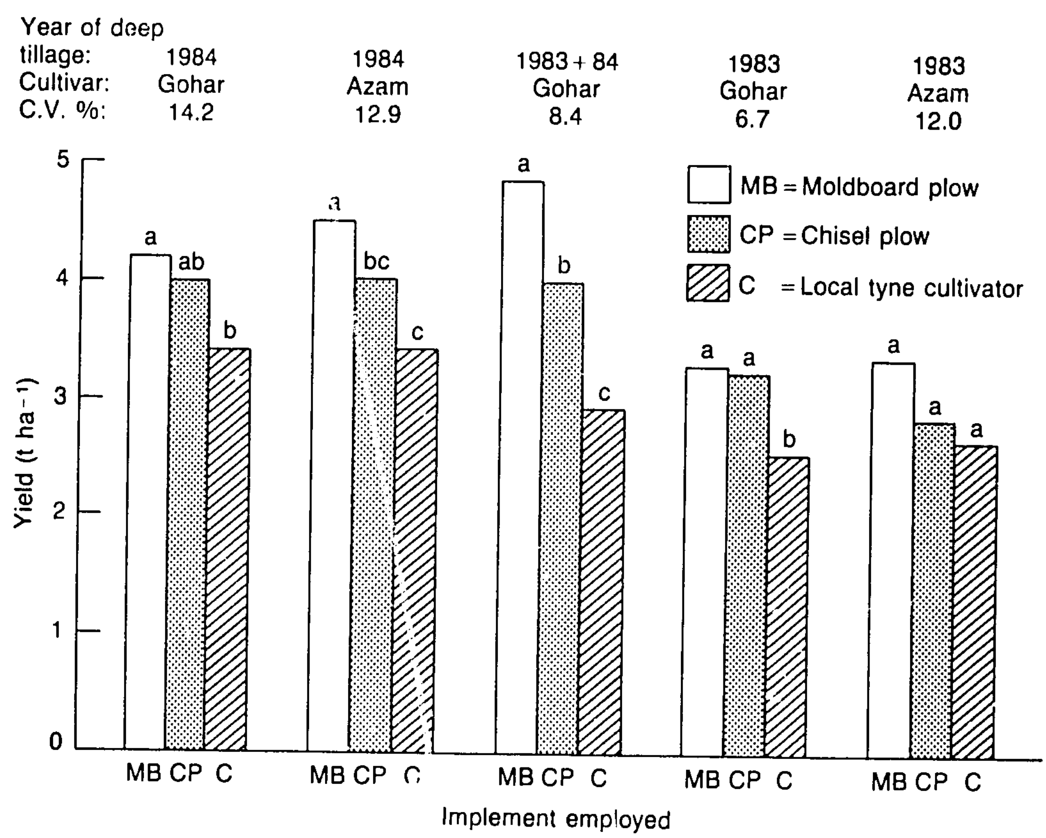


Figure 3. Effect of Implements and Deep Tillage on Yields of Grain from Two Maize Cultivars at Haripur, 1984. Columns Within a Trio Headed by the Same Letter are Not Different at the 5% Level of Probability.

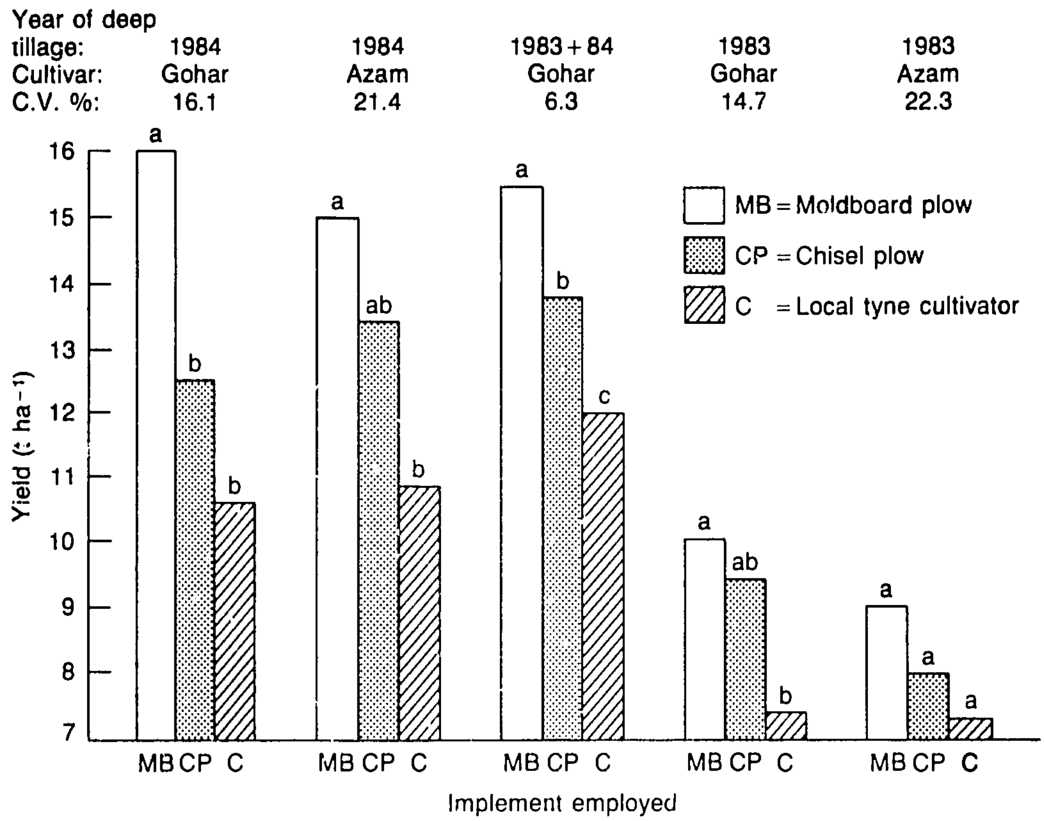


Figure 4. Effect of Implement and Deep Tillage on Yields of Stalk from Two Maize Cultivars at Haripur, 1984. Columns Within a Trio Headed by the Same Letter are Not Different at the 5% Level of Probability.

Strategies Used in Production Improvement

Recently there has been an increased emphasis placed on the development of barani areas. The most limiting factors have been identified: a need for improved cultivars of the important crops; availability of a continuing source of quality seed; and information on optimum fertilizer rates, weed control, and moisture conservation. Appropriate farm machinery is essential if the dryland farmer expects to maximize returns from his meager resources. Research and development have been conducted in different parts of the country. Pertinent research findings follow.

Soil Management

Increased Production Through Deep Tillage. To determine the benefits of deep tillage, land was deep-tilled in June 1984 with the moldboard plow penetrating to 25 cm and the chisel plow to 45 cm. Nine new fields were deep-tilled in 1984 and four fields that had been deep-tilled in 1983 were tilled with the traditional tractor-mounted tyne cultivator in 1984. Fields that had received only traditional tillage served as controls.

Figures 3 and 4 show that the effects of tillage equipment are consistent over maize cultivars for both stalks and grain yield. In all instances the moldboard plow treatment had the highest yields. The deep tillage effect was complementary when practiced in both 1983 and 1984. When deep-tillage in 1983 was followed by traditional cultivation in 1984, the benefits were no longer evident. From these results it appears that the moldboard plow is the best implement and it should be used annually since residual effects are limited. These results suggest that the greatest benefits accrue when the land is deep-tilled the year that the crop is planted.

Table 4. Comparison of Yields of Maize (cv. Azam) 1984 Planting After Moldboard Plowing (30 cm) and Traditional Tillage with Tractor-Mounted Cultivator at Haripur.

Preseeding Treatment-1984	Tillage Treatment-1983	
	Moldboard Plow	Cultivator
	kg ha^{-1}	
Moldboard plow	5,700	4,570
Cultivator	3,290	3,220

Land preparation prior to seeding is always a very important practice in farming, but particularly under barani conditions where moisture conservation is so important. Traditionally all tillage, primary as well as secondary, has been done with either a tractor-mounted cultivator with chisel tynes or the bullock drawn plow with a pora-funnel. Frequent passes are made with the implement often resulting in significant moisture loss despite subsequent planking.

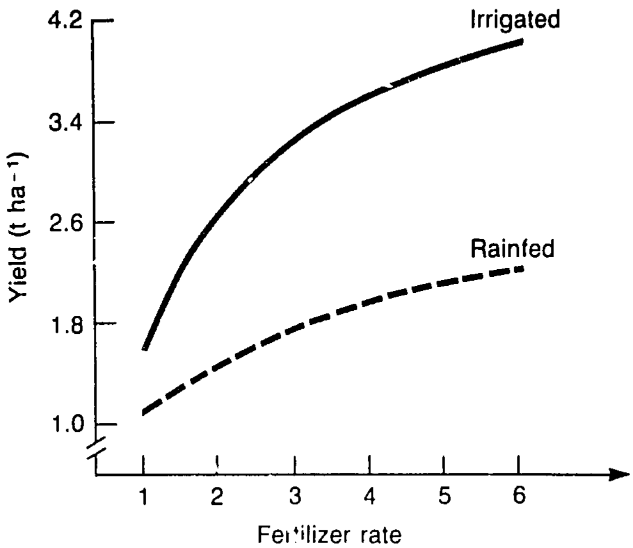
In our experiments with maize, deep tillage has proven to be very beneficial, especially with a moldboard plow. Hobbs (PARC, 1985) has shown a similar beneficial effect on wheat production. Maize yields were greater from land that had been deep plowed two consecutive years than when the soil was deep plowed in only the current year or tilled with the traditional cultivator (Table 4).

Soil Fertility. The usual practice of fallow with leguminous weeds helps to maintain the fertility of the soil but the benefits are low and the cost high. It is estimated that fallowing the land for one year with frequent cultivation results in an additional 45 kg ha^{-1} nitrogen in the soil (Government of Punjab, 1976). The practice is even less effective in increasing phosphate levels. There is great potential for using fertilizers to increase agricultural production in rainfed areas. Fertilizer experiments conducted in rainfed areas have shown that crop yields can be increased substantially by applying proper levels of balanced fertilizers.

Fertilizer tests were established on farmers' fields. The results of 119 rainfed wheat trials from 1970 to 1977 showed a 120 percent yield increase from 1060 to 2330 kg ha^{-1} with 60:60:30 (N: P_2O_5:K_2O) kg ha^{-1} application. The response curve is shown in Figure 5.

Using the yield data from no-fertilizer fields, fertilized wheat fields, and yield contest farmers (combining fertilizer in a package of improved technology with good management) the achievable yield potential in both irrigated and rainfed wheat in Pakistan can be estimated. Figure 6 shows that a 130 to 144 percent increase in yield could be attributed to fertilizer and another 43 to 54 percent increase to good management under rainfed and irrigated conditions. Proper management, then, is both a challenge and a promise for the future (Saleem, 1983).

There are two important measures of the profitability of fertilizer use: the value-cost ratio (VCR), i.e., the ratio of the value of the additional wheat yield to the cost of fertilizer; and net return, i.e., the value of the additional wheat yield minus the cost of fertilizer.



Fertilizer Rates (kg ha-1)

	Irrigated	Rainfed
1	0 – 0 – 0	0 – 0 – 0
2	56 – 56 – 0	30 – 0 – 0
3	112 – 62 – 0	30 – 30 – 0
4	112 – 112 – 0	60 – 30 – 0
5	168 – 112 – 0	60 – 60 – 0
6	168 – 112 – 62	60 – 60 – 30

Figure 5. Response Curves for Irrigated and Rainfed Wheat in Pakistan (Saleem, 1983).

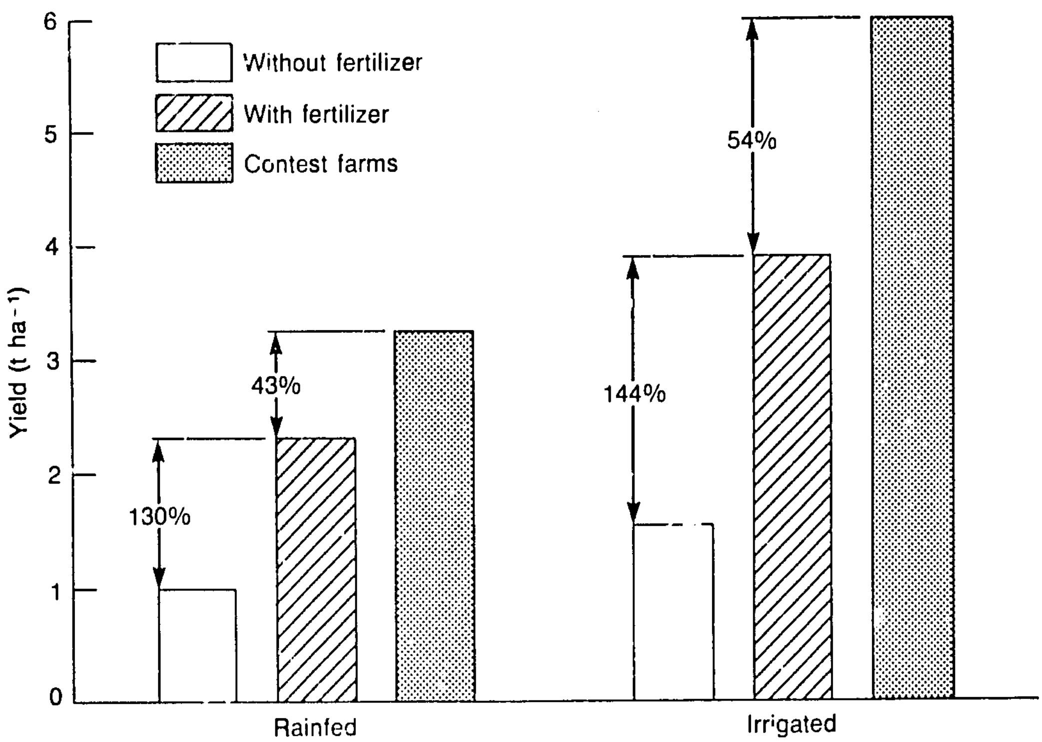


Figure 6. Yield Potential in Wheat Production (Saleem, 1983).

Table 5. Economics of Fertilizer Use (Saleem, 1983).

Treatments $N:P_2O_5:K_2O$	Response	VCR†	Net Profit
	kg ha⁻¹		*Rs ha⁻¹*
30: 0: 0	460	4.8	582
60: 0: 0	520	2.7	524
30:30: 0	670	4.2	819
60:30: 0	920	2.9	1065
60:60: 0	1130	3.6	1302
90:60: 0	1200	2.9	1263
60:60:30	1260	3.7	1468

† The prices used are, as of February 1983:
N at Rs 5.13 kg^{-1}; P_2O_5 at Rs 3.330 kg^{-1}; K_2O at Rs 1.40 kg^{-1}; wheat at Rs 1.60 kg^{-1}; and IS + 12.75 Rupees (Rs).

Table 6. Effect of Ridge and Furrow Planting During Kharif Season on Soil Moisture Available to Subsequent Rabi Crop Planted at NARC, 1984.

Depth of Soil Sample	Soil Moisture			
	Ridge-Furrow		Flat Planting	
	Maize	Fallow	Maize	Fallow
cm	.... %	....		
0-12.5	8.99	8.99	5.34	7.38
12.5-25	11.8	11.9	7.6	9.70
25-50	15.6	16.1	12.7	14.4

The VCRs and net profits for different fertilizer treatments under rainfed conditions are given in Table 5. VCRs are highest for 30 kg ha^{-1} N and 30:30 (N: P_2O_5) kg ha^{-1} treatments whereas net profit is highest for the 60:60:30 (N: P_2O_5 : K_2O) kg ha^{-1} treatment. Thus, considering both the VCR and the net profit, 60:60:30 is the most profitable fertilizer for rainfed wheat in this study (Saleem, 1983).

Water Management

Moisture conservation is fundamental to successful production under barani conditions. Regardless of which crops are grown, fallowing land is the principal means of conserving soil moisture. Experiments, however, indicate that there is no difference in soil moisture with fallow or without, and with a proper soil moisture conservation system. A technique used successfully in many parts of the world for moisture conservation consists of planting in a ridge and furrow configuration. Tests conducted at the National Agricultural Research Center (NARC) have confirmed its value in Pakistan. Table 6 shows that the moisture available in mid-October (rabi planting time), after a summer crop was planted in the ridge and furrow configuration, is greater than moisture available in flat beds after summer fallow (PARC, 1985).

Table 7. Approved Varieties of Different Crops for Barani Areas of Punjab.

Crop	Recommended Varieties	New Varieties/Lines
Wheat	Lyllpur-73; PAK 81 (early sowing) Arz (mid-season) Blue Silver (late season)	K-342 (B-83) V-80001; V-81188; V-80099; V-8116; V-80067
Gram	C-44; CM-72; C-235	C-141; E-23.6; E-2283; C-88; C-89; C-91
Masoor	6-9	AARI 337; 355
Mung	66.1; 66.2; M-28	No. 41; No. 87; E-56; A-17
Mash	No. 48; No. 80	No. 59; No. 216
Groundnut	No. 45; N . 334; Banki	Ne-6; Ne-7
Sunflower	—	Sankum 90; 110
Toria	Raya Toria Selection "A"; Raya L-18	B-Carinata, Poorbi-Raya 80; Yellow Raya "00"

These experiments are being repeated, but they are sufficiently impressive to deserve testing on-farm. If the ridge and furrow system is to be practiced, appropriate equipment must be available to the farmer.

Crop Management

Wheat is the most important crop grown under rainfed conditions; it is followed by rape, mustard, and groundnut. Millets, gram, lentils, pulses, and sunflower are minor crops.

The net income under rainfed conditions is not as high as under irrigated conditions, making it increasingly difficult for the dryland farmer to compete with his counterpart in the irrigated areas. Wheat cultivation requires the use of nitrogen and phosphate fertilizers, whereas a cropping system with leguminous crops (groundnut, summer pulses, winter pulses) can greatly reduce the need for expensive nitrogenous fertilizers.

Suitable Varieties. High-yielding varieties of different crops suitable for barani areas are available (Table 7). However, the barani farmer must be constantly prodded to cultivate improved varieties which are better adapted to barani conditions and have a high capacity to utilize fertilizers.

The Barani Agricultural Research and Development (BARD) Project has conducted various trials under barani conditions.

1) **Rapeseed/Mustard.** Canadian double-low varieties do well in the northern areas and in Islamabad Capital Territory. Farmers like the low glucosinolate trait and are rapidly accepting the Canadian variety Westar (500 packages of seed distributed for the rabi season in 1985). Local varieties and *Brassica juncea* are more drought and heat

tolerant than the Canadian rapeseed varieties. There are three areas for improvement: a) develop low glucosinolate *B. juncea*; b) identify a *B. napus* variety which yields better under barani conditions; and c) modify local oilseed processing for better oil.

2) **Sunflower.** A major constraint to developmental work on this crop has been the devastating disease charcoal rot. The project has identified a resistant hybrid, NK 212, which has good yield and other desirable agronomic characteristics. The inbred lines required to produce this hybrid are now in Pakistan. NK 212 has been widely tested in the country and is satisfactory for release to farmers.

3) **Groundnut.** The primary objective of the varietal improvement project is to find a short duration (120 days or less to maturity) variety to permit the development of an annual two-crop system where groundnuts are produced. Present varieties take 170 or more days to mature, and land is left fallow for up to 11 months between crops.

   Collections from ICRISAT, Senegal, and the United States have been evaluated. Several lines with less than 100-day maturity, high yields, and good nut size have been identified. These lines are being increased for more comprehensive testing before releasing them for on-farm production.

Intercropping and Planting Configuration. Intercropping is another agricultural practice used successfully in other countries to increase economic returns to the farmer. This technique consists of alternating crops from row to row. The crops and the ratio of rows of one crop relative to those of the other crop are both important aspects of attaining an acceptable intercropping pattern. If intercropping is to be successful, it must provide more rupees ha^{-1} (net) than when monocrops of either crop are grown on the same land. One of the successful intercropping combinations identified to date is sunflower and groundnut (1:1). Table 8 shows that with Banki, the bunch type of groundnut, dry matter production is greater when it is intercropped with sunflower than when it is grown as a sole crop.

Similar results were obtained when the spreading type of groundnut was intercropped with sunflower. The advantage of the ridge and furrow configuration over flat planting was also confirmed (Table 9).

Weed Control. It is well-known that weed control is essential if the farmer is to obtain the best yields. It is less well-known that the time of weed removal is very important in maximizing crop yields. Table 10 shows the beneficial effect of weed control. If the farmer is to get the most from his weed control activities, he must remove them no later than the fourth week after planting.

Experimental results from kharif season in 1984 show how seriously weeds can affect maize yield in the farmer's fields (Table 11). The crop treated with herbicide produced almost double the yield of both grain and stalks compared to that treated in the traditional seal fashion.

Table 8. Yield Comparison for Groundnut and Sunflower Intercropped Under Ridge-Furrow and Flat Planting Conditions at NARC, 1984.

Crop	Planting Configuration			
	Ridge-Furrow		Flat Planting	
	Sole	Intercrop	Sole	Intercrop
	kg ha^{-1}			
Sunflower	1070	1250	681	678
Groundnut	1440	1610	291	305

Table 9. Effect of Planting Configuration, Cultivar, and Row Spacing on Groundnut Yield at NARC, 1984.

Planting Configuration	Cultivar			
	Banki		C-334	
	60 cm	75 cm	60 cm	75 cm
	kg ha⁻¹			
Ridge	973	1150	1360	1090
Furrow	1030	1060	1170	905
Flat	757	732	1080	788

Table 10. Effect of Time of Weed Removal After Planting on Soybean Biomass at NARC, 1984.

Weed Removal	Soybean Biomass
weeks after planting	*kg ha⁻¹*
2	2730 a†
3	2820 a
4	2640 a
5	2070 b
6	2140 b
2 and 4	2910 a
3 and 5	2850 a
2, 4 and 6	2830 a
No weeding	1410 c

† Column values followed by the same letter are not significantly different at the 5% probability level.

Table 11. Effect of Weed Control on Maize (cv. Azam) Yield at Haripur (NWFP), 1984.

Treatment	Yield		
	Grain	Stalk	Total
	kg ha⁻¹		
Primextra†	4810	14600	19400
Seal‡	2580	8330	10900

† Applied with knapsack sprayer at the rate of 2.5 l ha^{-1}

‡ A post-emergence cultivation that reduces populations of both maize & weeds.

References

Amir, M. 1979. Keynote address delivered at the National Seminar on Rice Research and Production, 18-22 February 1979. PARC, Islamabad, Pakistan.

Biggs, T.S. 1981. Overview of constraints research in Pakistan. International On-farm Yield Constraints Workshop, 1-2 July, 1981. PARC, Islamabad, Pakistan.

Chaudhri, S.A. 1985. Agricultural Research in Pakistan. USDA/PARC, Pakistan.

Government of Pakistan. 1979. Pakistan basic facts 1978-79. Finance Division, Eco. Wing. Islamabad, Pakistan.

Government of Punjab. 1976. Report of the Punjab Barani Commission.

Malik, D.M. 1981. Studies on wheat yield constraints. Directorate of Soil Fertility Survey and Soil Testing Institute, Department of Agriculture, Lahore, Pakistan.

National Agricultural Research Center. 1985. Pakistan economic survey 1984-85, wheat program. Pakistan.

National Fertilizer Development Center. 1982. Fertilizers and their use in Pakistan. Agri. Ex. Guide. Planning and Development Centre, Islamabad, Pakistan.

NFDC. 1985. Fertilizer and agriculture. Planning and Development Center, Islamabad, Pakistan.

Pakistan Agricultural Research Council. 1980. Agro-ecological region of Pakistan. PARC, Islamabad, Pakistan.

PARC. 1984. Barani Agricultural Research and Development Project, 1983-84 annual report. PARC, Islamabad, Pakistan.

PARC. 1985. Barani Agricultural Research and Development Project, 1984-85 annual report. PARC, Islamabad, Pakistan.

Saleem, M.T. 1983. Water and fertilizer management for wheat in Pakistan. Proc. 17th Coll. Int. Potash Institute, Bern, Switzerland.

Soil Fertility and Soil Testing Institute. 1981. Yield constraint studies in wheat, Lahore 1980-1981. Pakistan.

Zia, M.S., and M.A. Khan. 1985. Management of salt affected soil in Pakistan. (Unpublished.)

Land Management, Crop Rotations, and the Effect of Weeds on Soil Moisture and Crop Production in Arid Zones

M. J. Al-Ahmad
Arab Center for Studies in the Arid Zones and Drylands,
Damascus, Syria

ABSTRACT. Weeds reduce crop yields through their consumption of limited water and nutrient supplies. Their effect is particularly evident in arid and semiarid regions where rainfall is low. In the 1983/84 growing season, a study was conducted at the Izraa research station in Syria (290 mm annual rainfall) to determine the effects of crop rotations, tillage, and weed control on yield under rainfed conditions. Wheat/fallow and wheat/lentil rotations were examined in a split-plot experiment with 3 tillage treatments, no tillage, medium (5-10-cm), and deep (20-cm) tillage, and 3 weed control treatments, herbicide, manual weeding, and no weeding. Yields were greatest with medium tillage and manual weeding in both crop rotations. Water consumption and economic returns were higher in the wheat/lentil rotation than in the wheat/fallow rotation. Continued studies are needed to establish agronomic recommendations for maximum economic yield due to erratic rainfall in this region.

Introduction

Productivity of agricultural crops in the Arab world is low in comparison with that of the world at large due to the fact that most cropped areas (76.5 percent) depend on rainfall. Rainfed agriculture is characterized by low intensity agriculture, usually a monocrop rotation which includes fallow. Moisture and moisture conservation play an important role in rainfed agriculture in the Arab world and therefore agriculturalists are making efforts to improve productivity in arid zones through:

1) Expansion of agricultural mechanization;
2) Improved varieties;
3) Improvement of fertilization and its application; and
4) Crop protection and weed control.

Agricultural mechanization helps farmers to carry out agricultural operations rapidly and with minor costs. The improved varieties should be suitable for mechanical harvesting, of high physiological ability, high-yielding, and have good characteristics in using moisture. Appropriate fertilization will improve production in cases where moisture is sufficient during growth (Alkämper, 1967). Crop protection and weed control increase production indirectly through conserving moisture and nutrients. It should be noted that losses caused by weeds in arid regions are higher than those in areas receiving moderate rainfall. Cramer (1967) noted that average losses caused by weeds were 9.8 percent for wheat, 8.6 percent for barley and 13 percent for corn. In general, when the number of weeds per unit area increases, losses in crop yields also increase as shown in Figure 1.

In arid areas moisture is the most limiting factor affecting production. It is important to make use of moisture through sound means such as:

1) Land management by weeding and appropriate tillage operations.
2) Chemical and manual weed controls.

Research on the amount of moisture used by weeds is limited. Korsomo (1930) mentioned that 1 g of weed dry matter requires 6.57 g of water and that 1 g of wheat, oats, or potatoes requires 3.3 g of water.

Christiansen-Weniger (1970) reported that weeds have great effects on soil moisture, nitrogen, and crop production. Wheat crop losses resulting from weeds were 68 percent in fallow lands.

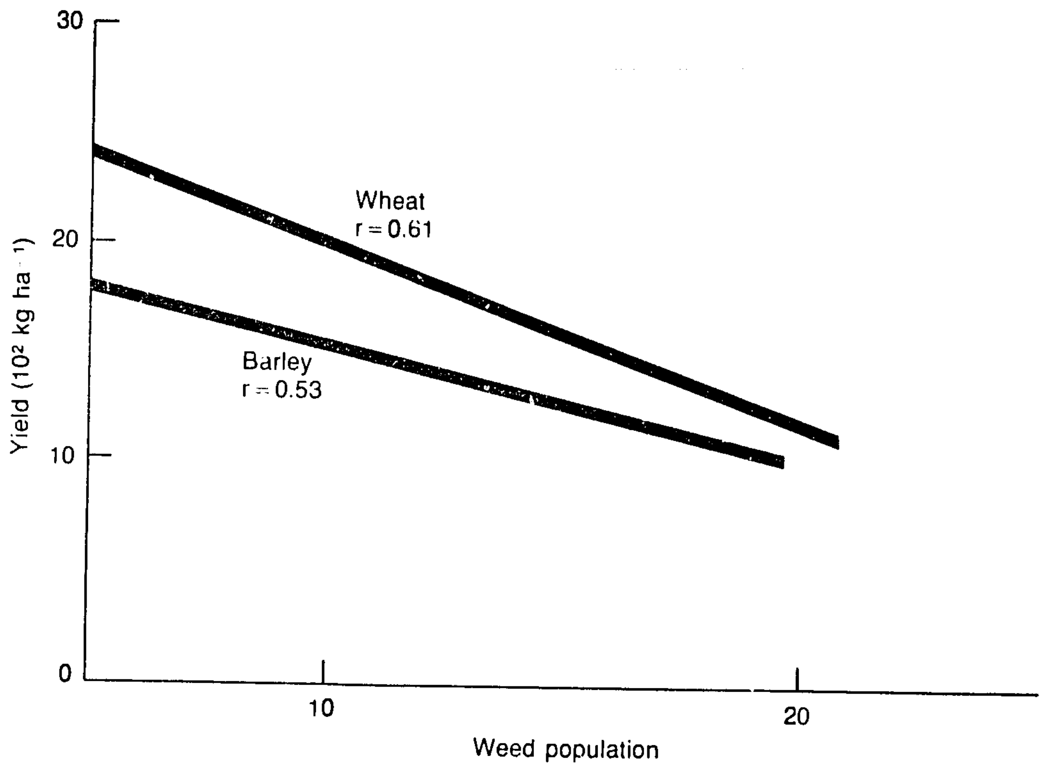


Figure 1. Effect of Weeds on Production of Wheat and Barley (Alkämper, 1972).

The effect of weeds on soil moisture conservation is great in fallow lands, particularly on the soil surface. Weeds consume about 75 percent of the available nitrogen, causing a decrease in production of 70 percent. The nutrients used by weeds were studied by a number of scientists and researchers (Henrich, 1981; Kiessling, 1963; Koch and Kocher, 1968).

Weeds use the largest quantity of nutrients during early growth and this competition weakens field plants (Koch and Kocher, 1968). Pessios (1979) reported that nutrients taken up by weeds in a field planted with corn were 150, 26, and 175 kg ha^{-1} N, P_2O_5, and K_2O, respectively.

The loss of these quantities has been demonstrated by a number of researchers ((Alkämper, 1967; Henrich, 1981; Koch and Kocher, 1968; Pande and Bhan, 1966; Pessios, 1979; Do Vanlong, 1978). Weeds use more nutrients than field crops, proving the importance of weed control. To avoid crop losses, the Arab Center for Studies in the Arid Zones and Drylands (ACSAD) has conducted a land management program with the following objectives:

1) Conserve moisture in arid regions through: (a) use of appropriate agricultural machinery; (b) identification of the effect of tillage depth on productivity; and (c) weed control by mechanical weeding and the use of chemicals.
2) Compensate for labor shortages through the use of agricultural mechanization.
3) Practice the best crop rotations with the objective of increasing production.
4) Adopt varieties which prove to be superior in dry areas.
5) Increase productivity through optimal fertilizer treatments.
6) Apply research findings concerning rangeland and land management.

Table 1. Materials Used in Wheat and Lentil Experiments.

Material	Wheat	Lentil
Variety	ACSAD 65	Horani (local)
Seed rate	80 kg ha^{-1}	80 kg ha^{-1}
Phosphate fertilizers	50 kg^{-1} ha triple super phosphate 46% P	50 kg ha^{-1} triple super phosphate 46% P
Nitrogen fertilizers	100 kg ha^{-1} NH_4NO_3 33.5% N, two doses (at planting and tillering)	20 kg ha^{-1} NH_4NO_3 33.5% N. All fertilizers were applied at planting
Herbicides	2,4D at a rate of 1 l ha^{-1} on 2/27/83 by tractor-mounted sprayer	Bladex 50% at a rate of 1 kg ha^{-1} on 11/24/83 with 300 l ha^{-1} water

Work on this program started in 1982/83 at Izraa station in Syria. The results of 1982/83 were considered preliminary because of the unavailability of the variable lands needed to apply crop rotations. Therefore, the results of 1983/84 have been presented.

Materials and Methods

Materials used in experiments on wheat and lentil are shown in Table 1.

An area of 6 ha was divided into two plots, each consisting of one crop rotation: a) a wheat/lentil rotation; and b) a wheat/fallow rotation.

A split-plot design with the land divided in long strips was used in order to allow the use of machinery. There were 3 tillage treatments × 3 weed control treatments × 4 replications and plots for observation. Each plot was 50 m × 4 m (200 m^2).

The main treatments were:

1) No tillage (zero tillage);
2) Medium tillage (5-10-cm); and
3) Deep tillage (20-cm).

The secondary treatments were:

1) Herbicides;
2) Manual weeding; and
3) Control (without treatment).

Table 2. Dates of Critical Developmental Stages for Wheat and Lentil Grown in 1983-1984.

Developmental Stage	Date	
	Wheat	Lentil
Germination	12/22/83	12/17/83
Tillering	03/26/84	—
Heading	04/18/84	—
Flowering	—	04/03/84
Milk stage	04/30/84	—
Dough stage	05/10/84	—
Maturity	06/07/84	05/29/84
Harvest	06/24/84	05/19/84

Wheat was planted by drill and fertilized on November 23, 1983. The second dose of nitrogen fertilizer was applied on March 26, 1984. Wheat and weeds were sampled on April 15, 1984, and again at harvest.

Lentil was planted by drill and fertilized on November 24, 1983. Crop and weeds were sampled on April 8, 1984, and again at harvest.

All plant samples were dried in an oven at 70°C, weighed, and the nutrients analyzed.

Rainfall averaged 398 mm in 1982/83 and 282 mm in 1983/84. Soil moisture was measured in both crops after each rain at depths of 0 to 20 cm, 20 to 40 cm, and 40 to 60 cm in order to determine total soil water content and water consumption.

Results

The dates that the two crops entered critical developmental stages are shown in Table 2.

Wheat

The highest quantity of weeds in the first cut was in the control treatment and in the 5 to 10 cm tillage treatment with herbicide of the wheat/fallow rotation (Figure 2). A comparison of weed production in the two crop rotations shows that weed production in the wheat/fallow rotation was higher than that in the wheat/lentil rotation by 30 percent. The highest quantity of weeds in the wheat/fallow rotation was in the no-tillage treatment (zero-tillage) while the weed production in the wheat/lentil rotation was highest in the 5 cm and 20 cm tillage treatments. The high weed productivities were reflected in the consumption of soil moisture in the fallow rotation where weed dry matter was 2771 and 1528 kg ha^{-1} in 1982/83 and 1983/84, respectively.

Statistical analysis revealed that:

1) Herbicide was superior to the control treatment at both the 1 and 5 percent levels of probability in the wheat/fallow and wheat/lentil rotations, respectively.

2) Hand weeding was superior to both the herbicide and control treatments at the 1 percent probability level in the wheat/fallow rotation.

3) There were no significant differences between the 5 cm and 20 cm tillage treatments. The 5 cm and 20 cm tillage treatments differed significantly from the no tillage (zero tillage) treatment at the 1 percent level of probability.

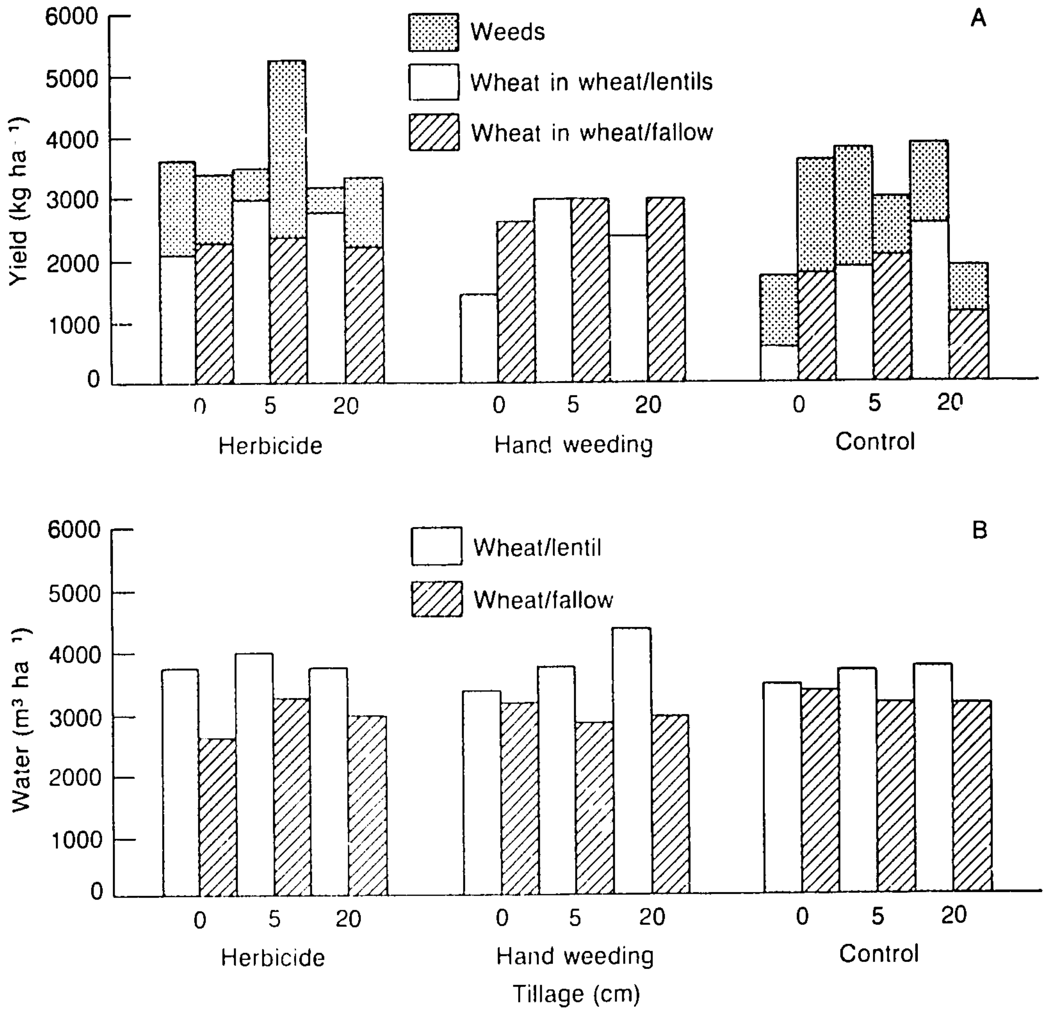


Figure 2. Yield of Wheat and Weeds (A) and Water Use (B) in Wheat/Lentil and Wheat/Fallow Rotations at Izraa', 1983/84.

Uptake of nutrients by weeds is shown in Figures 3, 4, and 5. The highest consumption of nutrients by weeds was in the wheat/fallow rotation with herbicide and 5 cm tillage treatment; weeds accumulated 53.6 kg ha^{-1} N, 74.4 kg ha^{-1} K_2O, and 6.2 kg ha^{-1} P_2O_5. In the control treatment, the highest accumulation of nutrients by weeds was also found in the wheat/fallow rotation with no tillage; weeds accumulated 24.2 kg ha^{-1} N, 56.7 kg ha^{-1} K_2O, and 4 kg ha^{-1} P_2O_5.

Water consumption in the wheat/lentil rotation was much higher than that in the wheat/fallow rotation, ranging from 3600 to 4000 m^3 ha^{-1}, in contrast to 3100 m^3 ha^{-1}, respectively (Figure 3). Water consumption was much lower than in the previous year, about 4100 m^3 ha^{-1}. Productivity in 1982/83 was 40 percent higher than in 1983/84. This could be related to poor distribution of rainfall during the cropping season. An economic feasibility study (Figure 6) showed that the best economic return for wheat with 5 cm tillage ranged from 3700 to 4000 Syrian pounds ha^{-1}. Yield per hectare in the wheat/lentil rotation was about 4021 Syrian pounds ha^{-1} in the herbicide treatment and about 2439 Syrian pounds ha^{-1} in the control treatment, i.e., herbicides increased profits by 60 percent. These results were similar to those in the wheat/fallow rotation.

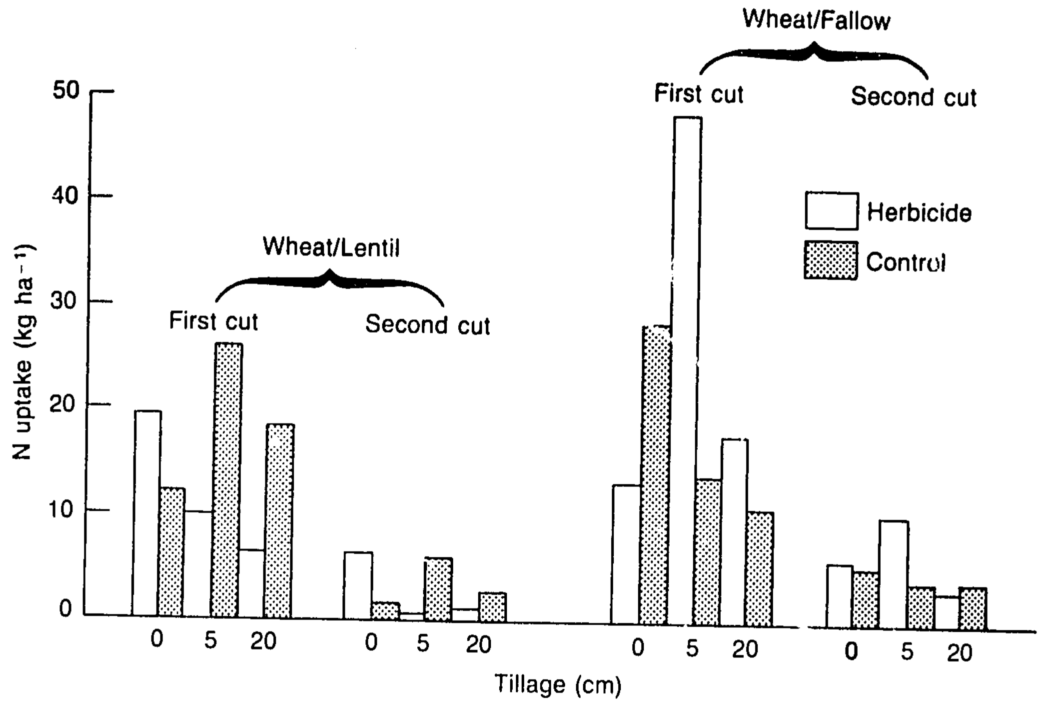


Figure 3. Nitrogen Uptake of Weeds in Wheat/Lentil and Wheat/Fallow in Two Cuts in the 1983/84 Season.

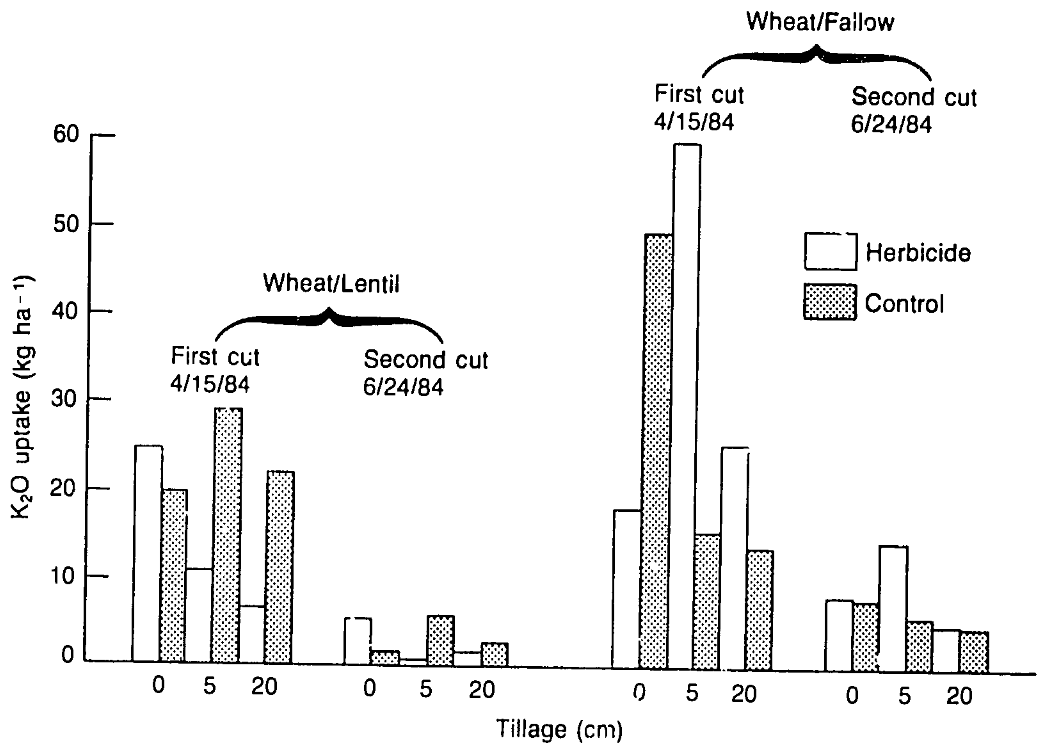


Figure 4. K_2O Uptake by Weeds in the Two Cuts of Wheat/Lentil and Wheat/Fallow Rotations in the 1983/84 Season.

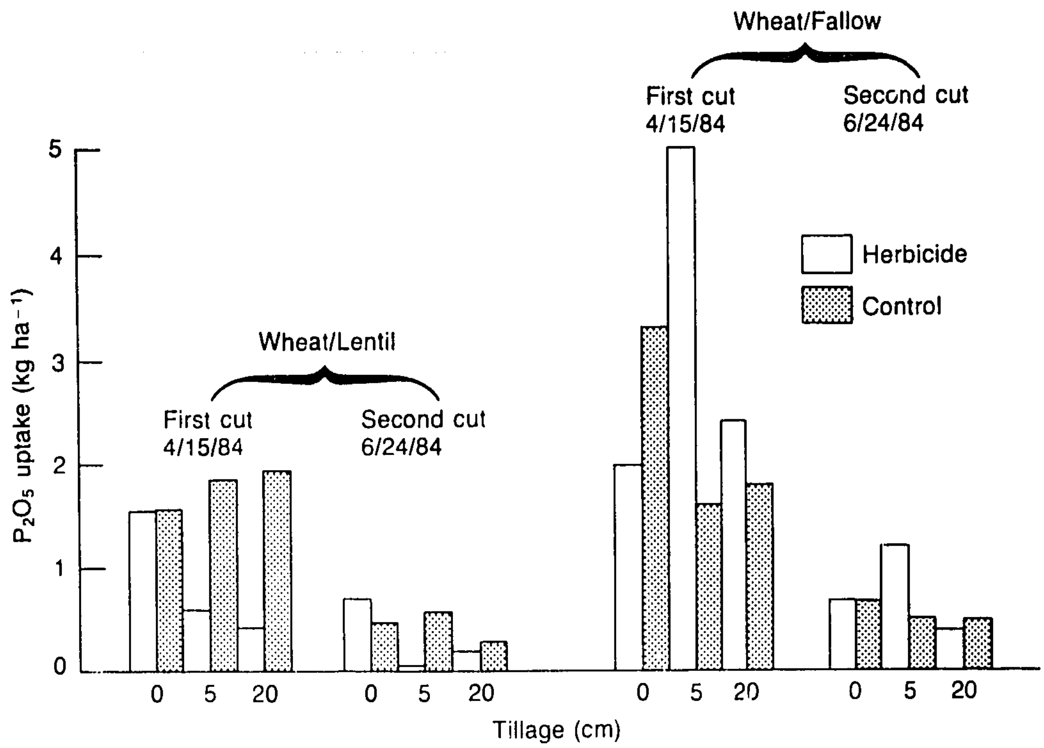


Figure 5. P Uptake by Weeds in Wheat/Lentil and Wheat/Fallow Rotations in Two Harvests in the 1983/84 Season.

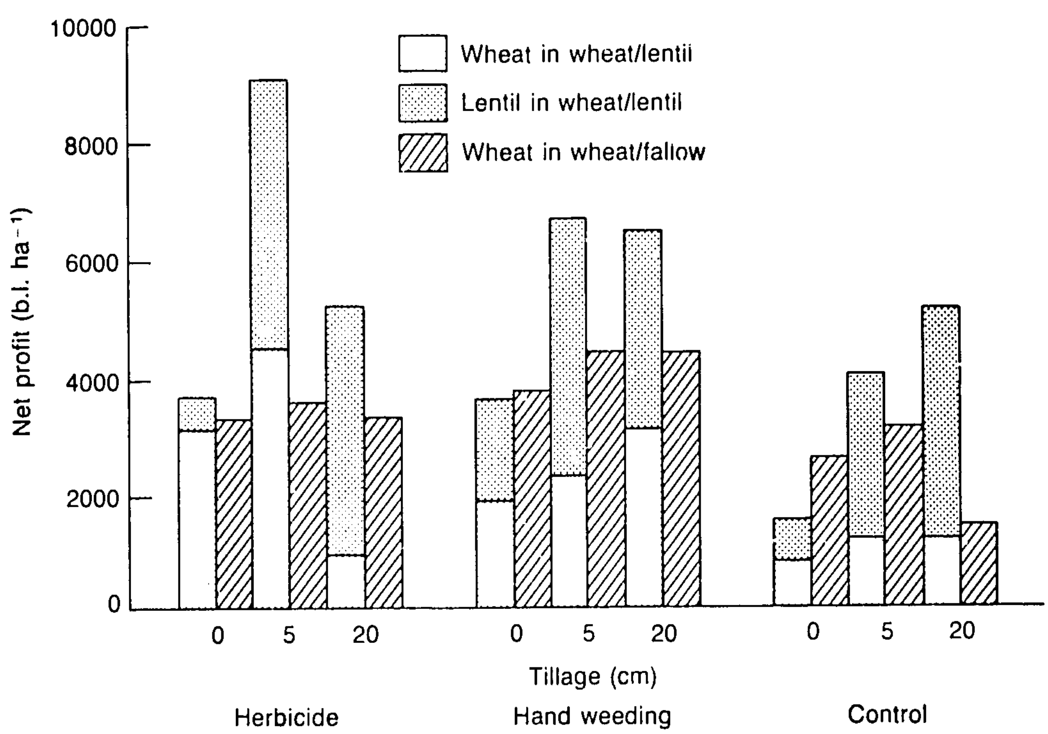


Figure 6. Net Profit (Syrian Pounds) for Wheat in Wheat/Lentil and Wheat/Fallow Rotations.

A comparison of the two rotations showed no significant differences in net profits, 3209 Syrian pounds ha⁻¹ for the wheat/lentil rotation and 3317 Syrian pounds ha⁻¹ for the wheat/fallow rotation. When profits from both wheat and lentil yields in the wheat/lentil rotations were totaled and compared with the profit from the wheat/fallow rotation, differences appeared. Total profits for the wheat/lentil rotation with 5 cm tillage and herbicide treatment were 9116.6 Syrian pounds ha⁻¹ in contrast to a maximum profit for wheat in a wheat/fallow rotation of 3562.5 Syrian pounds ha⁻¹ These figures are very important in terms of economic returns to rainfed farming. It is important to continue these studies in order to determine the most profitable crop rotations in rainfed regions.

Lentils

Hand weeding resulted in lentil yields that were twice that of the control treatment, 787 kg ha^{-1} and 379 kg ha^{-1}, respectively (Figure 7). Yields in the herbicide treatment averaged 568 kg ha^{-1}. The 5 cm tillage treatment was superior to the others, resulting in yield 1.58 times that in the zero tillage treatment and 1.2 times that in the 20 cm tillage treatment.

Although production among treatments was variable, there were no significant differences in consumption of soil moisture.

The lowest consumption of soil moisture was in the 5 cm tillage treatment compared to other tillage treatments.

Figure 8 shows that weed production was very high in both the herbicide treatment and the control. The lowest production of weeds occurred in the 5 cm tillage treatment and the highest production was in the 20 cm tillage treatment with herbicide, 5600 kg ha^{-1} dry matter. Herbicides were not effective during this year so mechanical weeding was used in addition to the herbicide.

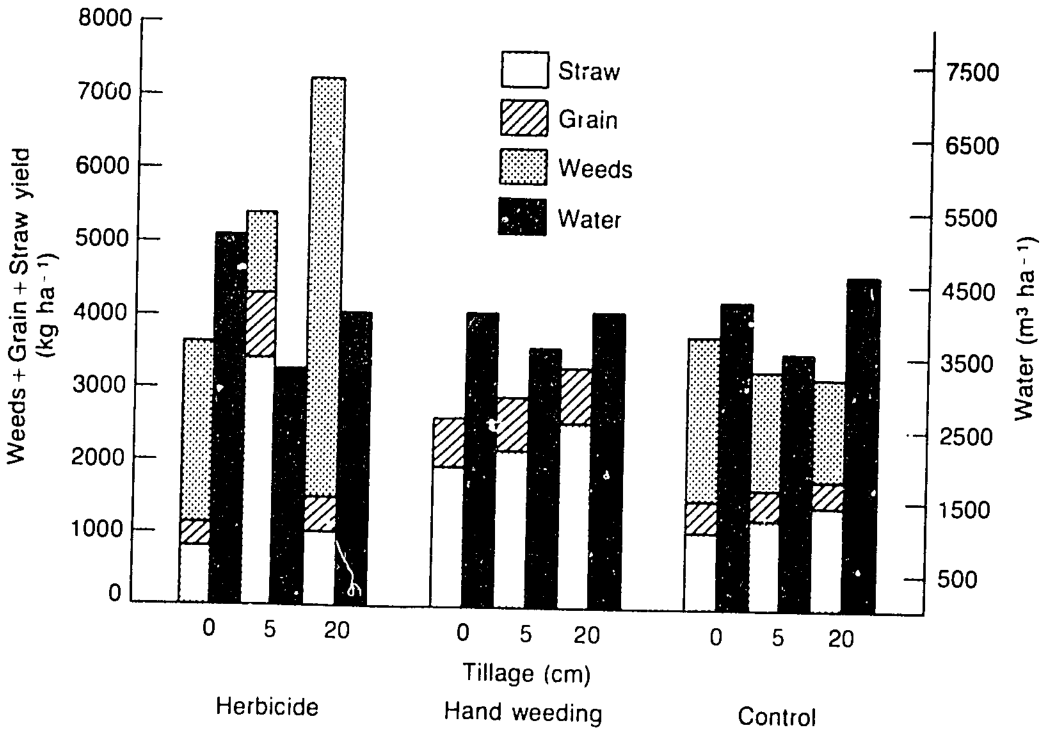


Figure 7. Yield of Weeds and Grain and Straw, and Water Use for Lentils in 1983/84.

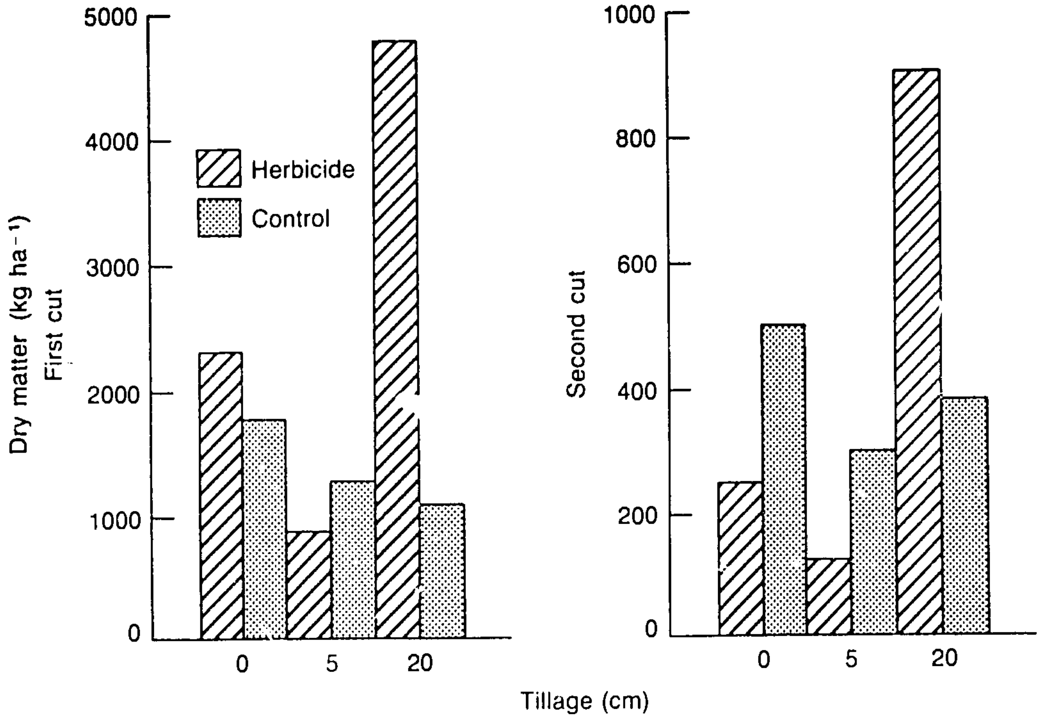


Figure 8. Dry Matter Yield for Weeds in Lentils for Two Harvests, April 2, 1984, and May 28, 1984, in 1983/84.

Figures 9, 10, and 11 show weed uptake of N, P, and K. Total consumption of N by weeds from both harvests ranged from a high of 252 kg ha^{-1} in the 20 cm tillage treatment with herbicide, to the lowest consumption in the 5 cm tillage treatment with herbicide, 48 kg ha^{-1}. Accumulation of P and K by weeds reflected the same patterns as N.

Statistical analysis revealed that:

1) Manual weeding was significantly different from the control at the 1 percent probability level and the herbicide treatment at the 5 percent level.

2) The 5 cm tillage treatment was superior to zero tillage at the 1 percent probability level and the 20 cm tillage treatment at the 5 percent level.

3) The 20 cm tillage treatment had significantly higher yields than the zero tillage treatment at the 5 percent level of probability.

4) The herbicide and 5 cm tillage treatment had significantly higher yields than the herbicide and control treatment with zero tillage. The herbicide and 5 cm tillage treatment also had significantly higher yields than the 20 cm tillage treatment at 1 percent level.

5) The manual weeding and 5 cm tillage treatment outyielded the herbicide and control treatments at the 1 percent level of probability.

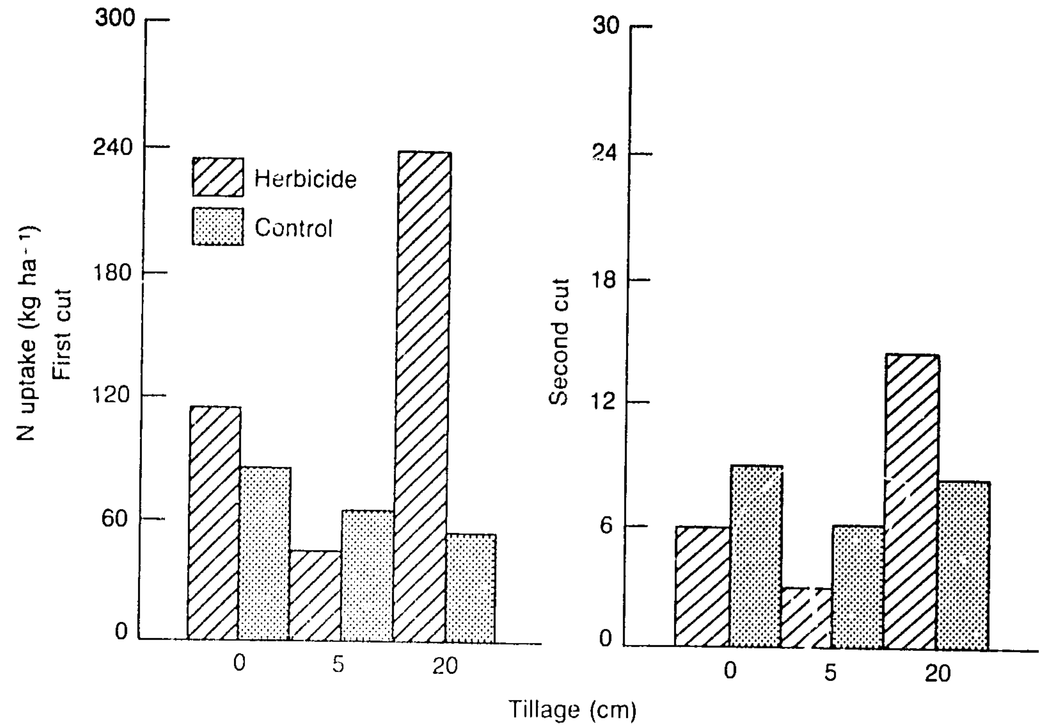


Figure 9. N Uptake by Weeds Associated with Lentils in Two Harvests, April 2, 1984, and May 28, 1984, in 1983/84.

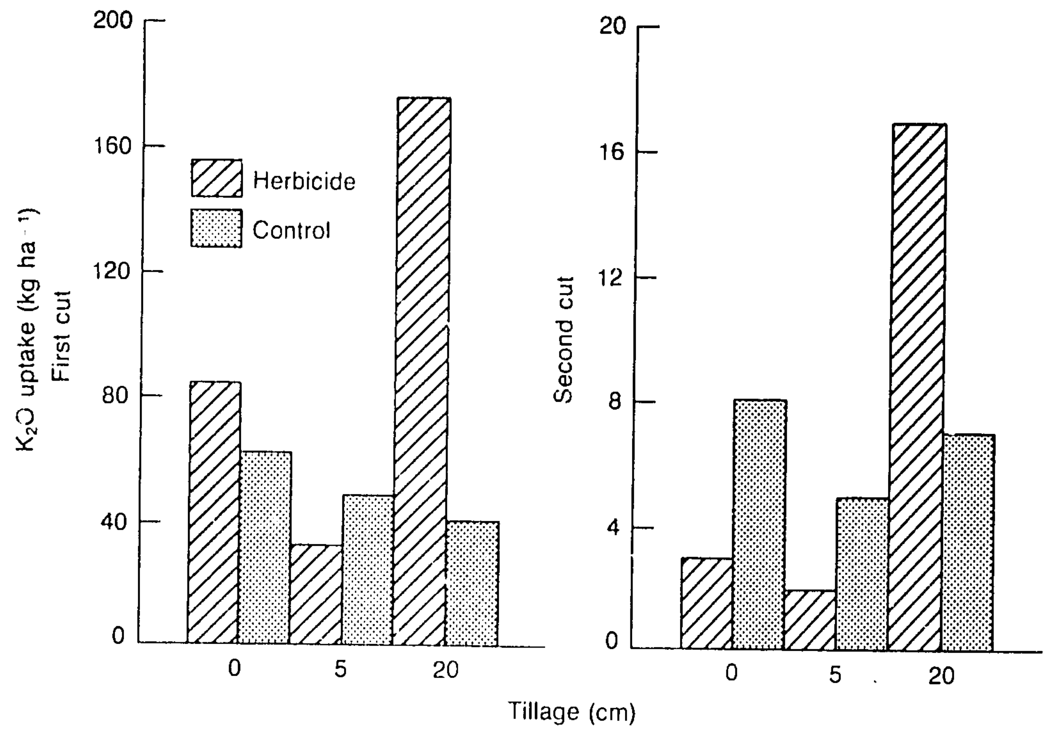


Figure 10. K_2O Uptake by Weeds Associated with Lentils in Two Harvests, April 2, 1984, and May 28, 1984, in 1983/84.

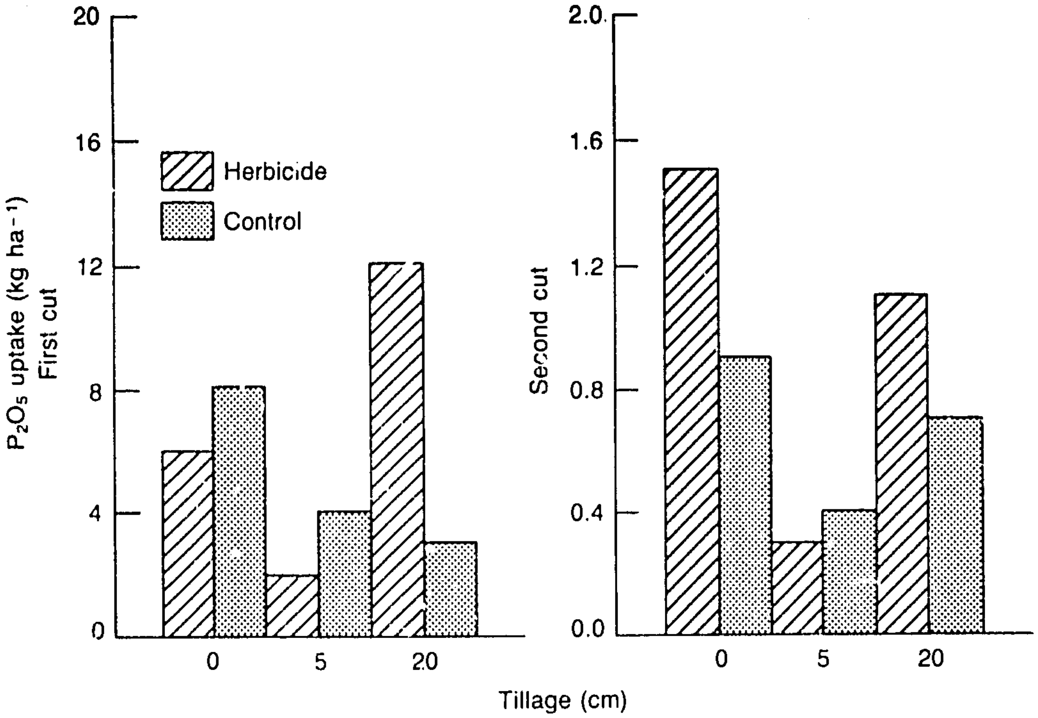


Figure 11. P_2O_5 Uptake by Weeds Associated with Lentils in Two Harvests, April 2, 1984, and May 2, 1984, in 1983/84.

Table 3 shows that the average net income per ha in the manual weeding treatment was 2430 Syrian pounds. This is more than twice that of the control treatment. The average net profit for the herbicide treatment is 80 percent greater than that for the control treatment.

With respect to tillage treatments, the best lentil yields were in the 5 cm and 20 cm tillage treatments. Weed production was influenced by tillage with the lowest production of weeds found in the 5 cm tillage treatment. Water consumption was also lowest in the 5 cm tillage treatment. Grain production and economic returns were highest in the 5 cm tillage treatment. Weeding increased yields and economic returns. Mechanical and manual weedings should be done several times during the growing season and row spacing should be wider to allow the use of machinery for weeding. Herbicide use should be given more attention.

Recommendations for Wheat Crops

The following agronomic recommendations are made for wheat.

1) Use of herbicides.
2) Continuation of the practice of 5 cm tillage which proved to be superior to other tillage practices in these experiments.
3) Continuation of the practice and study of the wheat/lentil rotation which proved to have superior economic returns.
4) Provision for machinery to carry out agricultural operations and make comparisons of the use of such machinery in different sites in each country.

Table 3. Summary of Yield and Economic Feasibility for Lentil Crop in Syrian Pounds Ha-1.

Treatment	Depth	Cost	Income of Grains	Income of Straw	Total Income	Net Profit
		.... *S.L. ha-1*				....
Herbicide	zero	994	736	816	1552	558
	5 cm	1009	2093	3400	5493	4484
	20 cm	1037	1006	'046	2052	1015
Hand weeding	zero	1538	1481	1931	4312	1874
	5 cm	1552	1692	2153	3845	2293
	20 cm	1581	2142	2560	4702	3121
Control	zero	978	783	1132	1915	937
	5 cm	992	956	1231	2187	1195
	20 cm	1021	824	1415	2239	1218

Recommendations for Lentil Crops.

The following agronomic recommendations are made for lentil.

1) Use of herbicides and mechanical weeding.
2) Use of mechanical weeding several times during the growing season.
3) Spraying herbicides with more care and attention.
4) Row spacing should be wider to allow for mechanical weeding.
5) Use of varieties suitable for mechanical harvesting.

References

Alkämper, J. 1967. Einge Beispiele zur steigerung der pflanzlichen produktion in subtropischen landeren zeitschrift fur auslandische land wirtschaft 6:98-184.

Alkämper, J. 1972. Allegemeine probleme der unkinet bekämpfung berichte aus der abt-furhe ologie an der universitat. Hohenheim (3) 81-92.

Christiansen-Weniger, F. 1970. Ackerbau formen in Mittelmeerraum und Nahen Ostenm dargestellt am Beispiel der Turkei. DLG-verlag Frankfurt am main.

Cramer, H. 1967. Pflanzenschutz und Welternte. pflanzenschutz Nachrichten Bayer 20:1-523.

Do Vanlong. 1978. Nahrstoffkonkurrenz zwischen kulturpflanzen und unkrä uteren bei gesteigerter dungung Diss-Giessen.

Henrich, J. 1981. Dungereinsatz und unkrautbekampfung im reisbau in Sierra Leone, Diss-Giessen.

Kiessling, L. 1963. Untersuchungen uber den nahrstaffgenalt von Ackerunkrautern und Getreidepflanzen in verschiedenen Entwicklungestadien. Meded. Laudbauwhogesch Gent 28:1087-1096.

Koch, W., and M. Kocher. 1968. Zur Bedeutung des Nahrstoffaktors bei der Konkurrenz zwischen kulturpflanzen und unkrauteren. Z. Pflanzenkrankheit und Pflanzenschutz, Sonderheft 4:79-87

Korsomo, E. 1930. Unkrauter im Ackerbau der Neuzeit. Springer Verlag, Berlin.

Pande, H.K., and V.M. Bhan. 1966. Effect of row spacing and levels of fertilization on growth, yield and nutrient uptake of upland paddy and on associated weeds. Estrado da Rivista il Riso 15:47-67.

Pessios, E. 1979. Wirkung gesteigerter Dungergaben auf Estrag und Nahrstoffenfrahme von mais und unterschiellischen undrautgeselschafften Diss-Gresseb.

An Overview of Soil, Water and Crop Management Systems for Dryland Agriculture in Egypt

A.T.A. Moustafa
Soils and Water Research Institute, Agricultural Research Centre, Ministry of Agriculture, Arab Republic of Egypt

ABSTRACT. Rainfed agriculture in Egypt is mainly concentrated in the northwest coast. As a result of the growing population in Egypt, the coastal zone of the western desert attracted the attention of the Government. Many studies, including soil and water resource surveys, were conducted. In the last few years, research on rainfed agriculture in this area has also been conducted. The resulting recommendations are practiced now in some locations. Ongoing and proposed research activities deal mainly with maximizing agricultural production with available resources. For proper planning, detailed research, evaluating the water resources in the area, is needed. Currently, some estimates are used to calculate available water resources.

Introduction

Egypt lies in the northeastern corner of Africa occupying nearly 3 percent of the continent. It extends over ten degrees of latitude, from 22°N to 32°N, with one-fourth of its area south of the Tropic of Cancer. Egypt is 1073 km in length from north to south and 1262 km in breadth from west to east with a total area of almost one million km^2 (Ali, 1982).

Most of Egypt falls within Africa's dry desert region except for a narrow strip of land in the north which has a Mediterranean type of climate. Rainfed agriculture in Egypt is concentrated mainly on the northwest coast which has a rather special climate, differing from the inland desert area of the south.

As a result of the growing population in Egypt, the northwest coast region has attracted the attention of many government organizations planning several agricultural and settlement projects. Research on soils, water resources, geology, and other subjects has been initiated at many sites along the coast.

The northwest coast of Egypt extends westward about 600 km from Alexandria to longitude 29°50′ in the east to longitude 25°10′ at El-Sallum in the west. A succession of ridges and depressions from the sea to the Libyan Plateau characterize the topography of the area.

Physical Resources for Agriculture in the Northwest Coast Region

Climate

The northwest coast has a rather special climate which differs from the inland desert areas to the south. Rainfall varies over the region and ranges from 100 to 150 mm per year. Rainfall varies considerably from month to month at the same site and may also differ widely at two neighboring sites in the same month or season. Alexandria, the rainiest city, may have precipitation as low as 5 mm during the winter months (December, January, and February) while in another year it may receive over 100 mm in a single month. October is the first month that can be considered wet or rainy. By this month the whole Mediterranean coastal region has received at least 10 percent of its annual precipitation. From November to March the coastal region receives at least 75 percent of its annual rainfall. Rainfall is unevenly distributed along the coast, and this can be explained by the configuration of the coastline (Ali, 1982). Figure 1 shows the rainfall distribution map for the northern coast.

Air temperatures are mild, with a mean annual maximum of 25°C and mean annual minimum of 15°C. The mean maximum temperature in July is 29°C and the mean minimum in January, 9°C. Relative humidity does not vary greatly throughout the year, ranging from 50 to 60 percent at noon and from 60 to 70 percent in the morning and evening. Potential evaporation appears to be fairly constant from year to year and totals 1500 mm.

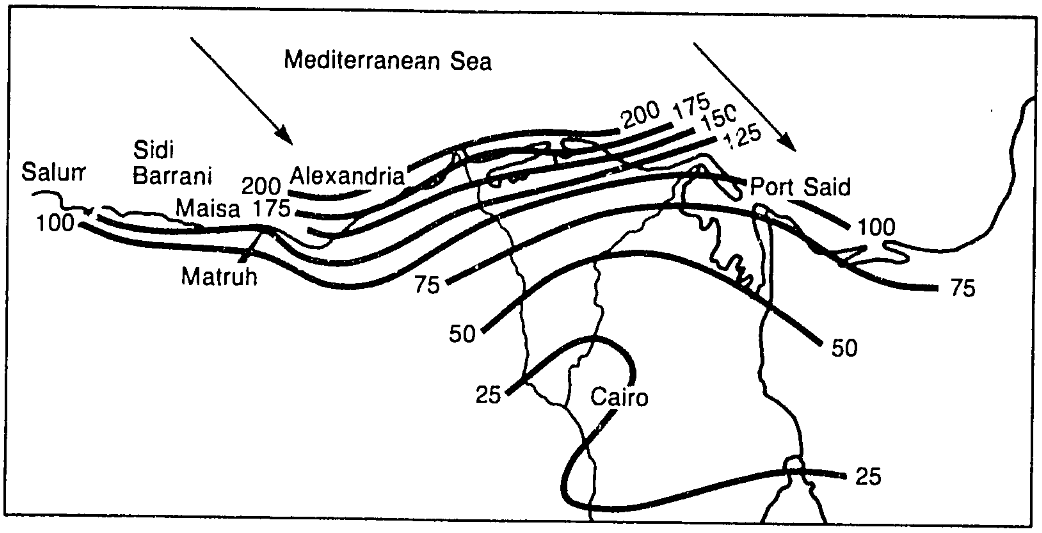


Figure 1. Isohyets (mm) for the Northern Coast of Egypt (Hamdi *et al.*, 1980).

Land

Along the north coast, one or more parallel ridges of dunes lie separated by narrow, elongated plains. Just south of these, windblown soils and alluvial fans deposited by the wadis occur. Further south, the rocky Libyan Plateau rises at varying distances from the coast.

Soils suitable for agriculture are found in small areas surrounded by nonarable land. Generally, the soils are underlain by caliche or rock which determines the depth of the soil (Ismail *et al.*, 1976).

Arar (1980) estimated that under the most favorable conditions the present rainfed areas with expected increases would total 10,000 ha by 1985; Ismail (1985) estimated 20,700 ha.

Some soil surveys and classifications have been conducted in this region (Abd El-Samie *et al.*, 1957; Balba and El-Gabaly, 1965; Hamdi *et al*, 1980; Harga and Rabie, 1974). The main factors used in grouping the soils of the area are:

1) Depth of profile to hard rock or water table.
2) Some characteristics of profile layers including, texture, structure, color, and stoniness.
3) Salinity of the saturated extract.
4) Presence and depth of caliche and gypsic horizons.
5) Calcium carbonate concentration.
6) Position and topography.

As an example of the variability of these soils, Abd El-Samie *et al.* (1957) found eight different soil types in an area of 2270 ha. These were scattered and intermingled with one another (Figure 2).

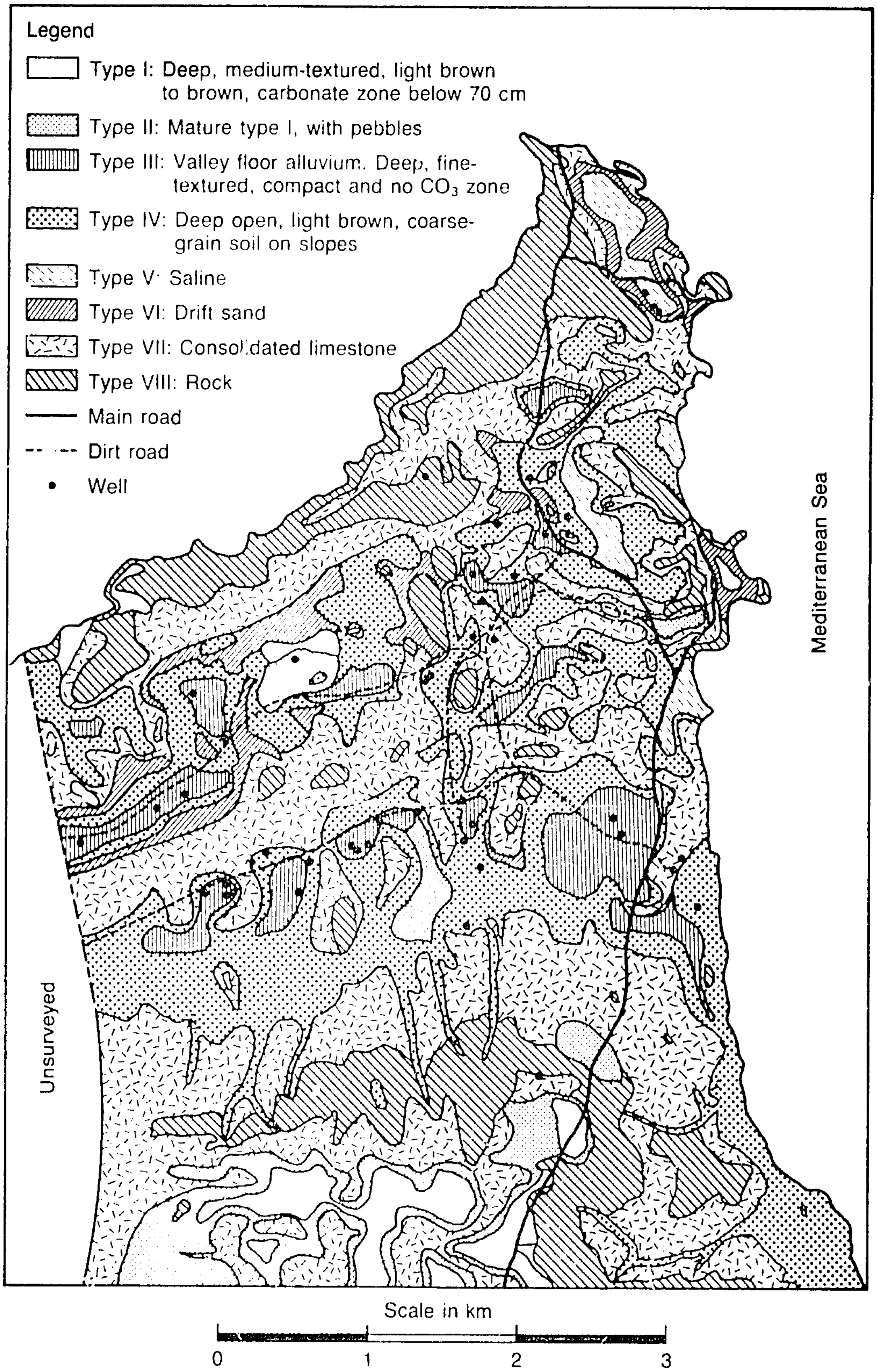


Figure 2. Soil Map of Ras El-Hekma (Abd El-Samie *et al.*, 1957).

Utilization of Water

Surface Water

The main source of water is rainfall. In winter water accumulates naturally in:

1) The depressions where the topography favors the accumulation of the runoff of wadis or the surface runoff from the higher areas; and
2) The water spreading zones where the runoff of wadis is spread freely, flowing down slopes and accumulating behind natural obstacles (sand dunes or rocky hills).

This natural wetting is very irregular, depending mainly on the topography. In addition, water collection is carried out on a small scale through:

1) Constructing dikes to prevent the flow of the runoff from wadis to the sea.
2) Constructing dikes in the flood plains to divert runoff from the wadis. Small channels can be opened which carry the runoff to isolated fields.
3) Constructing traversal stone or earth barrages in the beds of small wadis to facilitate sedimentation, creating terraces which collect runoff from the wadis.
4) Constructing small dikes parallel to the contour lines to retain surface runoff.

Surface water can be used to supplement rainfall in several ways.

Flooding. This is suggested for gently sloping areas which are free from gullies or depressions.

Water Spreading. This method is suggested for areas with greater slope and when runoff is not sufficient to submerge the entire field.

Terracing. In the wadis with even bank-slopes and in cases where there is no land suitable for cultivation downstream of the wadis terracing is suggested.

Sheet Runoff. In the flat areas where there are no wadis, sheet runoff can be collected for immediate use. The water harvesting system should conduct the sheet runoff onto restricted areas of good soil. By reducing the area which receives the sheet runoff, the amount of water per surface area is increased.

Also, sheet runoff can be stored in the numerous cisterns which exist in the coastal region. More than 3000 cisterns, dating back to the Roman period, have been excavated in the rock. Their capacity varies from 100 to 3000 m^3. Once the cisterns have been cleaned and repaired, water stored in them can be used for human and animal consumption. In some cases, tree plantations can be established by supplying young trees with small amounts of water during the dry season. Small dikes or ditches may be necessary to conduct the sheet runoff into the cisterns.

Groundwater

Groundwater in the region can be exploited in three ways.

1) **Dug Wells.** To avoid salinization of groundwater, wells equipped with windmills should not be pumped beyond their capacity.
2) **Drilled Wells.** Wells deeper than 20 m are usually drilled by the rotary method.
3) **Collecting Galleries.** Groundwater stored in coastal sand dunes is exploited by means of collecting galleries.

Traditional Agricultural Production

Rainfed Barley

Rainfed barley is produced by the Bedouin farmers using the traditional methods of land preparation and harvesting, mainly with animal traction and hired labor. Cereal production originally served a double function: 1) to meet the basic food needs of the Bedouin families; and 2) to meet the need for supplementary feed for the Bedouins' animals, i.e., sheep and goats. Rainfed barley yield is just 10 percent of irrigated yield.

Fruit Orchards

Olives, figs, and almonds are found at various locations scattered along the coast. Figs and almonds are mostly found on slopes of sand dunes where groundwater accumulates. Traditionally, fruit trees are irrigated only during their first 3 to 4 years. Subsequently, they survive with rainfall and groundwater. Productivity under these conditions is low; olive yield is one-fourth that of irrigated trees. The trees are widely spaced with as few as 20 to 70 trees per ha compared to 500 trees per ha under irrigated conditions. The low density allows for optimal use of rainfall and surface runoff.

Animal Production

Sheep and goats are the main livestock in this region along with camels and donkeys. The overgrazing of rangelands is the main problem.

Constraints to Soil Productivity

Based on studies carried out in this region the main constraints to soil productivity are: soil topography; soil slope; soil stratification; the depth of soil profile to bedrock or the water table; soil texture and calcium carbonate content; soil salinity; soil fertility; and soil erosion (wind and water).

These constraints affect soil productivity through their effects on soil physical properties, soil chemical properties, soil-water-plant relations, rooting zone and depth, etc. One usually finds one or more of these constraints at any given site because of the great heterogeneity of the soils of the region.

Research to Overcome Soil Production Constraints

The objectives of the Government are to maintain a stable society, and increase food production, employment and income. Toward these ends, the Ministry of Agriculture established a farm at Burg El-Arab to conduct regional research and distribute crop cultivars which proved successful along the northwest coast.

Trials of controlled grazing and other agricultural practices of dryland farming were conducted at the Ras El-Hekma Project located 200 km west of Alexandria. Other objectives of this project are to identify natural and introduced vegetation with better nutritive quality, and show the Bedouins how to improve forage and increase their livestock.

Other research has been carried out in the area to identify the constraints in specific locales and solutions to overcome them. Examples are: improving grazing in Ras El-Hekma; sand dune fixation (through plantings); soil and water conservation through spreading and distributing the water; and improvement of water resources.

Ongoing research includes: introducing new varieties of trees which can tolerate the prevailing climate and soil; evaluating soil resources; developing uses and management systems for calcareous soils; evaluating different irrigation systems for use in newly reclaimed lands; and the Arid Land Project for the agricultural development of the northwest coast.

Other projects which have been proposed are the improvement of rainfed agriculture, development of an extension service for the Bedouins, range improvement, in addition to continued development of the northwest coast.

Recommendations and Conclusions

Research on the northwest coast of Egypt has resulted in numerous recommendations. Some which have been successfully implemented are:

1) The use of mechanical land preparation and harvesting for rainfed barley.
2) Supplemental irrigation for olive orchards. Yield can be increased from 1 to 4 t when the trees are properly irrigated and maintained.
3) Identification of areas suitable for growing fruit trees, especially olive, based on soil and underground water availability.
4) Redistribution of rainfall by earth dikes designed to move the water to selected areas, control soil erosion, and reduce water loss.
5) The use of windbreaks to reduce wind erosion and limit the loss of crop and tree flowers.
6) The use of groundwater supplies by digging surface wells and pumping the water with windmills.
7) Soil and water conservation practices which limit surface runoff and consequently soil erosion, and increase water infiltration into the soil.

Research has also indicated areas where more information is needed. For example, the grazing project in Ras El-Hekma found that controlled grazing and the use of both rainfall and water reservoirs improved productivity. However, there is still a critical need for summer fodders for summer and autumn animal feeding. The introduction of wells and windmills failed miserably among the farmers in the northwest although the technology was sound; less than 5 percent of the 1000 windmills established in 1967 are now in operation. As a result, farmers are unwilling to embark again upon a windmill development program. This demonstrates the need for socioeconomic studies and extension activities in the region.

Currently, research is underway to:

1) Develop and introduce new varieties which can tolerate drought and salinity, and can be grown in a short season;
2) Introduce new field and forage crops with potential as industrial material;
3) Recommend the proper use and management of the soils in the area; and
4) Recommend a range improvement program.

But gaps still exist in our knowledge of soils, water, crops, and their interrelationships. Recommendations for future research are:

1) To quantify the relationship between precipitation and runoff on a per area basis.
2) To measure recharge to groundwater.
3) To monitor the salinity of the groundwater.
4) To determine the effects of dew and relative humidity on crop growth and yield.

There is also a need for a detailed map of the soils and topography of the northwest coast. This information would be valuable for land use evaluation and planning.

References

Abd El-Samie, A.G., M.A. Abd El-Salam, and A. Mitkees. 1957. Report on the soil survey and classification of Ras El-Hekma with reference to its water supply and land use. The Desert Institute Bull. No. 10, Mataria, Egypt.

Ali, A.A. 1982. Atlas of climate of Egypt by the computer. Book General Egyptian Authority.

Arar, A. 1980. The role of rainfed agriculture in the Near East Region: Summary of present situation, potential and constraints. Proc. FAO Regional Seminar on Rainfed Agriculture in the Near East and North Africa, Amman, Jordan, 5-10 May 1979. FAO, Rome, Italy.

Balba, A., and M.M. El-Gabaly. 1965. Soil and ground water survey for agricultural purposes in the North West coast of Egypt. Research Bull. No. 11. Alexandria J. of Agricultural Research, Fac. Agric., Alexandria Univ. Alexandria, Egypt.

Hamdi, H. *et al.* 1980. Project soil map of Egypt: Soil map of the western coastal littoral. 6th report, Academy of Scientific Research and Technology, Soil and Water Resources Council, Egypt.

Harga, A.A., and F.A. Rabie. 1974. The classification of the soils of the Mediterranean. J. Soil Sci. Egypt. 14:177-186.

Ismail, H. *et al.* 1976. Regional plan for the coastal zone of the western desert. Final report. Ministry of Housing and Reconstruction, ILACO, Egypt.

Ismail, H. *et al.* 1985. Master plan of general development for the North West Coast (100 km - 268 km), Final report. Ministry of Housing, Reconstruction and Land Reclamation, Egypt. (in Arabic).

An Overview of Agriculture Research at the Arab Scientific Institute for Research and Transfer of Technology in the Occupied West Bank

S.A. Assaf
Arab Scientific Institute for Research, Jerusalem, Israel

ABSTRACT. The Arab Scientific Institute for Research was established to assist the development of the Palestinian people in the occupied West Bank and Gaza Strip. The Institute stimulates technology transfer and applied research in the agricultural sciences, nutrition, public health, and environmental science. Agricultural activities include research on jojoba, thyme, the Assaf sheep, broom-rape, and olive oil, among others.

Introduction

The Arab Scientific Institute for Research (ASIR) is a nonprofit technical research institute established in El-Bireh, West Bank by Arab and Arab-American scientists. It has an office in Amman and a mailing office in Houston. The aim of the Institute is to generate applied science research activity in the fields of agriculture, food, water, health, and the environmental sciences in general with the overall objective of achieving better development of the Palestinian people in the occupied West Bank and Gaza Strip.

The Institute began with the creation of a data base on the West Bank and Gaza Strip using a mini IBM computer. The scientists and engineers working with ASIR realize that the Institute is self-supporting with very few international, local, and Arab grants for equipment and specific research projects. Therefore, compensation for work done at ASIR depends only on the grants and contracts that it obtains and on what the Institute generates from consulting and from the agricultural experiment stations in the Jenin district north of the West Bank.

If ASIR is to be described in one sentence, it is "a Technology Transfer Institute with concentration on agriculture technology and matters related to farmer development".

Agricultural Activities

The agricultural activities of ASIR include the following.

A Field Investigation of the Feasibility of Planting Jojoba in the West Bank and other Arab Countries

The Institute has planted this oil producing desert bush in the hills and semiarid field crop areas of the West Bank. A comparison will be made with similar experiments conducted by the Institute in Jordan's Yarmouk University and in the Industrial Technical Center of Qatar in Doha.

The trees in the West Bank cover an area totaling 50 dunums (5 ha). They are doing well and some lots have actually produced after only three years of growth.

A summary of this research project will be submitted to ICARDA. The Institute now has 50,000 seedlings of jojoba ready for planting between February 1986 and May 1986. Seedlings may be obtained for joint projects by interested institutes or agencies. The Institute holds a certificate of Arab origin from the Government of Jordan.

Production of Thyme (Za'atar) Seedlings and Field Cultivation

The Institute has been able to produce 250,000 seedlings per year and is supplying them to farmers at cost with subsidies from the Save the Children Foundation-USAID program. The Institute hopes to do this in other Arab and foreign countries.

A Field Investigation of the Feasibility of the Assaf Hybrid Sheep

The Assaf hybrid sheep is a repetitive cross between the imported Friesian sheep and the local Awassi sheep. The Institute has 90 head of this hybrid as well as another ten of a cross between the Keos sheep imported from Cyprus and the Assaf. This new hybrid is called Kesaf. These hybrids produce two times more milk, meat, and lambs than the local Awassi sheep. However, they require intensive husbandry including drugs and feed. This research was presented at the 1984 Sheep Conference in Amman at the University of Jordan.

Research on the Eradication of the Parasitic Plant Broom-Rape which Attacks Vegetable Crops

Experiments were conducted in the West Bank in collaboration with a Palestinian plant protection professor on sabbatical from the University of Jordan. Methods of controlling broom-rape on cabbage were evaluated.

Investigation of the Physical and Chemical Properties of West Bank Olive Oil

This work encompassed ASIR's analysis of olive oil samples taken from nearly 300 olive oil mills in the West Bank. The olives have been harvested, handled, and pressed in various agricultural areas under different conditions. The results were presented to the International Olive Oil Council at a conference sponsored in 1982 by the Union of Arab Food Industries.

A Study of Wells

A chemical and hydrological study of the wells of the Arab Development Society Project in Jericho is supported by the Swedish Consulate General.

Evaluation of Drinking Water Projects

A field evaluation of drinking water projects in villages of the West Bank and Gaza Strip was funded by the Save the Children Foundation.

Food Security Issues in the West Bank and Gaza Strip

This study included the following topics: human, land, and water resources; plant and animal production; the role of the private and public sectors; consumption; and export. It was submitted in 1984 to the joint United Nations ECWA/FAO Division.

The Water Situation in the West Bank and Gaza Strip

This study was presented at the Arab Waters Conference which was sponsored by the Arab Fund for Social and Economic Development and held in Kuwait in February 1986. It is a detailed study of the water resources, utilization problems, and rules and regulations in the occupied territories.

Research on the Agricultural Plant Production in the Occupied Territories

This study was submitted to the Sixth Conference of the Union of Arab Agricultural Engineers in Amman in November 1984.

Feasibility Studies

A feasibility study for the development of a complete agricultural project on 3000 dunums of land in the Jordan Valley was conducted in 1983. Plant and animal production on private land in Fesayel in the Jordan Valley were evaluated.

A study was conducted to determine the feasibility of developing a large egg-laying farm in Ramallah District in the West Bank.

A study was undertaken to justify the development of an agricultural implements factory in Jenin. This factory has now been enlarged and is valued at several million dollars. It is the largest in the West Bank and Gaza Strip.

The report on an investigation into the feasibility of establishing an Arab University of Technology was submitted to the Higher Council of Education in the West Bank.

Study of the Technology Gap between the Occupied Territories and Israel

This study emphasized technical education and research centers, the brain drain, and absorption. The research was done for the Joint Committee in Jordan and submitted to the Office of the Deputy Minister of Occupied Territories in Amman, Jordan in 1985.

Transfer of Technology in the Hands of Expatriates

This study was submitted to the Expatriate Conference in Amman in 1985.

Status of Agricultural Education and Workers

A study on the status of agricultural education and agricultural workers in the occupied territories and a proposal for establishing a college of agriculture in the West Bank were commissioned and submitted to ALECO, the Arab League in January 1986.

The Role of Olive Oil in the Prevention of Thrombotic Disease

This study showed statistical data that olive oil actually prevents heart disease in humans compared to other fats and oils. The paper was presented to the Kuwait Medical Society Conference in 1984.

SECTION IV

Methods and Techniques for Assessing Conservation Production Systems

Mechanics of Water Erosion: Measurement, Prediction and Control

D.K. McCool
U.S. Department of Agriculture, Agricultural Research Service, Pullman, Washington, USA

ABSTRACT. Accelerated soil erosion is a constant threat to the ability to feed and clothe the world's population. With growing population in many developing nations, the need to increase production by cultivating unsuitable lands increases erosion rates. Research on erosion rates with current farming methods, on the effect of erosion control practices, and on improving prediction technology is important to assess current status and future trends, evaluate specific practices, and develop policies and strategies.

Techniques and methods for planning and conducting erosion research are discussed, along with a number of current prediction models. Erosion prevention and control techniques are discussed.

Introduction

Erosion can severely affect the productivity of cropland, particularly where cultivated topsoils are shallow and subsurface layers impede root penetration, have low water-holding capacity, or are otherwise inhospitable to plant growth. The major causes of productivity decreases due to erosion are nutrient losses and changes in soil structure which control infiltration and retention of soil moisture (Wolman, 1985). Williams *et al.* (1981) identified the loss of plant available soil water capacity as the major reason erosion reduces productivity.

Erosion rates range from negligible to severe, depending upon climate, topography, soil, and management factors. An inventory of cultivated cropland in the United States in 1982 (National Research Council, 1986) indicated an average sheet and rill water erosion rate of 10.8 Mg $ha^{-1}y^{-1}$. However, about 40 million ha, or about 25 percent, had rates of greater than 11.2 Mg $ha^{-1}y^{-1}$; this is often considered to be the erosion level at which productivity can be sustained over a long period of time on a renewable soil. Erosion rates in other parts of the world are much higher (El-Swaify, 1982). Frequently, overpopulation and the accompanying necessity to cultivate unsuitable lands increases erosion rates. This is particularly true in the humid tropics, where denuding steep, forested lands results in severe erosion rates. In some places such as in Haiti, the process is so severe as to be considered virtually irreversible (Wolman, 1985).

Erosion can undermine efforts to feed a growing world population. Research on the measurement, prediction, and control of erosion is essential. Predictive capability is necessary to select strategies to optimize food and fiber production and prevent irreversible degradation of the soil resource base.

Erosion Measurement

Erosion measurements are made for a number of purposes. Measurements have traditionally been used to directly compare specific treatments and for monitoring particular areas; more recent emphasis has been for model calibration and verification. Methodology depends upon the purpose of the project. Runoff plots are used to measure hillslope soil loss. Instrumented watersheds are used to calibrate larger scale models that include channel hydraulics or delivery ratio concepts. Instrumentation is frequently based on the complexity and resolution of the models to be calibrated. Plots for comparison of specific treatments or for calibration of lumping and averaging models such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965; 1978) require less extensive instrumentation than those used in calibrating and verifying more complex models that predict erosion from individual events.

Available resources may control the type of research conducted. In developing countries with a lack of capital and an abundance of labor, manpower is frequently substituted for expensive equipment and instrumentation. Thus, plot borders may be simple and installed by hand, and catchments may be of rock and mortar rather than concrete or steel. Manual readings may be substituted for recording equipment. With proper training and supervision, good quality data can be collected with rather simple equipment.

In many areas of the world, baseline data on precipitation quantities and rates may be limited. This makes plot and watershed design difficult and uncertain, and also hampers modeling efforts. References are available that provide broad-scale estimates of precipitation, runoff, and other hydrologic parameters (Landsberg, 1985; UNESCO, 1977, 1978). Whenever possible, more detailed information should be located.

Runoff Plots

Runoff plots are small hillslope areas artificially bounded so that only runoff from that specific area will enter a collection system (Figure 1). A number of configurations have been used but a standard size installed at the original erosion stations established in the United States in the early 1930s was 22.1 m long by 1.8 m wide, giving an area of 0.004 ha (0.01 acre). Plots subjected to natural rainfall are still frequently 22.1 m long by 1.8 m or more wide. Borders can be of sheet metal, wood, plastic, bermed earth, or other material. Termite activity precludes the use of wood in some areas. The artificial borders are frequently 150 to 250 mm high with half of the border buried in the soil.

In order to speed data collection and hence shorten project time and costs, rainfall simulators are frequently used. These simulators should be selected or designed to apply water at rates and with drop size and energy characteristics of the local precipitation (McCool, 1979). In general, the plots will be smaller than those to be subjected to natural rainfall. A wide range of rainfall simulators are available (USDA, 1979).

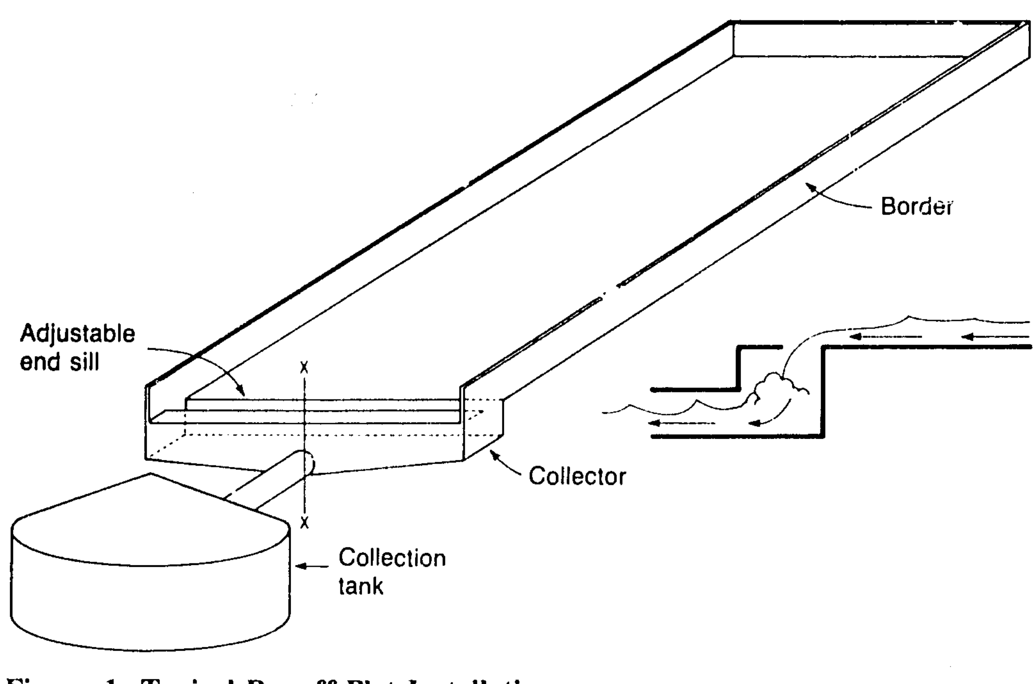
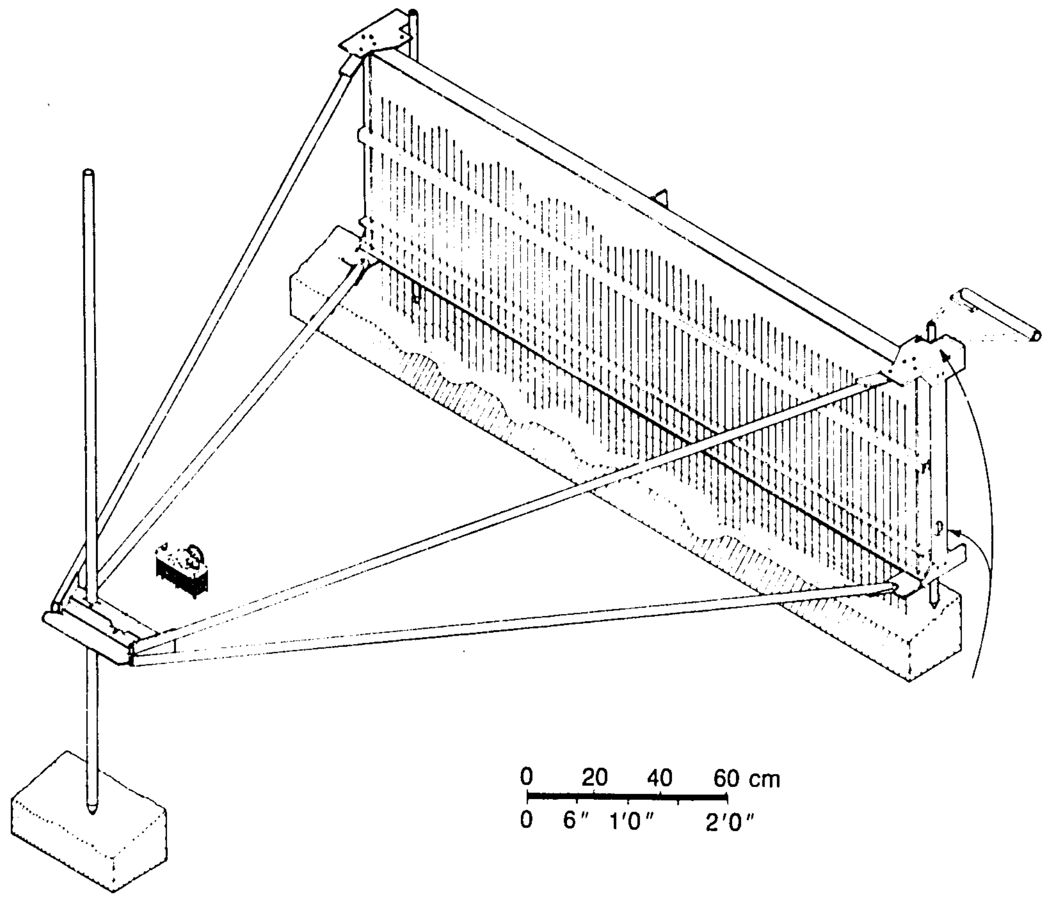


Figure 1. Typical Runoff Plot Installation.



Note: Handles can be added for ease in carrying. Folding handles can be added to top. Front and one rear leg are equipped to screw together to form handles at bottom. Meter can then be folded and carried like a stretcher.

Figure 2. Photographically Recording Rill Meter.

The runoff from a plot usually flows over an adjustable end sill into a collector. Total runoff can then be collected in a tank, a portion can be collected after passing through a divisor or splitting box, or a measuring flume with a sampling device can be used (Brakensiek *et al.*, 1979; Mutchler, 1963).

Where rilling is severe, a rill meter or surface profile meter (Figure 2) can be used to measure the eroded area in the rill (McCool *et al.*, 1981). Only if both rill and interrill erosion are severe can this device be used to measure total soil loss, and then only if a reliable datum can be established and bulk density does not change with time.

If a tank is used to collect runoff, proper sampling of the sediment is essential. If the liquid is low in suspended solids, the major portion of the solids can be allowed to settle and the liquid siphoned off. A representative sample of the remaining material can be collected and dried. Stirring a large tank and obtaining a representative suspended sediment sample is very difficult, if not impossible. Pumps and splitters are sometimes used to accomplish this task.

Tipping bucket measuring devices are sometimes used to measure runoff. Results have been mixed. Some researchers indicate that tip rate must be kept within specified limits for reliable operation (Barfield and Hirschi, 1987).

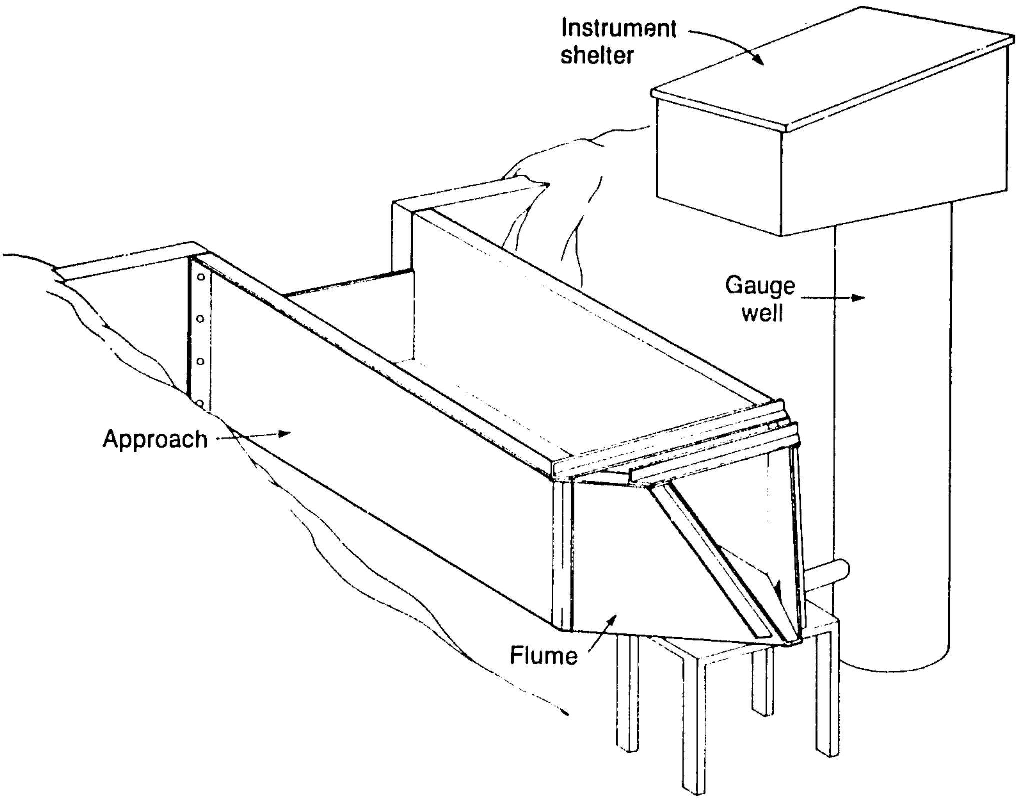


Figure 3. Typical Flume Installation for a Small Watershed.

Watersheds

Watersheds are usually naturally bounded areas and can range in size from a fraction of a ha to several km^2. The known or expected range in runoff rates and conditions influences the type of measuring device. Commonly used devices are flumes, weirs, bridges, culverts, and natural controls (Brakensiek *et al.*, 1979; Buchanan and Somers, 1969; Carter and Davidian, 1968; U.S. Geological Survey, 1977).

Relatively small watersheds can be equipped with temporary or permanent flow measuring devices of various kinds (Figure 3). Flumes can be made of sheet metal, plastic, or fiberglass and can be moved to other locations at the conclusion of a project. Measuring devices for large catchments must be permanently installed. In order to reduce expenses, existing structures that control the flow, such as bridges and culverts, are used wherever feasible. Frequently, an auxiliary low-head control must be installed in addition to the existing structure (Brakensiek *et al.*, 1979; Holtan *et al.*, 1962).

Measurement of the suspended sediment passing the station is accomplished by a sampling technique (Brakensiek *et al.*, 1979; Guy and Norman, 1970; U.S. Geological Survey, 1977). The sediment concentration of the sample is determined and multiplied by the flow rate to determine the sediment discharge rate. Sampling of large flows can be done manually or by an automatic device that pumps a small sample from the stream (Brakensiek *et al.*, 1979; U.S. Geological Survey, 1977). For small watersheds a flow-splitting device or a flow driven sampler can be used.

In some streams the bedload must be measured. The bedload is the sediment that moves at velocities less than the surrounding flow by sliding, rolling, or bounding on or very near the streambed. The bedload is difficult to measure because the presence of any mechanical device will disturb the flow and the rate of bedload movement. Nevertheless, a number of samplers have been devised to collect bedload samples (Brakensiek *et al.*, 1979; Guy and Norman, 1970; U.S. Geological Survey, 1977). Brakensiek *et al.* (1979) mention that no sampler developed to that time had proved entirely satisfactory for all conditions, and that the selection of a bedload sampler was highly dependent upon conditions at the sampling site.

Sediment Determination

Several methods are available to determine sediment concentration. Two of the most common are evaporation and filtration (Brakensiek *et al.*, 1979; Guy, 1969). Filtration is generally more suitable for low concentrations. Evaporation is better for higher concentrations that would plug the filter. The evaporation method may require an adjustment for dissolved solids. To speed up the evaporation method a flocculant is sometimes used and the supernate siphoned off. However, flocculant cannot be used on a sample on which aggregate size is to be determined, because aggregates will be broken down. In either case the sediment or filter paper containing the sediment is dried in an oven. In selecting balances and setting up procedures for determining sediment concentration, the accuracy of all phases must be considered.

Knowledge of particle size distribution is necessary for calibration and verification of many runoff and erosion models and for studies of chemical movement. Techniques for determining particle size distribution are described by Brakensiek *et al.* (1979) and by Guy (1969).

Meteorological Observations

Meteorological observations are an important part of any erosion research project. The very simplest installation should include a standard nonrecording raingauge and max/min thermometer. For calibration of even very simple models, a recording raingauge is necessary. For more complex models more elaborate instrumentation is required, including solar radiation and soil temperature data. For a more detailed discussion of meteorological observations and techniques see Brakensiek *et al.* (1979).

Erosion Prediction

Erosion prediction is used for farm management planning, projecting long-term effects of farming practices, assessing the status of the natural resource base, and as an aid in planning governmental policies with regard to land use, resettlement, and financial support of conservation practices. Prediction technology ranges from the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965; 1978), a relatively simple model for predicting average annual hillslope erosion over a long period, through more complex models capable of predicting soil loss and nutrient movement on an event basis and including stream channel as well as hillslope erosion (Beasley, 1977; Simons *et al.*, 1977; Foster, 1987).

The USLE is a general equation containing variables derived from empirical relationships. The general equation is:

$$A = RKLSCP \qquad [1]$$

where:

A = soil loss per unit area, Mg $ha^{-1}y^{-1}$;
R = rainfall and runoff erosivity factor, MJ mm $ha^{-1}h^{-1}y^{-1}$;
K = soil-erodibility factor, Mg h $MJ^{-1}mm^{-1}$;
L = slope length factor;
S = slope-steepness factor;
C = cover and management factor; and
P = supporting conservation practice factor.

The empirical relationships for the variables were developed from data collected from runoff plots located east of the Rocky Mountains in the United States. Since the development of the USLE, it has been found that regional relationships may be required for some of the factors. For example, the R factor, as developed from the kinetic energy and intensity of rain, correlates poorly with the high winter erosion rates of the Pacific Northwest rainfed cropland. In the Pacific Northwest erosion is believed to be better correlated to runoff and low soil strength during the thawing of frozen soil. Similarly, research in Mediterranean and Saharan zones has indicated deficiencies in the R factor under these conditions (Roose, 1977). Research in the Pacific Northwest of the United States also indicates that the S factor for this region differs somewhat from that in the USLE. In this region erosion has been found to be related to slope steepness:

$$S = \left(\frac{\sin \theta}{\sin 5.143°}\right)^{0.6} \qquad [2]$$

where S = slope steepness factor; and θ = field slope gradient in degrees.

Thus, the USLE should be used with some caution in areas that have no erosion data against which to compare the predictions. Currently the USLE is perhaps the most used erosion prediction equation in the world, and a literature search may find an application for a situation similar to nearly any that one will encounter. A major problem may be in finding sufficient precipitation data to drive even this simple model.

The Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) was developed to determine sediment yield from small watersheds. The equation is:

$$SY = a(Q\, q_p)^b\, K\, LSCP \qquad [3]$$

where SY = sediment yield from an individual storm, Mg; Q = storm runoff volume, m^3; q_p = peak runoff rate, m^3s^{-1}; K = erodibility factor, Mg h $ha^{-1}N^{-1}$; $LSCP$ = factors from USLE; and a,b = fitted coefficients.

Williams found values of a and b to be 9.05 and 0.56, respectively (Foster, 1982). Note that this equation uses most of the parameters of the USLE, replacing only the R factor with a term containing runoff parameters.

The Erosion Productivity Impact Calculator (EPIC) (Williams *et al.*, 1983) was developed to investigate, on a United States-wide basis, the effects of soil erosion on crop production. The EPIC model predicts erosion event by event by the MUSLE (Williams, 1975), the Onstad-Foster Equation (Onstad and Foster, 1975), or the USLE (Wischmeier and Smith, 1978). It includes a crop growth model and operates on computer-generated rainfall data. The model may require calibration for local conditions.

Another model is the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model (Knisel, 1980). The CREAMS model was developed to estimate runoff, erosion, and chemical losses from field scale areas. It operates on an event basis using overland flow, channel flow, and impoundment concepts. The model includes several parameters from the USLE and has been successfully used in most areas of the United States.

Two models more recent than CREAMS are GLEAMS (Leonard *et al.*, 1987) and OPUS (Smith and Ferreira, 1986). Both are best used on watersheds of less than 40 ha because they use rainfall input from a single gauge. GLEAMS routes surface flow, but its major strength is its capability of routing infiltrated water through the root zone to ground water. OPUS routes surface runoff using a physically based infiltration and runoff model with solution by a finite difference technique, rather than by runoff curve number as CREAMS does.

Of all the models mentioned to this point, only the USLE can be used without at least a microcomputer. Using previously developed charts, an erosion prediction with the USLE can be made by hand calculation.

The Agricultural Research Service of the USDA is currently developing a replacement for the USLE. The Water Erosion Prediction Project (WEPP) is intended to produce a completed model by 1989. The WEPP Model is intended to be event-based, but will be capable of operation on small, portable personal computers so that results can be obtained even in the field (Foster, 1987).

Erosion Prevention and Control

If the goal of sustainable agricultural production is to be accomplished, erosion prevention and control are essential. Otherwise soil losses will exceed tolerable limits, particularly in areas where population pressures cause cropping of steep, highly erodible land.

Agronomic measures such as cover crops, multiple cropping, strip-cropping, and surface mulches, are highly effective means of preventing erosion. A surface mulch of 1.1 Mg ha^{-1} has been found to reduce erosion to 18 percent of that when no mulch is present (Laflen *et al.*, 1985). Cover crops or intercropping can protect the soil while a crop is being established.

Vegetative measures, while highly effective in reducing erosion and maintaining a desirable soil structure, may be difficult to apply. Fodder may be used as livestock feed, fuel, or building material, so the farmer may be reluctant to leave these materials in the field. Furthermore, they may interfere with cultivation and may increase disease problems. Cultural and societal influences may override other considerations. For example, nomadic herdsmen may use crop residues to feed their herds during certain times of the year. Farmers may also be reluctant to try new and relatively unproven techniques that require investments of time and energy, and from which the returns are not immediate.

While cultural and vegetative measures are considered the most desirable means of erosion control, mechanical measures may also be necessary. This is true if slope steepness is great, if rainfall quantities are excessive, or if vegetative measures are not acceptable to the farmer. Mechanical practices may include terraces, contour bunds, contour furrows, and furrow dikes.

Terraces are embankments or channels constructed across a slope at regular intervals to reduce slope length and control runoff. In semiarid regions they may be designed to collect all runoff for infiltration. In wet areas they are designed to channel the runoff to an established channel or pipe system. A number of terrace systems have been developed, including bench terraces, hillside ditches, basins, orchard terraces, mini-convertible terraces, and a hexagonal system (El-Swaify *et al.*, 1982).

The term contour bunds has been applied to more than one mechanical practice (Hudson, 1971). In this paper it refers to a low bank pushed up by hand or with a machine, with the excavated channel upslope. Its purpose is to intercept and infiltrate runoff. If the channel is too small to collect and retain all runoff, progressive failures will ruin the system (Hudson, 1971).

Contour furrows or contour ridges involve tillage with a lister or ridger on the contour. The crop is seeded in the furrow or on the ridge, depending upon specific conditions. The practice is effective unless runoff exceeds the water storage capacity of the ridges. Should this occur, progressive failures of the ridges may result in more erosion than if up- and downhill seeding had been used.

Tied ridges or basin listing is a practice in which dikes are formed across furrows at regular intervals. Water collected in the basins will ultimately infiltrate the soil. The small dams must be reestablished each time cultivation occurs and, in sandy soils, after each heavy rain. Hudson (1971) suggests placing the furrows on a grade with a suitable protected outlet, and forming the ties slightly lower than the ridge. In case of an extreme rainfall event, massive progressive failure is thus avoided.

Lack of resources constrains the application of mechanical measures, particularly those requiring heavy or special equipment. Also, there is little incentive for a farmer using communal lands to apply such measures. For application of mechanical measures incentive and support programs are required.

Summary

Soil erosion requires constant attention, particularly in times of increasing world population and intensity of agriculture. Research on gross erosion rate, comparison of practices, and prediction technology is important to assess current status, future trends, evaluate specific practices, and develop overall policy and management strategies.

References

Barfield, B.J., and M.C. Hirschi. 1987. Tipping bucket flow measurements on erosion plots. Trans. ASAE 29:1600-1604.

Beasley, D.B. 1977. ANSWERS: A mathematical model for simulating the effects of land use and management on water quality. Ph.D. Thesis, Purdue Univ., West Lafayette, IN.

Brakensiek, D.L., H.B. Osborn, and W.J. Rawls. 1979. Field manual for research in agricultural hydrology. USDA, Agric. Handbook 224. U.S. Gov. Print. Office, Washington, DC.

Buchanan, T.J., and W.P. Somers. 1969. Discharge measurements at gaging stations. Book 3, Chapter A8. Techniques of water-resources investigations of the U.S. Geological Survey. U.S. Gov. Print. Office, Washington, DC.

Carter, R.W., and J. Davidian. 1968. General procedure for gaging streams. Book 3, Chapter A6. Techniques of water-resources investigations of the U.S. Geological Survey, U.S. Gov. Print. Office, Washington, DC.

El-Swaify, S.A., E.W. Dangler, and C.L. Armstrong. 1982. Soil erosion by water in the tropics. Research Extension Series 024. HITAHR. College of Tropical Agriculture and Human Resources. University of Hawaii, Honolulu, HI.

Foster, G.R. 1982. Modeling the erosion process. p. 297-380. *In* C.T. Haan, H.P. Johnson, and D.L. Brakensiek (ed.) Hydrologic modeling of small watersheds. American Society of Agricultural Engineers, St. Joseph, MI.

Foster, G.R. (ed.). 1987. User requirements: USDA-Water Erosion Prediction Project (WEPP). NSERL Report No. 1. National Soil Erosion Research Laboratory. USDA-ARS, W. Lafayette, IN.

Guy, H.P. 1969. Laboratory theory and methods for sediment analysis. Book 5, Chapter C1. Techniques of water-resources investigations of the U.S. Geological Survey. U.S. Gov. Print. Office, Washington, DC.

Guy, H.P., and V.W. Norman. 1970. Field methods for measurement of fluvial sediment. Book 3, Chapter C2. Techniques of water-resources investigations of the U.S. Geological Survey. U.S. Gov. Print. Office, Washington, DC.

Holtan, H.N., N.E. Minshall, and L.L. Harold, committee. 1962. Field manual for research in agricultural hydrology. USDA, Agric. Handbook 224. U.S. Gov. Print. Office, Washington, DC.

Hudson, N. 1971. Soil conservation. Cornell University Press, Ithaca, NY.

Knisel, W.G. (ed.) 1980. CREAMS: A field-scale model for chemicals, runoff, and erosion from agricultural management systems. USDA, Conservation Research Report 26. U.S. Gov. Print. Office, Washington, DC.

Laflen, J.M., G.R. Foster, and C.A. Onstad. 1985. Simulation of individual-storm soil loss for modeling impact of erosion on crop productivity. p. 285-295. *In* S.A. El-Swaify, W.C. Moldenhauer, and A. Lo (ed.). Soil erosion and conservation, Proc. Int. Conf. on Soil Erosion and Conservation, Honolulu, HI. 16-22 January 1983. Conservation Society of America, Ankeny, IA.

Landsberg, H.E. 1985. World survey of climatology. Elsevier Science Publishing Co., Inc., New York, NY.

Leonard, R.A., W.G. Knisel, and D.A. Still. 1987. GLEAMS: Ground water loading effects of agricultural management systems. Trans. ASAE 30:1403-1418.

McCool, D.K. 1979. Regional differences in rainfall characteristics and their influences on rainfall simulator design. p. 17-21. *In* Proc. Rainfall Simulator Workshop, Tucson, AZ. 7-9 March 1979. USDA, ARM-W-10/July 1979. U.S. Gov. Print. Office, Washington, DC.

McCool, D.K., M.G. Dossett, and S.J. Yecha. 1981. A portable rill meter for field measurement of soil loss. p. 479-484. *In* Sediment and erosion transport measurements. Proc. Florence Symposium, IAHS, Publ. No. 133.

Mutchler, C.K. 1963. Runoff plot design and installation for soil erosion studies. USDA-ARS, ARS 41-79, U.S. Gov. Print. Office, Washington, DC.

National Research Council. 1986. Soil conservation. Assessing the national resources inventory. Vol. 1. National Academy Press, Washington, DC.

Onstad, C.A., and G.R. Foster. 1975. Erosion modeling on a watershed. Trans. ASAE 18:288-292.

Roose, E.J. 1977. Application of the Universal Soil Loss Equation of Wischmeier and Smith in West Africa. p. 177-187. *In* D.J. Greenland and R. Lal (ed.) Soil conservation and management in the humid tropics. Proc. International Conference on Soil Conservation and Management in the Humid Tropics. Ibadan, Nigeria, June 1975. John Wiley, New York.

Simons, D.B., R.M. Li, and T.J. Ward. 1977. A simple procedure for estimating on-site erosion. p. 95-102. *In* Proc. of the Intl. Symposium on Urban Hydrology, Hydraulics, and Sediment Control. Univ. of Kentucky, Lexington, KY.

Smith, R.E. and V.A. Ferreira. 1986. Effect of soil hydraulic properties on root zone transport processes. p. 123-137. *In* Proc. AGU Front Range Branch Hydrology Days. Hydrology Days Publ., Colorado St. Univ., Fort Collins, CO.

UNESCO. 1977. Atlas of world water balance. UNESCO Press, Paris, France.

UNESCO. 1978. World water balance and water resources of the Earth. UNESCO Studies and reports in Hydrology 25. UNESCO Press, Paris, France.

USDA. 1979. Proc. Rainfall Simulator Workshop, Tucson, AZ. 7-9 March 1979. USDA, ARM-W-10/July 1979. U.S. Gov Print. Office, Washington, DC.

U.S. Geological Survey. 1977. National handbook of recommended methods for water-data acquisition. USDI, U.S. Geological Survey, Office of Water Data Coordination. U.S. Gov. Print. Office, Washington, DC.

Williams, J.R. 1975. Sediment-yield prediction with universal equation using runoff energy factor. p. 244-252. *In* Present and prospective technology for predicting sediment yields and sources. USDA, ARS-S-40. U.S. Gov. Print. Office, Washington, DC.

Williams, J.R., R.R. Allmaras, K.G. Renard, L. Lyles, W.C. Moldenhauer, G.W. Langdale, L.D. Meyer, and W.J. Rawls. 1981. Soil erosion effects on soil productivity: A research perspective. J. Soil Water Conserv. 36:82-90.

Williams, J.R., P.T. Dyke, and C.A. Jones. 1983. EPIC—A model for assessing the effects of erosion on soil productivity. *In* Proc. Third International Conference on State-of-the-Art in Ecological Modeling, Colorado State University, 24-28 May 1982.

Wischmeier, W.H., and D.D. Smith. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. USDA, Agric. Handbook 282. U.S. Gov. Print. Office, Washington, DC.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting rainfall-erosion losses: A guide to conservation planning. USDA, Agric. Handbook 537. U.S. Gov. Print. Office, Washington, DC.

Wolman, M.G. 1985. Soil erosion and crop productivity: A worldwide perspective. p. 9-21. *In* R.F. Follett, and B.A. Stewart (ed.). Soil erosion and crop productivity. ASA-CSSA-SSSA, Madison, WI.

Mechanics of Erosion: Measurement, Prediction and Control

D.W. Fryrear
U.S. Department of Agriculture, Agricultural Research Service, Big Spring, Texas, USA

ABSTRACT. Erosion of soil by wind is an annual problem in semiarid and arid regions of the world. The mechanics of wind erosion have been researched, but the field measurement of wind erosion has been historically difficult because of inadequate equipment. New equipment has been developed that will collect samples of airborne dust from eroding fields. Soil particle movement, composition, and nutrient concentration can be determined from the samples.

Estimates of annual wind erosion can be made using the USDA Wind Erosion Equation. The equation works best in the small grain production area of the Great Plains, but it can be used to compare wind erosion control practices at any location. Estimates of the number of dust storms can be made using climatic models and these estimates will warn of potentially severe erosion.

Management of surface residues, tillage, or wind barriers are the major methods used to control wind erosion. Lack of rainfall will influence the selection of erosion control techniques and limit the quantity of residue produced. If even 30 percent of the soil surface is protected with nonerodible material, wind erosion losses will be reduced 80 percent. Soil ridges at least 10 cm high will reduce wind erosion losses 85 percent, except on deep sands. The timing of wind erosion control efforts with available soil water is important because ridging a moist noneroding soil is much more effective than ridging a dry eroding soil.

Introduction

The hazards of wind erosion on agricultural lands extend back into ancient history (Wilson and Cooke, 1980). Wind erosion received international notoriety when the Great Plains of the United States experienced serious wind erosion during the prolonged drought of the 1930s. It was this spectacular period that prompted the initiation of research into the nature of the wind erosion process and the development of effective wind erosion control practices.

Wind erosion is a unique erosion process. The wind-eroded material can be seen and the impact of windblown soil particles can be felt. Windblown soil particles physically damage plant tissue and if the exposure continues long enough, damaged plants will die.

Wind erosion can occur whenever bare, erodible soils are exposed to erosive winds. While coarse-textured, sandy soils are most susceptible, any unprotected soil that has erodible material on the surface can be eroded by the wind. In the United States every state has areas susceptible to wind erosion, but the majority of severe wind erosion occurs in the Great Plains region. The tremendous expanse of unprotected erodible soils and erosive winds during the spring months makes the Great Plains particularly susceptible to extensive wind erosion.

Whenever the wind speed exceeds the minimum threshold velocity, loose soil particles become unstable, are injected into the wind stream, and may return to the soil surface to dislodge additional particles. The process of detachment and transport will continue until the wind stream becomes saturated with soil particles. The absolute size and percentage will depend on the velocity and turbulence of the wind. Generally, 7 to 25 percent of the total soil movement will be particles 500 to 1000μ moving as surface creep, 50 to 80 percent will be particles 100 to 500μ moving in saltation, and 3 to 38 percent will be particles 2 to 100μ moving in suspension (Lyles *et al.*, 1985). Particles in suspension may be transported great distances and will contain the highest percentage of soil nutrients.

Measurement

Wind erosion can be observed via dust clouds that are generated, but actual quantitive measurements of wind erosion are difficult. Under extreme wind erosion conditions soil losses can be measured by the decrease in surface elevation, but this is usually not an acceptable procedure because a few mm of soil are equivalent to several tons of soil loss per ha. If vegetated areas are adjacent to the eroding fields, the volume of eroded material collected in the entrapment zone will be a partial measure of erosion. This will be a conservative measure because not all eroded material will be collected. Very fine eroded material can be transported hundreds of kilometers before being deposited. If data are available, changes in crop yields may be correlated with the soil loss that has occurred, but 30 to 50 years of record may be required depending on the severity of the annual erosion. Changes in crop yields may also reflect the impact of continuous cropping, decreased fertility level of the soil, changes in management, or possibly changes in diseases or insects. It is very difficult to separate the impact of erosion from other factors that influence yields without complete records of each factor.

Collecting Samplers

With the development of dust sampling or other erosion measurement equipment it is possible to collect samples of material eroded by wind. Wind erosion samplers have been developed by Bagnold (1941), Armbrust (1967), Merva and Peterson (1983), Steen (1977), Leatherman (1978), and Bocharov (1984). The most recent is the Big Spring Number Eight (BSNE) developed by USDA-ARS at Big Spring, Texas (Fryrear, 1985). The BSNE is not expensive, will operate unattended for weeks, and will collect at least 86 percent of the material passing the sampler. BSNE samplers can be located at various heights to determine the vertical distribution of eroded material and sufficient sample may be collected for detailed physical and chemical analysis. Details of the BSNE sampler are described in Appendix A.

Controlled Erosion

With laboratory wind tunnels, studies of wind erosion can be conducted by holding all but one or two factors constant. This technique has been used to identify the influence of cover, roughness, nonerodible elements, plant injury, and to simulate wind barrier influences. Field wind erosion can be measured by using portable wind tunnels on field plots. Various soil and vegetation treatments can be established under natural rainfall and weather conditions and the changes in erosion evaluated. Field wind tunnel tests do not require that soil or plant conditions be simulated as in laboratory conditions, but the investigator has no control over the rainfall or weather conditions. Field wind tunnel tests represent only the extreme windward edge of the field unless eroded material is introduced into the tunnel.

Prediction

Annual Soil Loss

Wind and sand movement reported by Bagnold (1941) fit a log (sand movement)-linear (wind velocity) relationship (Figure 1). With cultivated soils the relations developed by Bagnold may not be valid because of surface aggregation, roughness, and vegetation. Much of the early research on wind and soil conditions was conducted by W.S. Chepil and N.P. Woodruff. Chepil and Woodruff (1963) prepared an excellent summary of wind erosion research. This publication contains the majority of the information used to develop the initial Wind Erosion Equation (Woodruff & Siddoway, 1965). This equation is used throughout the United States to predict wind erosion under a wide variety of soil and climatic conditions. The Wind Erosion Equation (Appendix B) is empirical and assumes no interaction between the various factors. Its solution requires several tables and figures.

V. Pasak (1973) also developed an equation to describe the intensity of wind erosion. Pasak's equation (Appendix C) contains terms for velocity, nonerodible particles in the soil, and the moisture content of the soil. There are no parameters that introduce the influence of soil roughness or soil cover except wind velocity at 5 cm above the soil surface. The Wind Erosion Equation and Pasak's equation have not been verified with field measurements.

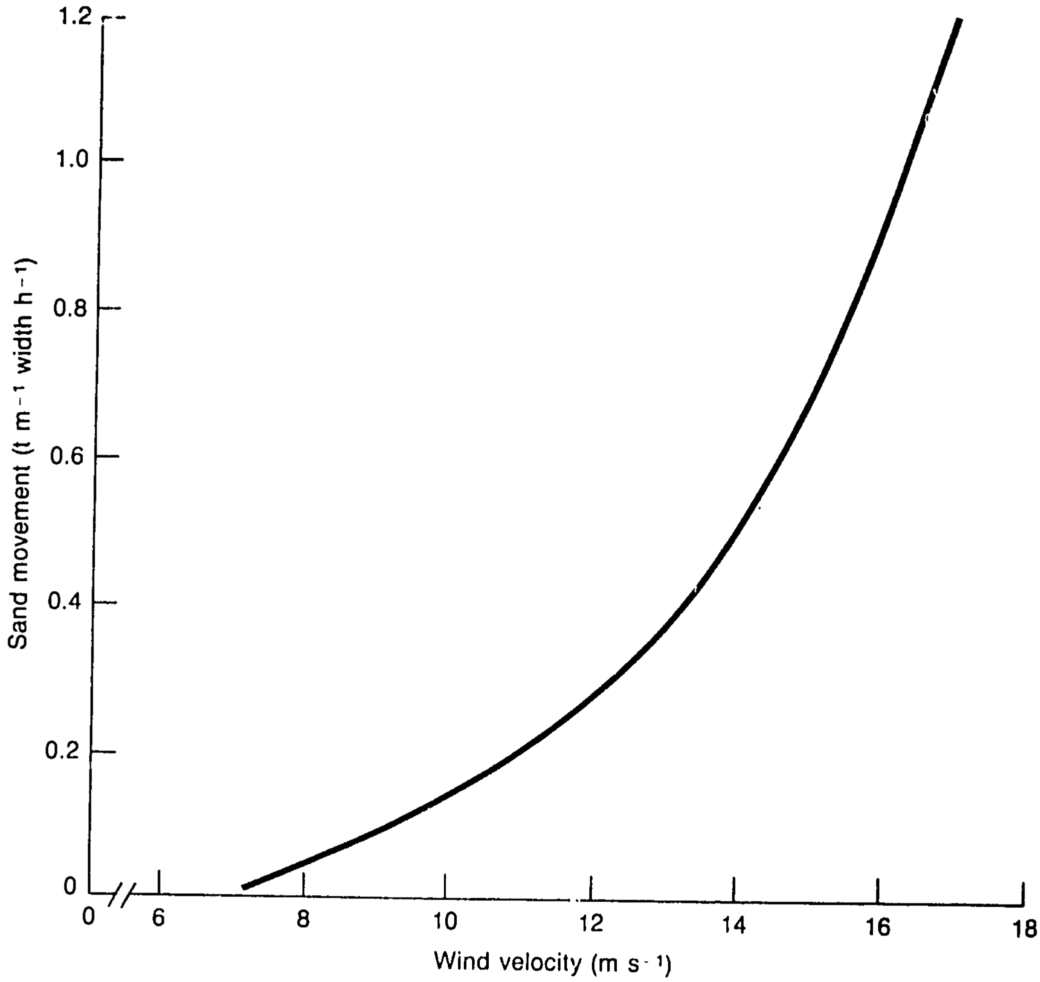


Figure 1. Relation between Wind Velocity and Rate of Sand Movement (Bagnold, 1941).

Number of Dust Storms

Prediction of the number of dust storms can be made using the climatic model of Chepil *et al.* (1963) or the Big Spring Index of Fryrear (1981). These equations (Appendix D) can be used to warn of potentially severe erosion several months in advance. Both equations are site or area specific and are not intended to apply to all areas. They do identify the major factors influencing dust storms in specific areas.

Controlling Wind Erosion

Wind erosion can be controlled by reducing wind velocity at the soil surface or by creating a soil surface that will not be susceptible to wind erosion. At this time it is not possible to reduce wind velocities over large land masses, but it is possible to reduce the wind velocity at the soil surface with standing vegetation, wind barriers, or nonerodible materials on the soil surface. Nonerodible materials could include flat residues, soil clods, or small stones. Erodibility of the soil surface can be reduced by increasing the fraction of the soil surface covered with nonerodible material, e.g., by roughening the soil with tillage implements. Soil erodibility can also be reduced by growing residue crops that will increase the organic matter content of the soil, or by applying soil stabilizers such as asphaltic mulches.

Standing Vegetation

Standing vegetation is several times more effective in reducing wind erosion losses than the same quantity of vegetation laying flat on the soil surface (Siddoway *et al.*, 1965). Because of weed problems or its use as fodder by livestock, it is not always possible to leave vegetation standing for extended periods of time. In many countries the vegetation remaining after crops are harvested is used for animal feed and is not available for controlling wind erosion in the field.

Wind Barriers

The effectiveness of a wind barrier will depend on the density and shape of the barrier (Woodruff *et al.*, 1963). If the major objective is to reduce wind velocities over the greatest distance leeward of the barrier, the barrier should have about 40 percent porosity. This will provide good protection for a distance about 10 times the height of the barrier (H) and will reduce wind erosion for a distance about 20 times the height of the barrier (Hagen, 1976). The denser the barrier, the greater the wind reduction is adjacent to the barrier but the shorter the distance which is protected. The desired density may also depend on the protection required. For example, if the crop between the barriers is susceptible to wind damage, the barrier must provide the maximum protection possible and the barriers may be spaced closer than 10 times H.

Nonerodible Elements

Nonerodible elements are any materials on the soil surface that will not be moved or transported by erosive winds. This includes stable soil aggregates (sometimes called clods), gravel or rock fragments larger than the maximum size that can be transported by wind, or may be large sections of plant material that have not decomposed. Soil loss will be reduced 80 percent if 30 percent of the soil surface is protected with nonerodible material. Figure 2 illustrates that soil loss from wind can be significantly reduced with a partial cover on the soil surface (Fryrear, 1985).

Roughness

Wind erosion losses will be reduced if the soil surface is ridged with tillage implements (Figure 3). The larger the ridge the greater the reduction in soil loss except for deep sands. Tillage implements will not control wind erosion on deep sands because the ridges are not stable. Soil roughness will reduce wind erosion until additional rain is received or the field is irrigated. Once the surface has been consolidated or crusted, soil roughness can be increased with subsequent tillage if the tillage is performed while the surface soil is moist.

Soil Amendments

Several chemical products have been tested that will successfully control wind erosion for a few weeks, but most were more expensive than anchored small grain straw (Chepil *et al.*, 1963). Armbrust and Lyles (1975) identified five polymers and one resin-in-water emulsion that reduce wind erosion for two months. The large volumes of material necessary, the expense, and reliable chemical weed control are problems that prevent the use of soil amendments except for high value crops.

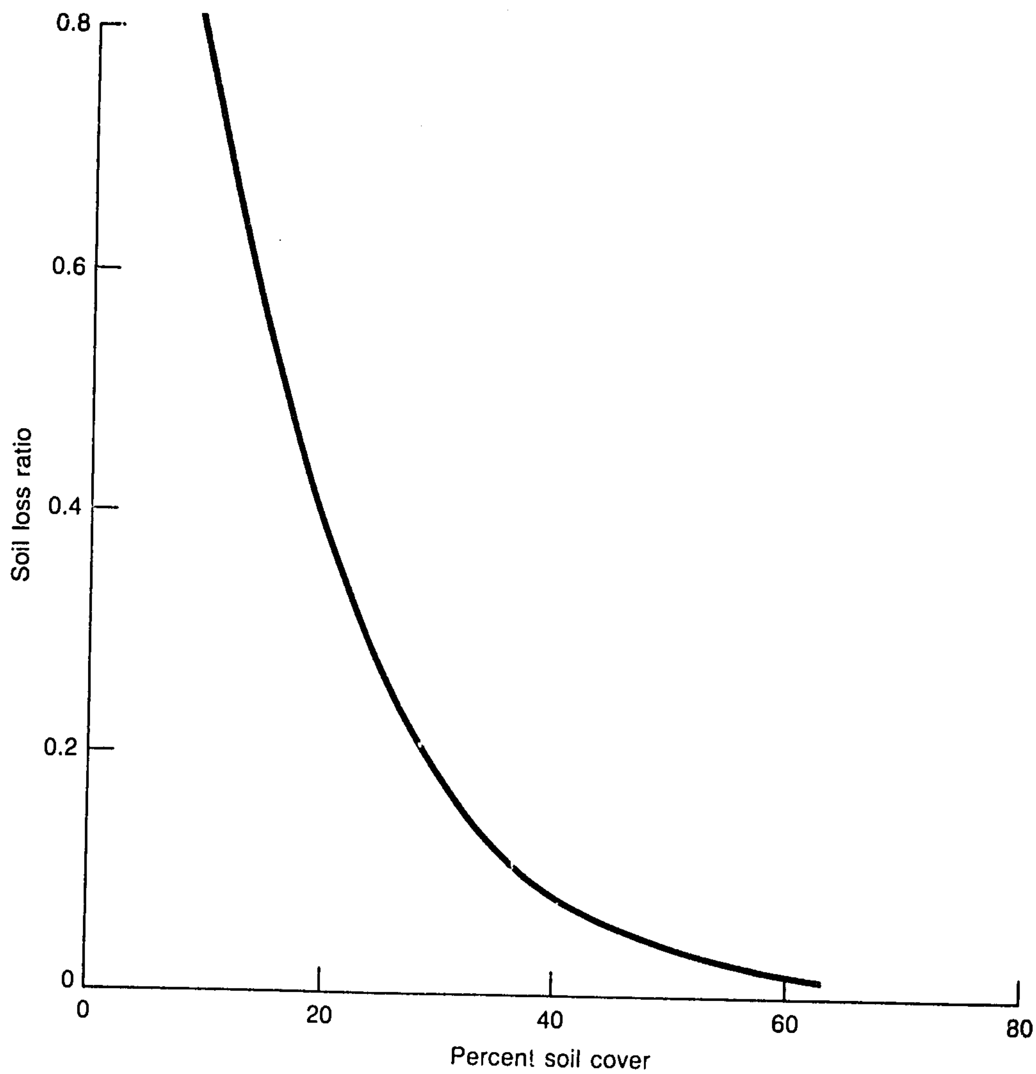


Figure 2. Relation between Soil Loss Ratio and Percent Soil Cover (Soil Loss with No Cover Equal to 1), when Various Percentages of Soil Surface Are Covered with Flat Nonerodible Material (Fryrear, 1985).

Plant Injury

Wind erosion during the crop establishment period can destroy young seedlings, reduce crop quality, or delay crop growth. All crops are not equally susceptible to wind damage (Table 1). As crops mature, their susceptibility to wind damage decreases. Exceptions are crops such as tobacco and cabbage in which crop quality and marketability may be decreased because of tissue damage and the presence of sand grains. To protect young seedlings farmers may use tillage implements to maintain soil roughness, or may grow wind-resistant, tall crops adjacent to the susceptible crop.

Conclusions

Wind erosion continues to be an annual problem in sandy land areas with a semiarid climate. The major factors involved have been identified and effective wind erosion control systems have been developed for high residue crops. Without surface residues, the soil surface must be roughened with tillage after each rainstorm. The effectiveness of the tillage system will depend on the timeliness and type of tillage. Wind erosion losses can be reduced 80 percent if 30 percent of the soil surface is protected with nonerodible material

Table 1. Crop Survival as Influenced by Duration of Exposure to a 15 m s^{-1} Wind with Sand Flux of 0.05 kg m^{-1} width s^{-1} on Plants 9 or 10 Days Old (Fryrear and Downes, 1975

Crop	Survival Rates at Three Exposure Times (min)		
	5	10	20
	.... %		
Pepper	75	8	0
Onion	100	100	100
Cabbage	100	87	56
Southern pea	100	94	72
Carrot	91	10	4
Cucumber	100	100	46
Cotton	100	85	15
Sunflower	91	88	72
Avg.	95	72	46

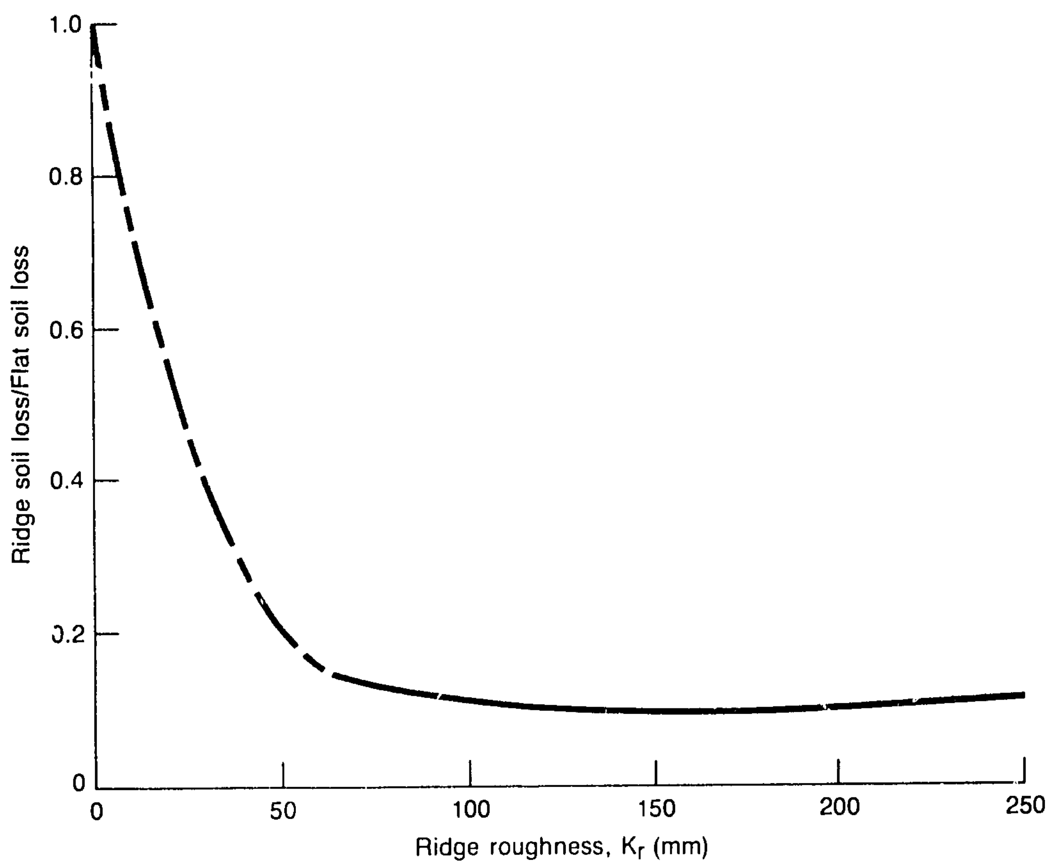


Figure 3. Relation between Soil Loss Ratio and Soil Ridge Roughness K_r with Wind Direction Normal to Ridges in the Wind Tunnel;

$$K_r = \left(\frac{4\ (\text{Ridge Height})^2}{\text{Distance between Ridges}} \right)$$ (Fryrear, 1984).

such as soil clods, rocks, or crop residues. Many crops will be destroyed or yields significantly reduced when seedlings are exposed to blowing sand. Farmers must strive to protect the young seedlings the first few days after emergence. Wind barriers or soil ridges oriented perpendicularly to the erosive winds can reduce crop injury.

References

Armbrust, D.V. 1967. Design and operation of a portable soil blowing wind tunnel. USDA-ARS 41-131. U.S. Gov. Print. Office, Washington, DC.

Armbrust, D.V., and L. Lyles. 1975. Soil stabilizers to control wind erosion. p. 77-82. *In* Soil conditioners. SSSA Spec. Publ. 7, Madison, WI.

Bagnold, R.A. 1941. The physics of blown sand and desert dunes. Methuen & Co., Ltd. London, UK.

Bocharov, A.P. 1984. A description of devices used in the study of wind erosion of soils. Kainar Publishers, Alma-Ata.

Chepil, W.S., and N.P. Woodruff. 1963. The physics of wind erosion and its control. Adv. Agron. 15:211-302.

Chepil, W.S., N.P. Woodruff, F.H. Siddoway, D.W. Fryrear, and D.V. Armbrust. 1963. Vegetative and nonvegetative materials to control wind and water erosion. Soil Sci. Soc. Amer. Proc. 27:86-89.

Chepil, W.S., F.H. Siddoway, and D.V. Armbrust. 1963. Climatic index of wind erosion conditions in the Great Plains. Soil Sci. Soc. Amer. Proc. 27:449-452.

Fryrear, D.W., and J.D. Downes. 1975. Consider the plant in planning wind erosion control systems. Trans. ASAE 18:1070-1072, 1075.

Fryrear, D.W. 1981. Dust storms in the Southern Great Plains Trans. ASAE 24:991-994.

Fryrear, D.W. 1984. Soil ridges-clods and wind erosion. Trans. ASAE 27:445-448.

Fryrear, D.W. 1985. Soil cover and wind erosion. Trans. ASAE 28:781-784.

Fryrear, D.W. 1986. A field dust sampler. J. Soil Water Conserv. 41:185-188.

Hagen, L.J. 1976. Windbreak design for optimum wind erosion control. p. 31-36. *In* Proc. of the Symp. on Shelterbelts on the Great Plains, Denver, CO. 20-21 April 1976. Great Plains Agric. Council Publ. 78. Lincoln, NE.

Leatherman, S.P. 1978. A new aeolian sand trap design. Sedimentology 25:303-306.

Lyles, L., G.W. Cole, and L.J. Hagen. 1985. Wind erosion: Processes and prediction. p. 163-172. *In* R.F. Follett and B.A. Stewart (ed.) Soil erosion and crop productivity. ASA-CSSA-SSSA, Madison, WI.

Merva, K.R., and G. Peterson. 1983. Wind erosion sampling in the North Central Region. ASAE paper 83-2133.

Pasak, V. 1973. Wind erosion on soils. Vum. Zbraslav, Scientific Monographs 3.

Siddoway, F.H., W.S. Chepil, and D.V. Armbrust. 1965. Effect of kind, amount, and placement of residue on wind erosion control. Trans. ASAE 8:327-331.

Steen, B. 1977. A possible method for the sampling of Saharan dust. p. 279-288. *In* Saharan dust mobilization, transport, deposition. Proc. Workshop Gothenburg, Sweden, 25-28 April 1977.

Wilson, S.J., and R.U. Cooke. 1980. Wind erosion. p. 217-252. *In* M.J. Kirkby and R.P.C. Morgan (ed.) Soil erosion. John Wiley and Sons, New York.

Woodruff, N.P., D.W. Fryrear, and L. Lyles. 1963. Reducing wind velocity with field shelterbelts. Kans. Agr. Expt. Sta. Tech. Bull. 131.

Woodruff, N.P., and F.H. Siddoway. 1965. A wind erosion equation. Soil Sci. Soc. Amer. Proc. 29:602-608.

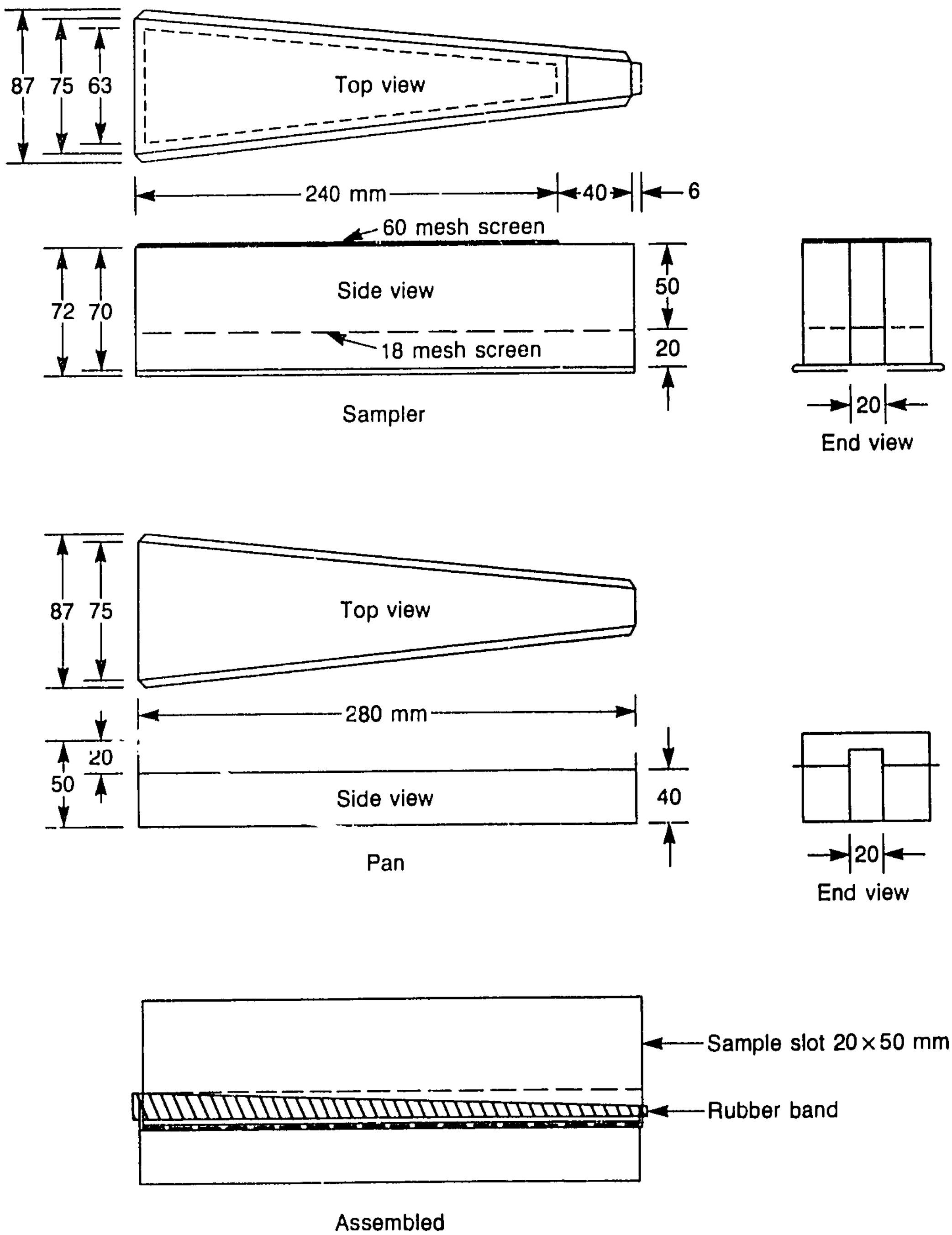
World Meteorological Organization. 1983. Meteorological aspects of certain processes affecting soil degradation-especially erosion. World Meteorological Organization Tech. Note 178, Geneva, Switzerland.

Appendix A

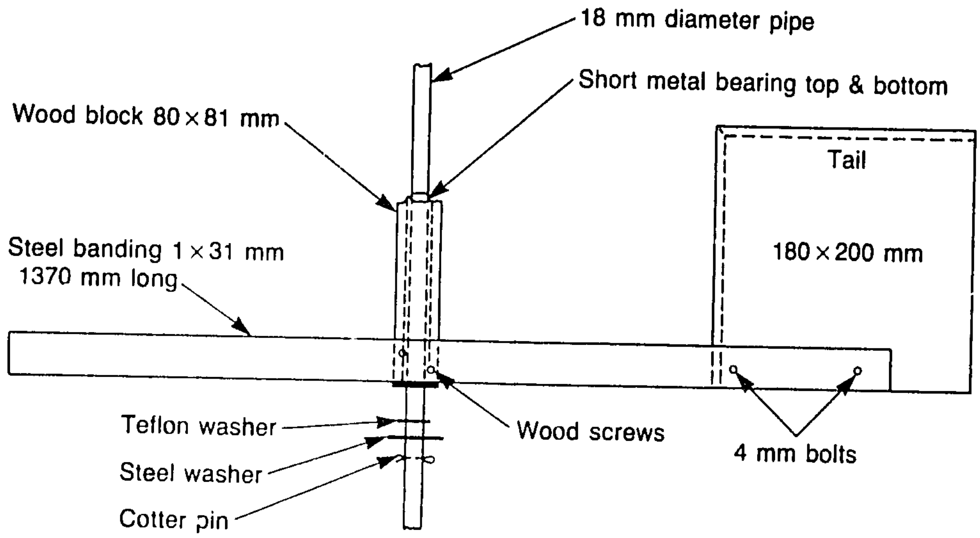
Big Spring Number Eight

Note: Tolerances on sample slot are ± 0.1 mm. All other dimensions are ± 2 mm. Sixty mesh screen must be stainless steel and 18 mesh screen must be steel. All joints and seams will be soldered. Rubber band cut from 9:50 × 15 inner tube.

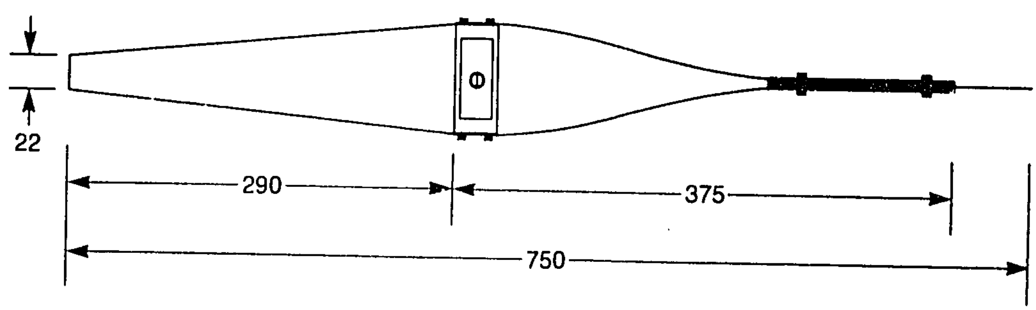
Big Spring Number Eight (BSNE)



Note: The 18 mm diameter pipe and cotter pin will be supplied by USDA. All dimensions are ± 2 mm.



Side view



Top view

Mounting section

Appendix B

USDA Wind Erosion Equation

$$E = f(I', K', C', L', V)$$

where:

E = Computed soil loss (short tons per acre per year);

I' = Erodibility index, obtained from two components: I - soil erodibility, dependent upon soil cloddiness (specifically percentage of soil fractions with diameter >0.84 mm), and knoll erodibility, which varies with length and degree of slope;

K' = A soil ridge factor which quantifies that contribution to surface roughness not due to clods or vegetation;

C' = A climatic factor = $\frac{34.483\ v^3}{(P/E)^2}$

where v = wind speed at 10 m above ground; and
P/E = Thornthwaite's ratio;

L' = Equivalent field length - distance (e.g. field width) along the prevailing wind direction less that under the influence of any shelter barrier (this zone is about ten times the height of the barrier if oriented at right angles to the wind or within ± 30° ($\leqslant \alpha$) of wind direction, and proportional to cos α otherwise);

V = Equivalent vegetation cover, itself a function of quantity, kind and orientation of vegetative cover.

For additional information the reader is referred to Woodruff and Siddoway (1965) or World Meteorological Organization (1983).

Appendix C

V. Pasak (1973) Derived Equation for the Determination of Wind Erosion Intensity

$$Ep = 22.02 - 0.72 P'' - 1.69V + 2.64v$$

where: E_p is soil eroded during wind action in time t = 15 min (g m^{-2});

P'' is the content of nonerodible particles in the soil (>0.8 mm) (%);

V is relative soil moisture and is determined by the relation of instantaneous moisture corresponding to the wilting point; and

v is wind velocity at ground surface level (5 cm above soil surface) (m s^{-1}).

Appendix D

Chepil, Siddoway and Armbrust (1963) Method of Estimating Number of Dust Storm Days during a Calendar Year from the Wind Erosion Climatic Index

$$N = -4.1 + 0.24\ (C_3)\ (r = 0.68)$$

where:

N = Number of dust storm days; and

C_3 = Previous three-year average of climatic index C.

$$C_1 = \frac{34.483\ V^3}{(P\text{-}E)^2}$$

where:

C_1 = Annual wind erosion climatic index;

V = Average annual wind velocity in mph corrected to a height of 30 feet; and

$P\text{-}E$ = Thornthwaite effective precipitation index.

This method is primarily used where residue crops are grown each year.

Fryrear (1981) Method of Estimating Number of Dust Storm Days

$$Y = 9.79 + 0.0265\ (BSI)\ (r = 0.69)$$

where:

Y = Number of dust storm days.

$$BSI = \text{Big Spring Index} = \sum_{Sep}^{Dec} \left(\frac{E}{P} = W\right)$$

where:

E = Monthly total evaporation from open pan;

P = Monthly total precipitation; and

W = Monthly total of daily average wind velocity at 2 feet.

The Fryrear method is satisfactory for areas where little or no surface residue is produced and where spring tillage is used to control wind erosion. If precipitation is above normal for the months of September through December, there will be sufficient soil moisture such that tillage will be very effective.

Measurement and Characterization of Soil-Water Relationships

D.J. Mulla
Washington State University, Pullman, Washington, USA

ABSTRACT. The measurement of soil water content and soil water potential are critical for efficient management of agricultural lands. A knowledge of these soil-water relationships facilitates improved irrigation scheduling and cropping decisions. In addition, physical properties of soil such as soil strength and permeability, and the partitioning of components of the water budget into evaporation, runoff, drainage, and storage are related to values for the soil water content and potential. In this paper, methods for measuring water content and water potential are discussed. A brief description of instrumentation is given along with a discussion of the principles upon which each method is based. Recommendations are made regarding the types of operating conditions in which each technique is useable, and a list of advantages and disadvantages for each method is given. Methods discussed for measuring soil moisture content include gravimetric, neutron probe, and microwave techniques. The measurement of soil water potential using tensiometers, pressure plates, moisture blocks, and thermocouple psychrometers is discussed. In addition, the use of an empirical expression is described for estimating soil matric potential from a knowledge of soil water content and soil texture.

Introduction

The importance of monitoring soil moisture content and the energy with which it is held in the soil should not be underestimated. Without a proper understanding of these soil-water relationships, it is likely that a poor understanding of agricultural, hydrological, and meteorological processes will result. Soil water is essential for the germination of seeds, the growth of crops and microorganisms, and largely determines the crop yield in semiarid regions. It is also the medium in which solute transport occurs, and the substance used in irrigation and in reclamation of saline soils. Water is a dynamic quantity, which is partitioned among that stored in the soil, draining through the profile, evaporating to the atmosphere, or running off at the soil surface. Water in soils affects physical properties such as soil permeability, strength, albedo, and temperature.

Methods for measuring water content and potential in soils have been reviewed in several texts and papers (Gardner, 1965; Hanks and Ashcroft, 1980; Holmes *et al.*, 1967; Marshall and Holmes, 1979; Papendick and Campbell, 1981; Schmugge *et al.*, 1980). In this paper, a comparison and contrast of the most popular techniques for measuring water content and potential will be presented. The emphasis will be on general principles, instrumentation, and advantages or disadvantages of the techniques. Gravimetric, neutron probe, and microwave techniques for monitoring soil water content will be discussed. The use of tensiometers, pressure plates, moisture blocks, and thermocouple psychrometers will be discussed for measuring soil water potential.

Methods for Measuring Soil Water Content

Gravimetric Methods

Gravimetric methods for measuring soil water content are among the most direct and accurate of all methods available. A summary of their uses and advantages appears in Table 1. Two types of gravimetric measurements may be obtained, depending upon the method used to collect soil from the field.

When soil samples are collected with an auger, shovel, or King tube, the normal approach is to determine the wetness of the sample on a mass basis (kg kg^{-1}). The value is obtained by determining the mass of the sample when it is collected from the field, as well as the mass of the sample after oven-drying at 105 C for 12 h. The mass wetness (w) is:

$$w = [(M_w + M_s) - M_s]/M_s \qquad [1]$$

where M_w represents the mass of water in the sample and M_s is the mass of its solid particles. The mass wetness is thus equivalent to the quantity (wet mass - dry mass)/dry mass.

Table 1. Summary of the Uses and Advantages of the Gravimetric Method of Measuring Soil Water Content.

Gravimetric Method	
Works best for:	Infrequent sampling in uniform, medium textured soils.
Not suited for:	Frequent sampling work in rocky, gravelly soils.
Advantages:	Accurate and inexpensive.
Disadvantages:	Time consuming, destructive sampling required. Care must be taken in heterogeneous profiles to take representative samples from each soil layer.

When undisturbed soil samples are collected from the field using a core sampler, the moisture content is usually expressed as a volume per unit volume of soil ($m^3\ m^{-3}$). Volumetric water content (θ) is determined from a knowledge of the sample mass before and after oven-drying at 105 °C for 12 h and from the known volume of the undisturbed core sample (V_t):

$$\theta = [(M_s + M_w) - M_s]/(\rho_w V_t) \qquad [2]$$

where ρ_w is the density of liquid water (approximately 1.0 Mg m^{-3}). Alternatively, the volumetric water content can be calculated if the mass wetness and soil bulk density (ρ_b) are known, using the relation:

$$\theta = (\rho_b/\rho_w)w. \qquad [3]$$

Radiation Methods

Two popular radiation methods for measuring volumetric water content are the gamma ray attenuation and neutron scattering techniques. Of these, the neutron scattering method is far easier, cheaper, and safer to use in the field than the gamma ray method. For an explanation of the gamma ray method the reader is referred to articles by Nofziger and Swartzendruber (1974), Schmugge *et al.* (1980), and Marshall and Holmes (1979).

In the neutron scattering method, a probe containing a source of fast neutrons is lowered into an access tube to a desired depth in the soil profile. The access tube must fit tightly into a hole drilled into the soil to insure good contact between soil and access tube. As fast neutrons collide with and are scattered from protons of water molecules in the soil surrounding the access tube, their kinetic motion is gradually reduced. After approximately 18 elastic collisions with hydrogen nuclei the neutrons, if scattered back to the probe, will be slowed down sufficiently to be detected. The number of thermalized neutrons returning to the detector per unit time is directly proportional to volumetric water content of the soil. As a consequence of this relationship, the sphere of influence of the measurements depends on soil water content. As soil water content increases, the volume of soil accessible to the neutrons and the sphere of influence decreases.

Typically, the source of radiation consists of 50 milliCurie (mCi) of a mixture of Americium and Beryllium. Neutrons emitted from such a source have an energy of approximately 2 million electron volts (MeV) and a velocity of 1600 km s^{-1}. The detector is only capable of sensing scattered neutrons having an energy of 0.03 eV, which

Table 2. A Summary of the Uses and Advantages of the Neutron Scattering Method of Measuring Soil Water Content.

Neutron Probe Method	
Works best for:	Uniform, medium-textured soils. Long-term experiments at fixed locations.
Not suited for:	Measurements near the soil surface or in shallow soils without specialized equipment. Rocky or gravelly soils. Soils containing appreciable boron or chloride. Highly stratified soils.
Advantages:	Frequent sampling at one location possible. Measurements are made in situ and are nondestructive. Results do not vary with temperature and pressure.
Disadvantages:	Radiation hazard to operator. Limited, variable spatial resolution (10-25 cm radius). Expensive equipment. Unable to distinguish between liquid water and ice.

corresponds to a velocity of 2.7 km s^{-1}. The detector is suspended on a cable which transmits the resulting signal to an amplifier, discriminator, and counting device at the soil surface.

The number of counts min^{-1} obtained with the neutron probe in the field is used along with a calibration curve to compute volumetric water content. A calibration curve usually can be described using a linear regression expression of the form:

$$\theta = (R_s/R_{std})b - j \qquad [4]$$

where R_s is the counting rate in the field; R_{std} is the counting rate for an access tube placed in pure water; b is the slope of the regression line; and j is a constant that accounts for background corrections and instrument dead time. Although manufacturers generally supply calibration curves with the purchase of their instruments, the researcher should periodically establish new curves in order to correct for changes due to electronic drift and to variations in soil properties. Special precautions are required in constructing calibration curves in swelling soils (Jaywardane *et al.*, 1983). For measurements near the soil surface (within about 25 cm) neutron probe measurements are inaccurate, and should be replaced by gravimetric measurements. A summary of the uses and advantages of the neutron probe appears in Table 2.

Time Domain Reflectometry

TDR is a method for measuring the volumetric water content of a soil. It is based on the principle that the time required for a pulse of microwave energy to travel between two parallel probes inserted into the soil will increase as the soil water content and dielectric constant increase. The transmission time depends upon the probe length as well as upon the dielectric constant of the soil, and these two factors can be used to compute the dielectric constant of the soil medium, K, using the relation:

$$K = [ct/(2L)]^2 \qquad [5]$$

where c is the speed of light; t is the measured transmission time; and L is the probe length. A calibration curve can be constructed to determine the relation between the soil

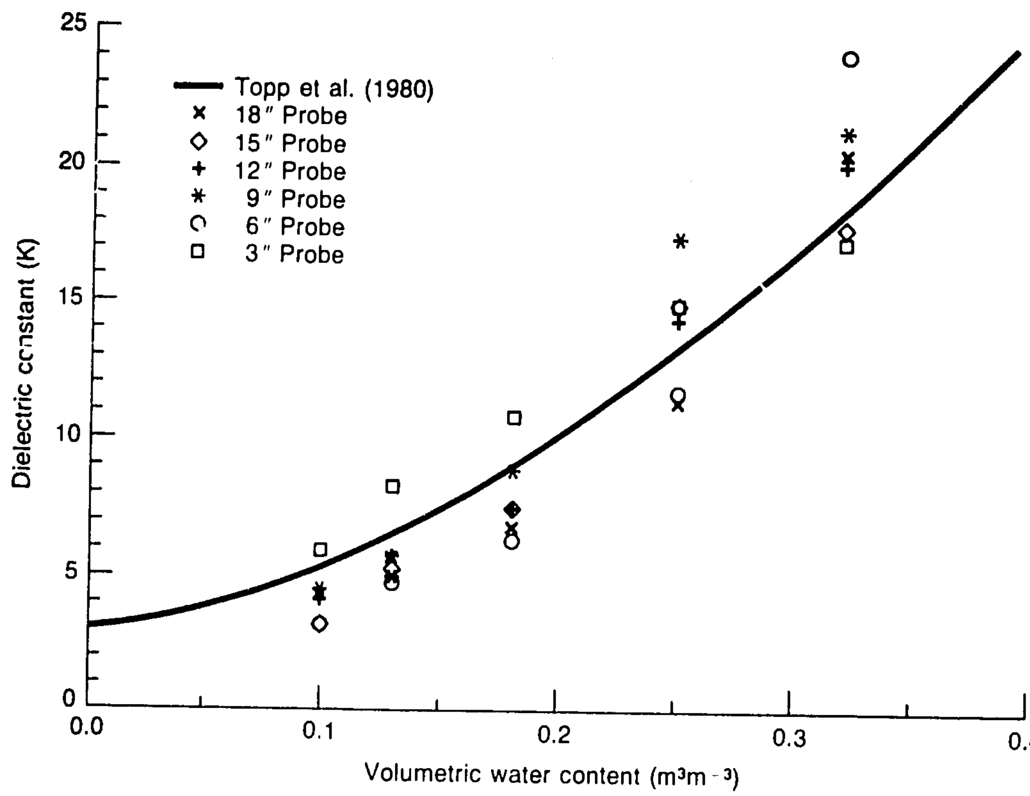


Figure 1. TDR Calibration Curve From Data of Topp *et al.* (1980) and Mulla (1985) Showing the Relation between Soil Water Content and the Dielectric Constant of the Soil Medium.

dielectric constant and soil volumetric water content. Numerous experiments (Mulla, 1985; Topp *et al.*, 1980) have shown that the form of this calibration curve (Figure 1) is given by the relation:

$$\theta = -5.3 \times 10^{-2} + 2.92 \times 10^{-2}K - 5.5 \times 10^{-4}K^2 + 4.3 \times 10^{-6}K^3. \qquad [6]$$

An advantage of the TDR method is that the form of this calibration curve is unaffected by factors such as soil texture, salinity, bulk density, temperature, and organic matter content. A recent investigation by Dalton *et al.* (1984) has show that the TDR method can also be used for simultaneous measurements of soil water content and electrical conductivity.

Physically, the TDR unit consists of a signal generator for the broadband microwave pulse (1 MHz to 500 MHz), a sampling head, and an oscilloscope to display the reflected waveform (Figure 2). This unit is connected via a coaxial transmission line and an impedance matching transformer to two parallel 1/4 in stainless steel probes which are inserted into the soil at a separation distance ranging from 3 to 7 cm. The length of the probes may vary from 8 cm to 50 cm, with a length of 30 cm being optimal for measurements in the rooting zone. Good contact between the probes and soil is essential as the method is sensitive to the dielectric properties of the entire medium between the parallel probes, including air. The method yields an average value for the water content of the soil volume contained between the probes along their entire length.

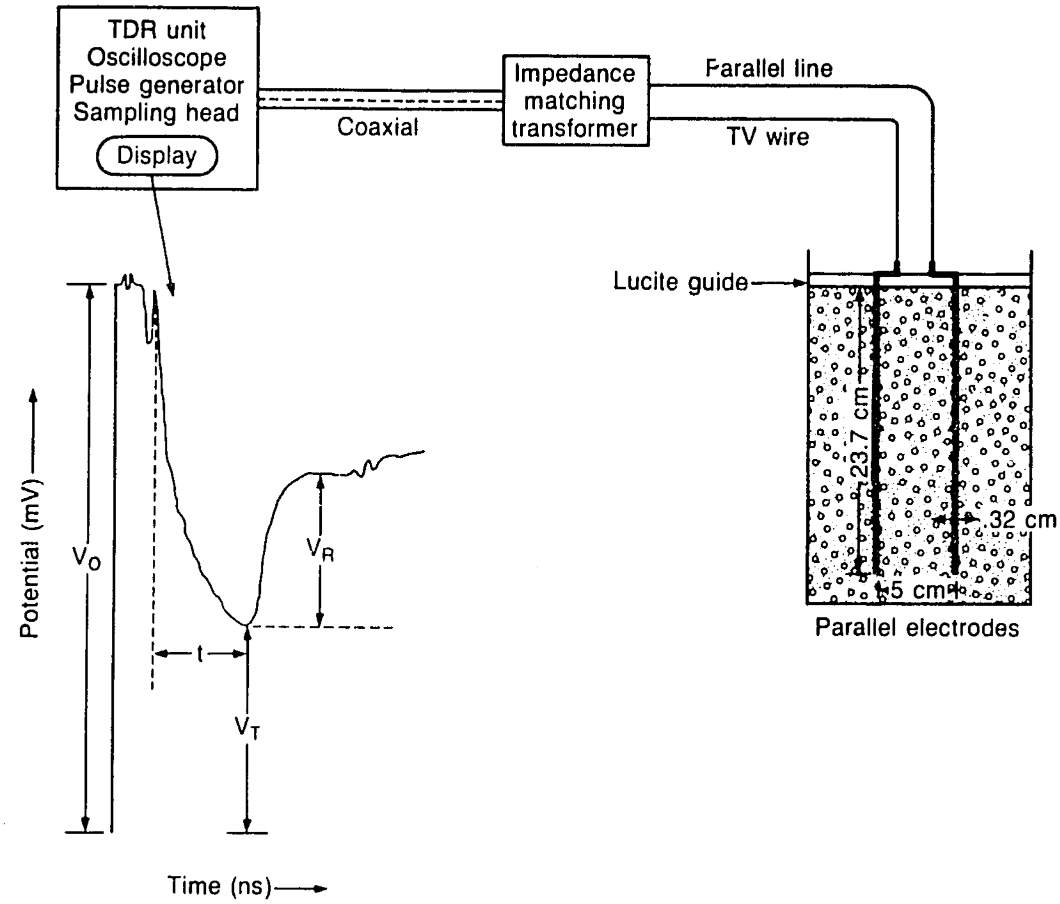


Figure 2. Schematic Diagram Showing Typical Instrumentation Used in Time Domain Reflectometry. V_0, V_T and V_R Represent the Voltage of the Step Pulse Generated by the TDR Unit, the Voltage of the Pulse Entering the Probes, and the Voltage of the Pulse Reflected From the Bottom of the Probes, Respectively.

The probes are easily inserted into moist soil and a reading may be obtained with some commercial instruments in as little as 5 s. Measurements in rocky, gravelly, or exceedingly dry clayey soils may be difficult due to problems in inserting probes into the soil. A summary of uses and advantages of time domain reflectometry appears in Table 3. Soil Moisture Equipment Corp. (P.O. Box 30025, Santa Barbara, California 93105) is a commercial supplier of a TDR unit (IRAMS unit) which is portable and automatically displays soil volumetric water content at each sampling location. Tektronix, Inc. supplies a TDR unit (Model 1502) which is suitable for theoretical research in the laboratory.

Soil Water Potential

Whereas soil water content is a measure of the amount of water held in soil, soil water potential is a measure of the potential energy with which a unit mass, volume, or weight of water is held in the soil matrix. The SI units for water potential expressed per unit mass, volume, or weight of water are joule kg^{-1}($J\ kg^{-1}$), megapascals (MPa), or meters (m), respectively. Note that soil scientists traditionally have used the units of bars to express water potential. In the SI system, 100 $J\ kg^{-1}$ = 0.1 MPa = 1 bar.

Table 3. A Summary of the Uses and Advantages of the Time Domain Reflectometry Method of Measuring Soil Water Content.

Time Domain Reflectometry	
Works best for:	Measurement in uniform, medium-textured soils. Rapid soil survey measurements.
Not suited for:	Highly stratified soils. Rocky or gravelly soils.
Advantages:	One calibration curve applies to all soils. Rapid, easy technique. Nondestructive, in situ measurements. Can measure water content and electrical conductivity simultaneously. Distinguishes between liquid water and ice.
Disadvantages:	Limited spatial resolution with depth. Expensive equipment. Limited testing in field experiments.

Plant stress is dependent primarily upon the water potential of the soil; i.e., the energy of water held by the soil. Water stress may be equivalent in a coarse-textured soil having a volumetric water content of 0.05 and a fine-textured soil having a volumetric water content of 0.15 if the water potentials of both soils are equal.

By definition, the water potential is measured relative to the energy of a reference pool of pure water at a specified elevation, pressure, and temperature (Papendick and Mulla, 1986). Conventionally, this reference pool is assigned a potential energy of zero. Water will be at equilibrium in the soil when the water potential is equal at all depths. Conversely, when water flows from one depth to another, it flows from a region of higher to lower (more negative) total water potential. Conventionally, field capacity water content corresponds to a water potential ranging from -0.01 to -0.03 MPa, while the permanent wilting point (PWP) corresponds to a water potential of about -1.5 MPa. Hence, water potential is a quantity which is useful in predicting the movement of water in soil and the ability with which plants can extract water from the soil.

Total water potential, ψ, refers to the total potential energy of water in the soil. In unsaturated soils ψ is normally a negative quantity, since energy must be expended to remove the water from the soil. The total energy of the soil water may be determined by several different types of forces acting upon it, including the forces of gravity, ion solvation, hydrostatic pressure, adsorption, and cohesion between water molecules. Each force can be associated with measurable components of the total water potential using the expression:

$$\psi = \psi_g + \psi_p + \psi_m + \psi_o \qquad [7]$$

where the symbols ψ_g, ψ_p, ψ_m, and ψ_o refer to soil gravity potential, pressure potential, matric potential, and osmotic potential, respectively. The gravity potential results from the force of gravity. It is zero at the reference elevation, positive above it, and negative below it. The pressure potential results from the hydrostatic pressure of water and is positive below the water table and zero above and at the water table surface. Matric potential results from the forces between soil particles and water. It is negative in unsaturated soil and zero below the water table or in saturated soil. Osmotic potential results from the forces between water and the ions or solutes in the soil, and is always a negative quantity.

The osmotic potential at saturation, ψ_{os}, can be estimated from measurements of electrical conductivity (E.C.) on a saturation paste extract using the expression:

$$\psi_o = -0.036 \times E.C. \qquad [8]$$

where E.C. is measured in mmhos cm^{-1} and osmotic potential is expressed in MPa. Papendick and Campbell (1981) give an expression which can be used with Eq. [8] to compute the osmotic potential at any water content:

$$\psi_o = \psi_{os} (\theta_s/\theta) \qquad [9]$$

where θ_s is the volumetric water content at saturation. In Eq. [9] it is assumed that no changes in ion activity occur and that no precipitation occurs; therefore Eq. [9] gives only approximate results.

Methods for Measuring Soil Water Potential

Most methods for measuring water potential involve instruments that are specifically designed to evaluate only the matric component of the total soil water potential. Estimates of the osmotic component may be obtained from Eq. [8] and [9]. The gravity component can be estimated (in Pa) from the expression:

$$\psi_g = -gz \qquad [10]$$

where g is acceleration due to gravity (9.8 m^2 s^{-1}) and z is the distance in m between the specified depth in the soil and a reference plane at the soil surface where z=0. The pressure potential may be estimated from the expression:

$$\psi_p = gz \qquad [11]$$

where z is the distance below the water table. The remainder of the discussion below will deal primarily with methods for measuring the soil matric potential.

Tensiometer

Tensiometers are widely used in situations where soils are not allowed to become drier than -0.08 MPa; they are particularly useful in helping farmers to schedule crop irrigation (Hanks and Ashcroft, 1980). A tensiometer consists of a ceramic cup connected via a continuous column of water to a vacuum gauge which reads from 0 to 100 centibars (cbar). The tensiometer is installed in the soil so that the cup is in good contact with soil. Equilibrium between the tensiometer and the soil water is established by the movement of water and ions through the porous cup. The vacuum established inside the tensiometer is read on the vacuum gauge and converted to matric potential using the expression:

$$\psi_m = -0.001 \times (\text{gauge reading}) + gz_0 \qquad [12]$$

where z_0 is the distance in m between the gauge and the middle of the porous cup and ψ_m is expressed in MPa. In practice, the last term in Eq. [11] is small and can be omitted with little loss of accuracy.

Air bubbles inside the tensiometer column must be completely eliminated for the system to work properly. To achieve this, the column must be filled with degassed water obtained by boiling the water for several minutes during evacuation. Tensiometers are not usable in dry soils having a matric potential less than -0.08 MPa due to cavitation in the hanging water column. Hence, the range of operation for tensiometers is limited to soil water potentials from 0 to -0.08 MPa; this range is characteristic of fairly wet soils. Another limitation of tensiometers is that they are sensitive to temperature fluctuations (Taylor *et al.*, 1961), and readings at different times of the day may vary. A summary of the uses and advantages of tensiometers in measuring soil water potential appears in Table 4. For automated recording of tensiometers, the vacuum gauge may be replaced with pressure transducers sensitive to pressure changes in the water column (Schmugge *et al.*, 1980), and a datalogger may be used to record the measurements.

Pressure Plate

The pressure plate is used in the laboratory to monitor water content in soils that may be much drier than those monitored with tensiometers. Soils that have matric potentials as low as -1.5 MPa may be studied with this technique. A summary of the uses and advantages of the pressure plate in measuring soil water potential appears in Table 5.

The pressure plate method involves the following steps. A dry disturbed soil sample or an undisturbed soil core is placed on the pressure plate and very slowly wet until saturated. The porous plate is placed in a sturdy steel chamber which can withstand as much as 1.5 MPa of applied pressure. The chamber is sealed, and air or nitrogen gas is applied to the chamber using a regulator to control pressure.

Table 4. Summary of the Uses and Advantages of Tensiometers in Measuring Soil Water Potential.

Tensiometers	
Works best for:	Moist soil. Irrigation scheduling. Repeated measurements at fixed locations. Rapid survey measurements.
Not suited for:	Dry soil.
Advantages:	Inexpensive and easy to install. Rapid and accurate measurements. Measurements are nondestructive and in situ. Automated readings possible with pressure transducers.
Disadvantages:	Limited to a range of from 0 to -0.08 MPa. Porous cups are easily broken during installation. Pores in cup may become clogged over time. Water in column must be refilled periodically. Readings are sensitive to temperature fluctuations.

Table 5. Summary of the Uses and Advantages of the Pressure Plate in Measuring Soil Water Potential.

Pressure Plate	
Works best for:	Disturbed soil samples.
Not suited for:	Rapid measurements.
Advantages:	Used for determining soil moisture characteristic curves. Large range of matric potentials (0 to -1.5 MPa). Several samples may be analyzed simultaneously.
Disadvantages:	Destructive sampling required. Time consuming measurements. In situ measurements not possible. Moderately expensive equipment required.

Once the gas pressure is fixed, water and solutes in the soil will pass through the plate into a body of free water below it at atmospheric pressure. When equilibrium is attained and water ceases to flow through the plate, the total water potential of the soil water is zero relative to the free water below the plate. Hence, the matric potential at equilibrium is given by:

$$\psi_m = -P \quad [13]$$

where P is the applied (constant) gas pressure in MPa. Attainment of equilibrium generally requires at least one and usually two days from the onset of pressure application. When equilibrium is reached the gas pressure is released, the soil samples are removed, and their mass basis water content is obtained using Eq. [1]. New samples can be prepared to determine their moisture content at other matric potentials.

The relation between moisture content and matric potential over the range from 0 to -1.5 MPa is easily determined as outlined above using a pressure plate. This relationship, known as the moisture characteristic curve (Figure 3), is one of the most fundamental and important of all relations in agriculture. It is used in determining the amount of plant available water in a soil, and illustrates the profound differences in water holding capacity between soils of different textures. Once a field measurement of soil matric potential is made for a soil whose moisture characteristic curve is known, the water content of the soil at that matric potential can be determined (or vice-versa).

Moisture Blocks

Electrodes placed in a porous block of fiberglass, gypsum, or ceramic are used to monitor the resistance (ohm) or conductance (mmho) of water in equilibrium with soil water outside the block. As external water content changes, water and solutes are free to move through the porous block until equilibrium is reestablished. Thus, the moisture block readings are indirectly related to soil matric potential. A calibration curve relating conductance to matric potential for the moisture block (Figure 4) can be easily determined in the laboratory by placing saturated moisture blocks on a ceramic plate in a pressure chamber and recording their conductance at each of several applied gas pressures.

Gypsum blocks have the advantage of being able to buffer changes in solute concentration of the soil solution so that the readings are less affected by changes in solution concentration of solutes than readings with fiberglass blocks. Fiberglass blocks have the advantage of not disintegrating during long-term usage in the field. The blocks must be installed in the soil, and good contact between the soil and blocks is essential. Readings are very sensitive to the effects of temperature fluctuations, and special precautions must be taken to compensate for them (Willoughby and Cuming, 1985).

Gypsum blocks are useful for monitoring soil water potential in the field for decisions affecting irrigation scheduling. Cary and Fisher (1983) have described a simple electronic system capable of controlling irrigation decisions with a network of gypsum blocks. A summary of the uses and advantages of gypsum blocks in measuring soil water potential appears in Table 6.

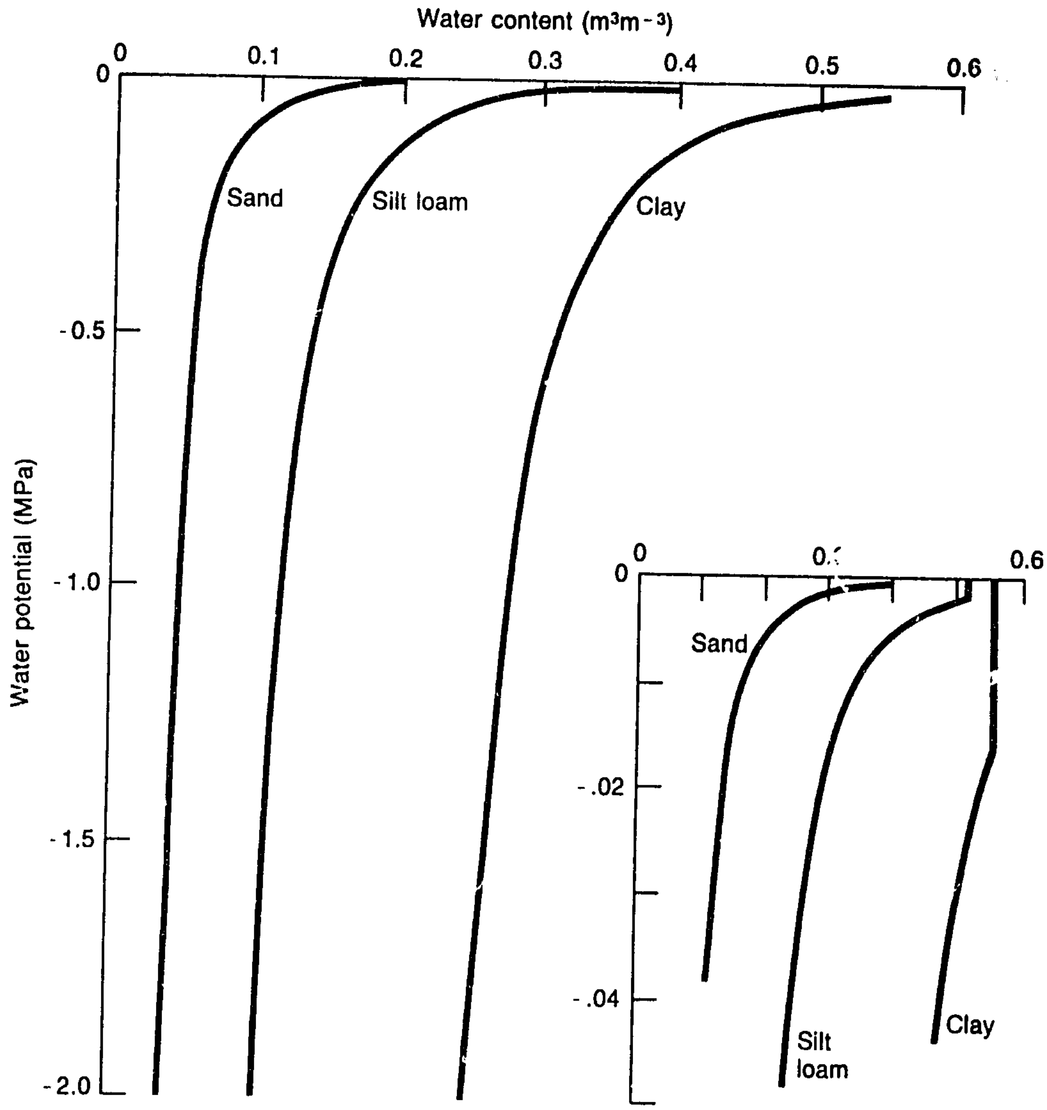


Figure 3. Typical Moisture Characteristic Curves for Soils with Sandy, Silt Loam, and Clayey Textures.

Thermocouple Psychrometers

A thermocouple psychrometer differs from the previous methods discussed in that it is a method for measuring the sum of the matric and osmotic components of soil water potential. It operates on the principle that the relative humidity, rh, of the air in equilibrium with a soil sample is related to the water potential through:

$$\psi_m + \psi_o = (RT/V_w) \ln(rh). \qquad [14]$$

In Eq. [14] the symbols R, T, and V_w represent the universal gas constant (8.31×10^{-6} m^3 MPa $mol^{-1}K^{-1}$), the absolute temperature, and the partial molal volume of water (1.8×10^{-5} m^3 mol^{-1}), respectively. Thermocouple psychrometry is a very accurate method for determining the relative humidity to within 1 part in 10,000. This determination, along with the expression in Eq. [14] allows the soil water potential to be computed over a wide range of values (at least from -0.05 to -50 MPa).

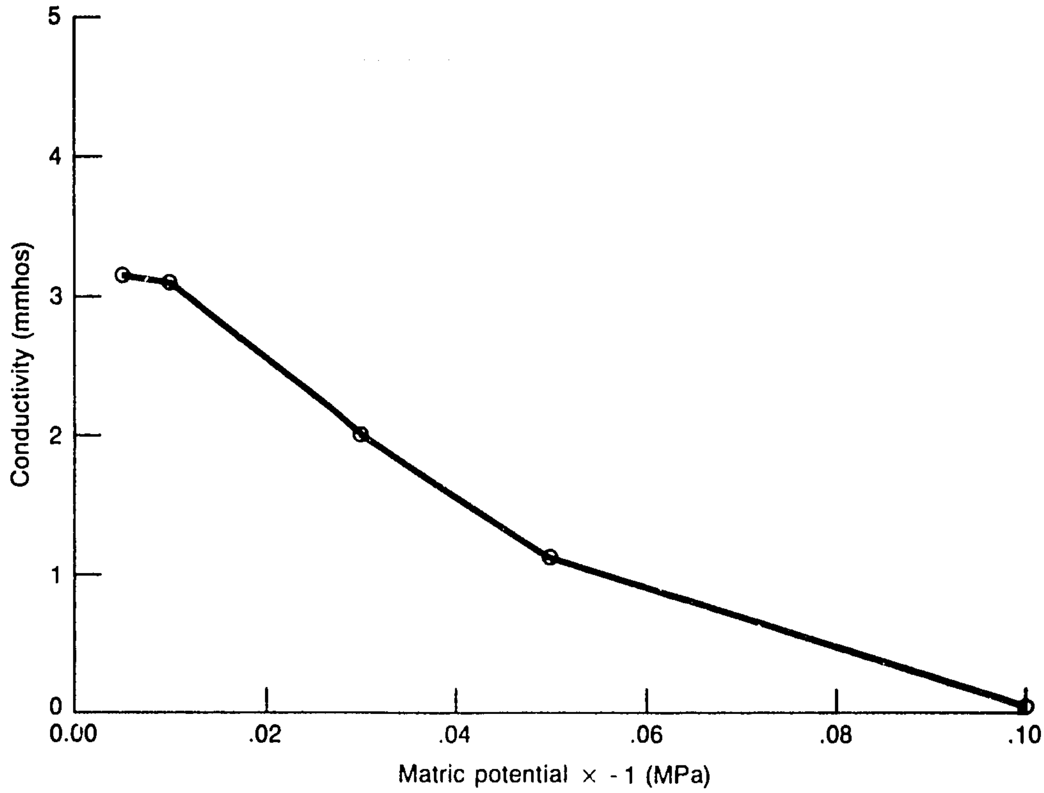


Figure 4. Typical Gypsum Block Calibration Curve, Showing the Relation Between Conductivity and Matric Potential.

Table 6. Summary of the Uses and Advantages of Gypsum Blocks in Determining Soil Water Potential.

Gypsum Blocks	
Works best for:	Medium-textured soils. Repeated in situ measurements at a fixed location.
Not suited for:	Very wet or very saline soils. Rocky or gravelly soils. Acidic soils (blocks may dissolve).
Advantages:	Inexpensive. Nondestructive, in situ measurements. May be used with datalogger for automated measurements. Gypsum in blocks buffers small changes in salt content.
Disadvantages:	Blocks disintegrate with time. Calibration curve changes with time and is nonlinear. Sensitive to temperature fluctuations. Each block must be calibrated individually.

The basic component of thermocouple psychrometers consists of two junctions of dissimilar metals. Commonly, a chromel-constantan junction is used for measuring the wet bulb temperature of the sample chamber in which the soil sample is placed, while either a chromel-constantan or a copper-constantan junction measures the dry bulb temperature of the sample itself. The reason for measuring wet and dry bulb temperatures is that they are related to the relative humidity through the expression:

$$rh = (\rho'_{vw}/\rho'_0) - 0.495(T_a - T_w)\rho'_0 \qquad [15]$$

where T_a and T_w are the dry and wet bulb temperatures, respectively, and ρ'_{vw} and ρ'_0 are the saturated vapor densities at the wet and dry bulb temperatures, respectively. The temperature difference between dry and wet bulb chromel-constantan junctions is directly proportional to the voltage output of the thermocouple psychrometer as shown by the relation:

$$V = (60\ \mu V/°C)(T_a - T_w). \qquad [16]$$

In practice, the following approach is used to determine the water potential of a soil sample in the laboratory. Tables given by Wiebe *et al.* (1971) are used to determine the water potential of salt solutions at known concentrations. As an example, a range of concentrations in KCl solutions can be used to obtain a calibration curve of water potential versus output voltage for the thermocouple psychrometer (Figure 5). Using linear regression, the relation between output voltage (V) and water potential in Figure 5 was found to be:

$$V = -5.08\psi + 0.521. \qquad [17]$$

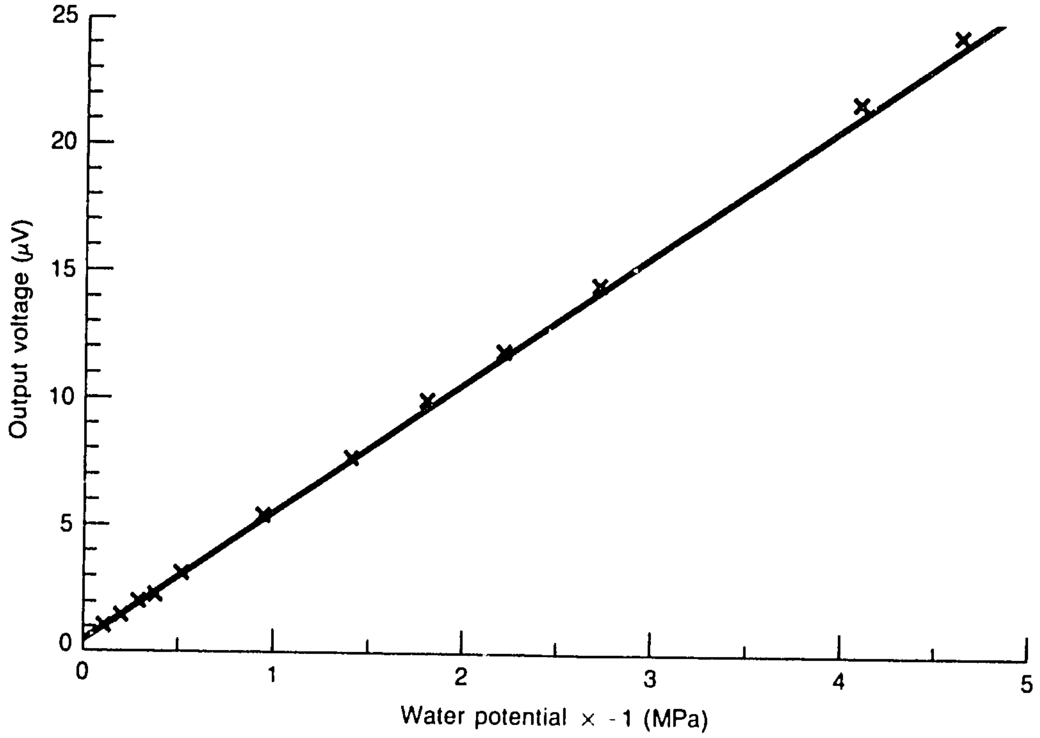


Figure 5. Typical Thermocouple Psychrometer Calibration Curve at 22 Degrees Celsius, Showing the Relation Between Output Voltage and Water Potential in a Series of KCl Solutions. The KCl Concentrations Used for this Curve were 0.025, 0.046, 0.066, 0.085, 0.118, 0.214, 0.319, 0.411, 0.505, 0.620, 0.934 and 1.053 Molal.

Table 7. Summary of the Uses and Advantages of the Thermocouple Psychrometer in Measuring Soil Water Potential.

Thermocouple Psychrometer	
Works best for:	Laboratory measurements of soils or solutions. Water potentials less than -0.05 MPa.
Not suited for:	Field measurements.
Advantages:	Accurate for water potentials from -0.05 to -50 MPa.
Disadvantages:	Very sensitive to contamination by dust or oil. Very sensitive to temperature fluctuations. Moderately expensive equipment.

Once the form of the calibration curve is known, soil samples may be placed in the sample chamber of the thermocouple psychrometer, and the voltage output can be directly used to infer water potential from the calibration curve.

Wet bulb depressions in the thermocouple psychrometer may be obtained using the Peltier effect (Wiebe *et al.*, 1971) in which cooling of the wet bulb junction occurs when current is passed through it. Water condenses on this junction when it reaches the wet bulb temperature. At this point the current is shut off. As the junction warms up, the temperature again reaches the wet bulb temperature, and evaporation of water then causes the junction to remain at the wet bulb temperature. When this occurs the psychrometer displays the output voltage corresponding to the temperature difference between the wet and dry bulb junctions. Wet bulb depressions may also be obtained using Richards-type psychrometers in which the wet bulb junction is actually dipped into distilled water and allowed to evaporate in the chamber containing the soil sample.

To avoid errors in making measurements with psychrometers, the sample chamber must be kept free of contamination to prevent adsorption of water vapor on its sides. Also, the chamber must be constructed of materials having high thermal conductivity and high heat capacity in order to maintain constant temperature in the chamber and prevent temperature fluctuations. Decagon Devices Incorporated (N.W. 115 State St., Pullman, Washington) is a commercial supplier of a thermocouple psychrometer (model SC-10) which conforms to these rigorous specifications. Thermocouple psychrometers for making in situ measurements of water potential in the field are available (Merrill and Rawlins, 1972; Campbell, 1979), but have never been very reliable or easy to use due to extreme sensitivity to temperature fluctuations which occur in the field. A summary of the uses and advantages of the thermocouple psychrometer appears in Table 7.

Empirical Form of the Moisture Characteristic Curve

As mentioned previously, the relation between water content and matric potential is known as the moisture characteristic curve. The form of this curve has been correlated to the physical properties of soils by many researchers (Campbell, 1974; Rawls *et al.*, 1982). A commonly used empirical expression for the moisture characteristic curve has the form:

$$\psi_m = -A\theta^B \qquad [18]$$

where A and B are empirical constants which are related to the physical properties of soils. Since it is often difficult to measure matric potential in the field, the use of Eq. [18] along with a measurement of field water content offers an alternative method for estimating soil matric potential.

Saxton *et al.* (1986) have determined the relation between the constants A and B in Eq. [18] and the physical properties of over 2500 soil profiles in the United States. These relations work well for soils with clay contents of less than 60 percent and for matric potentials less than -0.01 MPa. Statistical expressions for A and B are of the form:

$$A = \exp [-4.396 - 0.0715(\% \text{ clay}) - 4.880 \times 10^{-4} (\% \text{ sand})^2 - 4.285 \times 10^{-5} (\%\text{sand})^2(\% \text{ clay})] \quad [19]$$

and

$$B = -3.140 - 0.00222(\% \text{ clay})^2 - 3.484 \times 10^{-5} (\%\text{sand})^2(\% \text{ clay}). \quad [20]$$

For quick estimation of matric potential using Eq. [18] to [20] all that is needed are the measured or estimated values of soil water content, clay content, and sand content. Estimations such as these may suffice in situations when the actual measurement of matric potential is impractical or unobtainable. Caution should be used in applying the above relations, since they are developed from information on average soil properties in North America.

References

Campbell, G.S. 1974. A simple method for determining unsaturated conductivity from moisture retention data. Soil Sci. 117:311-314.

Campbell, G.S. 1979. Improved thermocouple psychrometers for measurement of soil water potential in a temperature gradient. J. Phys. Environ. Sci. Instrum. 12:739-743.

Cary, J.W., and H.D. Fisher. 1983. Irrigation decisions simplified with electronics and soil water sensors. Soil Sci. Soc. Am. J. 47:1219-1223.

Dalton, F.N., W.N. Herkelrath, D.S. Rawlins, and J.D. Rhoades. 1984. Time-domain reflectometry: Simultaneous measurement of soil water content and electrical conductivity with a single probe. Science 224:989-990.

Gardner, W.H. 1965. Water content. *In* C.A. Black (ed.), Methods of soil analysis. Part I, Agronomy monograph #9, Am. Soc. of Agron., Madison, WI.

Hanks, R.J., and G.L. Ashcroft. 1980. Applied soil physics. Springer-Verlag, Berlin.

Holmes, J.W., S.A. Taylor, and S.J. Richards. 1967. Measurement of soil water. *In* R.C. Dinauer (ed.), Irrigation of agricultural lands, Agronomy monograph #11, Am. Soc. of Agron., Madison, WI.

Jaywardane, N.S., W.S. Meyer, and H.D. Barrs. 1983. Moisture measurement in a swelling clay soil using neutron moisture meters. Aust. J. Soil Res. 22:109-117.

Marshall, T.J., and J.W. Holmes. 1979. Soil physics. Cambridge University Press, Cambridge, UK.

Merrill, S.D., and S.L. Rawlins. 1972. Field measurement of soil water potential with thermocouple psychrometers. Soil Sci. 113:102-109.

Mulla, D.J. 1985. Using time domain reflectometry to measure frost depth and unfrozen water content in soil. Water Research Center Report No. 64, Washington State University, Pullman, WA.

Nofziger, D.L., and D. Swartzendruber. 1974. Material content of binary physical mixtures as measured with a dual energy beam of rays. J. Appl. Physics 45:5443-5449.

Papendick, R.I., and G.S. Campbell. 1981. Theory and measurement of water potential. *In* J.F. Parr, W.R. Gardner and L.F. Elliot, (eds.), Water Potential Relations in Soil Microbiology, Soil Sci. Soc. of Am. special publication No. 9, Madison, WI.

Papendick, R.I., and D.J. Mulla. 1986. Basic principles of cell and tissue water relations. *In* P. Ayres (ed.), Water, fungi and plants. Bath Press, London, UK.

Rawls, W.J., D.L. Brakensiek, and K.E. Saxton. 1982. Estimation of soil water properties. Am. Soc. Agric. Eng. Trans. 25:1316-1320.

Saxton, K.E., W.J. Rawls, J.S. Romberger, and R.I. Papendick. 1986. Estimating generalized soil water characteristics from texture. Soil Sci. Soc. Amer. J. (In Press).

Schmugge, T.J., T.J. Jackson, and H.L. McKim. 1980. Survey of methods for soil moisture determination. Water Resour. Res. 16:961-979.

Taylor, S.A., D.D. Evans, and W.D. Kemper. 1961. Evaluating soil water. Utah Agricultural Experiment Station Bull. 426, Logan, UT.

Topp, G.C., J.L. Davis, and A.P. Annan. 1980. Electromagnetic determination of soil water content: Measurement in coaxial transmission lines. Water Resour. Res. 16:574-582.

Wiebe, H.H., G.S. Campbell, W.H. Gardner, S.L. Rawlins, J.W. Cary, and R.W. Brown. 1971. Measurement of plant and soil water status. Utah Agricultural Experiment Station Bull. 484, Logan, UT.

Willoughby, P., and K.J. Cuming. 1985. Automatic irrigation in a peach orchard. HortScience 20:445-446.

Crop Water Use Efficiency

P.J. Gregory
University of Reading, Reading, England

ABSTRACT. The efficient use of water is crucial to improving crop yields in the Near East and North Africa where 95 percent of the cultivated land receives less than 400 mm rainfall annually. In order to increase dry matter production and crop yields, farmers must increase the amount of water available to the crop, the water use efficiency (WUE) of a crop, that is, the ratio of aboveground dry matter production to the crop's evapotranspiration, or both. Harvesting water or selecting deep rooting crop varieties such as the barley variety Arabic Abiad, which can exploit soil water stored below the depth of wetting, are two methods of increasing the water available for crop growth. Proper crop selection and management can also increase WUE. Since WUE is directly related to the water vapor saturation deficit, it can be increased in Mediterranean climates by growing crops during the rainy season when the saturation deficit is low. WUE as defined here can also be increased by maximizing transpiration relative to soil water evaporation. This can be accomplished through the use of mulches, minimum tillage, and other soil and water conservation practices which decrease soil water evaporation. Optimal plant populations and fertilizer application result in rapid canopy development, also reducing evaporative loss from the soil. These agricultural practices are seen as alternatives to the traditional fallow system which can sustain and improve crop production in the semiarid lands of the Mediterranean.

Introduction

Transpiration is a necessary consequence of plant growth. In rainfed areas where water frequently limits agricultural production the efficient use of water is crucial in improving yields. In the Near East and North Africa, the area under cultivation is about 87 million ha, 60 percent of which is rainfed and 95 percent of which receives annual rainfall less than 400 mm (Arar, 1980). Although 60 percent of the 250 million people inhabiting the arid lands around the Mediterranean are engaged in rainfed agriculture, these areas contribute less than one-third of the total agricultural output. The increasing population and pressure on the land require that production is improved.

In addition to low rainfall, there is the problem of seasonal variability in the amount of rainfall received (see Dennett *et al.*, 1983, for an example in Northern Syria). Variable amounts of rain mean that in the past agricultural practices have been designed to conserve water and ensure long-term production in the region. If there are to be future increases in production, then water will have to be used as efficiently as possible. In this paper I shall outline the theoretical basis of the relation between growth and water use and show how management can change the amount of growth per unit of water used.

Water Use Efficiency

Water use efficiency (WUE) has been defined in many ways but is most commonly written:

$$\text{WUE} = \frac{\text{Yield per unit area}}{\text{Water used to produce yield}} \qquad [1]$$

Yield is frequently given as grain yield, but in many agricultural systems the straw also has important economic value, especially in the barley/sheep and goat system commonly practiced in the Near East and North Africa (ICARDA, 1985). When yield is expressed as aboveground dry matter, the dry matter of the root system is ignored. The ratio of root weight to total plant weight is typically 0.1 at maturity in cereal crops grown in temperate regions (Gregory *et al.*, 1978), but in drier environments with no fertilizer applied (grain yield of barley = 1.4 t ha^{-1}) the ratio increases to about 0.2 (Gregory *et al.*, 1984). The water use term (denominator) may be expressed in a number of ways. It is most usually denoted as the total water use (evapotranspiration) during the growing season and less frequently as the amount of water transpired. It may also be expressed in terms of rainfall, either as the rainfall within a crop rotation, e.g., fallow/barley (Bolton, 1981); as the rainfall between planting in one year and planting on the next occasion; or as the rainfall in the growing period of the crop. Strictly the use of the word efficiency is a misnomer since efficiency is a comparative term i.e., dimensionless, requiring a knowledge of the theoretical maximum value. Some workers therefore prefer to use the term water use coefficient rather than water use efficiency.

Growth and Transpiration

The early pioneering work of Lawes (1850) established that the amount of water transpired by plants in the production of dry matter differed and that the addition of manure generally increased dry matter production per unit of water use. For example, wheat and peas produced 4.04×10^{-3} and 3.86×10^{-3} g dry matter g^{-1} water transpired, respectively, when unmanured, but 4.50×10^{-3} and $4.74 \times 10^{-3}g\ g^{-1}$, respectively, when manured. Similarly, Table 1 shows a wide range of water use per unit weight of dry matter produced and that variations in climatic and soil conditions affect this value. de Wit (1958) reviewed many experiments in several countries and established that crop growth and water use could be empirically related by:

$$Y = mT/E_0^n \qquad [2]$$

where Y is the dry matter yield, T is the water transpired, E_0 is the average rate of evaporation from an open pan, and m and n are constants dependent on the crop and location respectively. The analysis was applied to crops from sowing to harvest. Table 2 shows values of m and n derived for different crops in two countries. In temperate regions, e.g., The Netherlands, n equaled 0 but in more arid environments n equaled 1, indicating that water use efficiency was directly related to evaporative demand. The theoretical basis of these relations has recently become clearer; it helps to explain the results cited previously and also to indicate the effects that different management practices may have.

Table 1. Estimates of the Amount of Water Transpired in Producing a Unit of Dry Weight (results from Briggs and Shantz, 1913).

Crop	Water Transpired per Dry Weight Produced	Comments
	g g⁻¹	
Wheat	507	Mean result for all
Barley	539	varieties grown at
Sorghum	306	Akron, Colorado
Pea	800	1911
Potato	448	
		Mean of 1910 and 1911
Wheat	556	Akron, Colorado
	763	Dalhart, Texas
Sorghum	327	Akron, Colorado
	336	Dalhart, Texas

Table 2. Values of Constants m and n Determined by de Wit (1958).

Country	Crop	m	n
		kg ha^{-1} mm^{-1}	
The Netherlands	Oats	26	0
	Sugar beet	61	0
	Peas	34	0
		kg ha^{-1} d^{-1}	
United States (Great Plains)	Sorghum	207	1
	Wheat	115	1
	Alfalfa	55	1

Transpiration (T_L) and photosynthesis (N_L) of leaves can be described in terms of the vapor pressure gradient and difference in CO_2 concentration between the intercellular spaces and the ambient air, and the resistances to diffusion (Penman and Schofield, 1951):

$$T_L = \frac{\varepsilon\rho}{p}\frac{e_i - e_a}{r_s + r_a}\text{; and} \quad [3]$$

$$N_L = \frac{c_a - c_i}{r_s' + r_a'} \quad [4]$$

where ε is the ratio of the molecular weights of vapor and dry air; ρ is the density of moist air; p is the atmospheric pressure; e_i is the saturated water vapor pressure in the substomatal cavity; e_a is the vapor pressure in the air; c_a and c_i are the concentrations of CO_2 in the air and intercellular spaces, respectively; and r_s and r_a are the stomatal and boundary layer resistances to water vapor (r_s' and r_a' for CO_2). It follows that the ratio of photosynthesis to transpiration can be written:

$$\frac{N_L}{T_L} = \frac{(c_a - c_i)(r_s + r_a)}{(e_i - e_a)(r_s' + r_a')}\frac{p}{\varepsilon\rho}. \quad [5]$$

This expression can be simplified in several ways. First, the stomatal and boundary layer resistances to both CO_2 and water transfer are inversely proportional to the diffusion coefficients and the square roots of molecular weights of the two gases. Therefore the ratio of $r_s + r_a$ to $r_s' + r_a'$ is approximately constant with a value of 1.6. Second, the concentration gradient of CO_2 is often maintained by stomata at an almost constant value for a given species (Wong *et al.*, 1979). Finally, because the daily average temperature of a leaf is frequently close to the mean air temperature, e_i-e_a can be approximated by the saturation deficit of the air (e_s-e_a) where e_s is the saturation vapor pressure of the air. With these assumptions and further assuming that crops and individual leaves behave similarly, Eq. [5] can be simplified to:

$$\frac{N}{T} = \frac{k}{e_s - e_a} \quad [6]$$

where k, the constant of proportionality, is crop specific (Bierhuizen and Slatyer, 1965). The validity of this expression must be tested but initial analyses suggest that the differences in saturation deficit between years may explain year-to-year differences in transpiration efficiency (dry matter/unit water transpired). Figure 1 shows such an analysis for barley crops grown in England in two contrasting years; similar analyses have been presented for potatoes in the United States (Tanner, 1981) and The Netherlands (Rijtema and Endrodi, 1970). A review by Tanner and Sinclair (1983) summarizes results from field experiments and explores the uncertainties in calculating the saturation deficit term.

Three aspects of practical importance follow from this analysis. First, it is clear from Eq. [6] that transpiration efficiency will be higher in humid regions where e_s-e_a is low than in arid regions where e_s-e_a is high. Crops growing in arid regions normally use more water than the same crops growing in temperate regions to produce the same dry matter (see Fischer, 1980). Similarly, in Mediterranean environments where saturation deficits are low in winter and increase rapidly during March and April, transpiration efficiency will be higher in early growth than during the grain-filling period. Second, Eq. [4] shows the importance of the CO_2 gradient. Recent measurements (see the review by Pearcy and Ehleringer, 1984) show that C_4 plants such as maize and sorghum can maintain lower internal CO_2 concentrations (100 to 150 ppm) than C_3 plants such as barley and legumes (220 to 260 ppm). The CO_2 concentration gradient between the intercellular spaces and the ambient air is therefore greater in C_4 plants than C_3 plants; C_4 plants will have a higher transpiration efficiency. As shown in Tables 1 and 2, sorghum (C_4) produced more dry matter per unit of water transpired than the C_3 crops. The higher transpiration efficiency of C_4 plants does not mean greater drought tolerance since the ability to withstand low water potentials is not directly related to the photosynthetic pathway. Finally, Eq. [6] is physiologically based so transpiration efficiency can be influenced only slightly by cultivar, water stress, or agronomic practice.

Crop Growth and Soil Water Use

Water is used by crops directly in transpiration (T) from the leaves and indirectly in evaporation (E) from the soil surface; this is commonly referred to as evapotranspiration (ET). Although the transpiration efficiency for a crop species does not vary widely, the WUE based on ET will vary considerably because it depends upon numerous crop, climate, and soil factors. WUE (Cooper, 1983) may be written as:

$$WUE = \frac{N/T}{1 + E/T} \qquad [7]$$

Because the transpiration efficiency is constant for a given saturation deficit and crop, increasing dry matter production in arid regions will depend on increasing the total amount of water used by a crop, maximizing T relative to E for a given amount of water available to a crop, or both. A range of agronomic and management practices can be used for changing either total water use or the balance between T and E, and the precise form will depend on local soil and climatic conditions.

Increasing Total Water Use

In many arid regions water harvesting is used as a means of increasing the total water supply available to a crop. Figure 2 shows such a practice near the ancient city of Petra in Jordan. Water is allowed to run off the higher slopes where soils are shallow and crop growth very poor, onto the terraced valley bottom where soils are deeper and able to store the water. On deeper soils, the control of runoff is important to increase infiltration of water and improve crop growth. Kilewe and Ulsaker (1984) studied Alfisols in Kenya where infiltration is reduced during the early part of the rainy season by surface sealing caused by raindrop impact. They showed that cultivation in wide furrows decreased runoff, increased yields of maize, and increased WUE. Work at ICARDA has shown that cultivation on shallow slopes may also reduce runoff and erosion (Table 3).

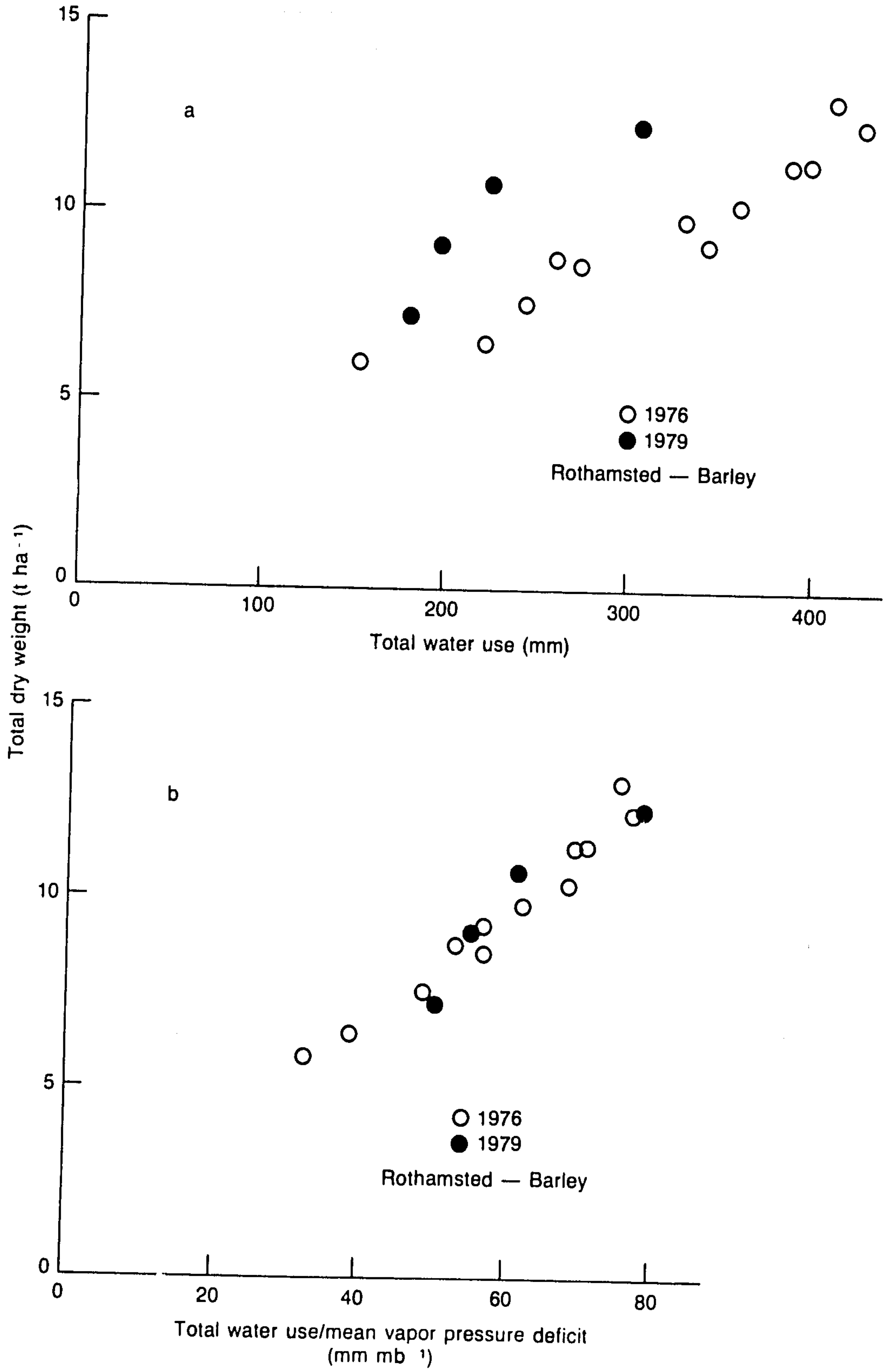


Figure 1. a) Growth and Water Use by Barley Given Different Amounts of Irrigation; 1976 (○) and 1979 (●). **b) Growth and Water Use Normalized for Saturation Deficit** (Day *et al.*, 1987).

Figure 2. Collection of Runoff (Rain Harvesting) near Petra, Jordan.

Table 3. Effect of Tillage on Runoff and Soil Loss Downslope on a 5% Slope at Tel Hadya (Syria) during Application of Water at a Rate of 50 m h^{-1} (ICARDA, 1986).

Time	Duckfoot Cultivator		Chisel Plow		Disc Plow	
	Runoff	Soil Loss	Runoff	Soil Loss	Runoff	Soil Loss
min	*mm*	*g* m^{-2}	*mm*	*g* m^{-2}	*mm*	*g* m^{-2}
30	0.1	0.5	0	0	0	0
36	0.2	1	0	0	0	0
42	0.45	2	0.1	1	0.1	1.5
48	0.8	9	0.25	3	0.3	6
54	1.6	22	0.5	9	0.7	10
60	3.0	38	1.0	22	114	22

Deep plowing and fallowing are often employed in Mediterranean-type climates to ensure infiltration and the storage of water for the next growing season. However, the amount of water available for succeeding crops is dependent upon soil depth and soil type. As an example, soils in northern Syria often contain appreciable quantities of swelling clay. Figure 3 shows that although water may be stored in the profile during the winter period, it is lost by evaporation during the hot, dry summer and only a small proportion is available to the succeeding winter cereal crop (15 to 25 percent of the season's rainfall depending on location). Summer crops (sesame and watermelons), however, may be successfully grown on this stored water. In contrast, sandy soils may form a dry mulch at the surface, effectively sealing in more of the stored water. This, together with stubble-mulching, may improve water storage; it may also increase T relative to E (for examples in the Pacific Northwest, United States see Bolton, 1981 and Caprio *et al.*, 1985).

In some dryland areas, applications of fertilizer, particularly nitrogen, to crops may increase yields and also increase the total water use by increasing the depth of water extraction through increased rooting depth (Brown, 1971). Table 4 shows that fertilizer applications have increased slightly the amount of water used in three of the four growing seasons at two sites in northern Syria.

It is frequently observed that water remains in the soil profile at the end of crop growth even in dry areas (Figure 4). Such observations have led to the suggestion that crops with deep root systems ought to be able to extract this water and thereby enhance growth. While this strategy may be beneficial to growth, it will be sustainable only if the annual

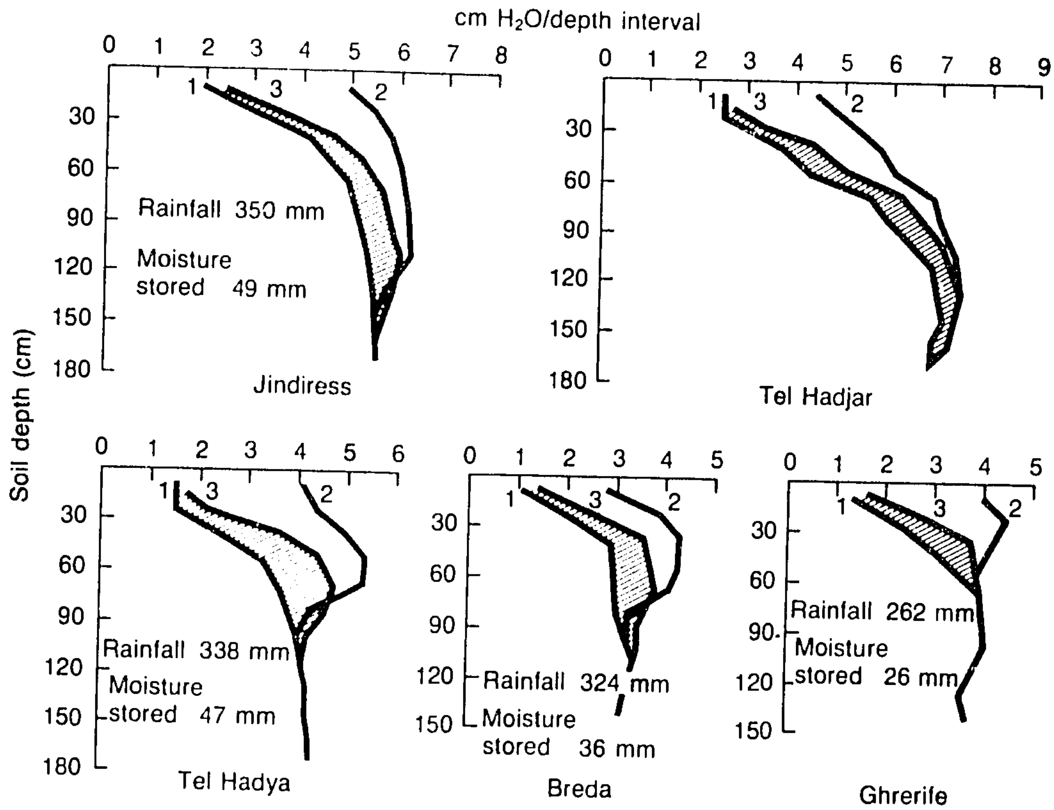


Figure 3. Changes in Water Content under Fallow at 5 Sites in Northern Syria Measured (1) at the Start of the Season, (2) at Maximum Profile Recharge, and (3) at 2 Months before Sowing the Succeeding Crop (ICARDA, 1983).

depth of wetting by rain exceeds, or is equal to, the depth of drying. Water below this depth of wetting must be regarded as fossil water and only extractable once, or only once between years of high rainfall. In many arid regions, then, the water below the depth of wetting must be regarded as unexploitable and deep rooting will not provide a means of increasing water use.

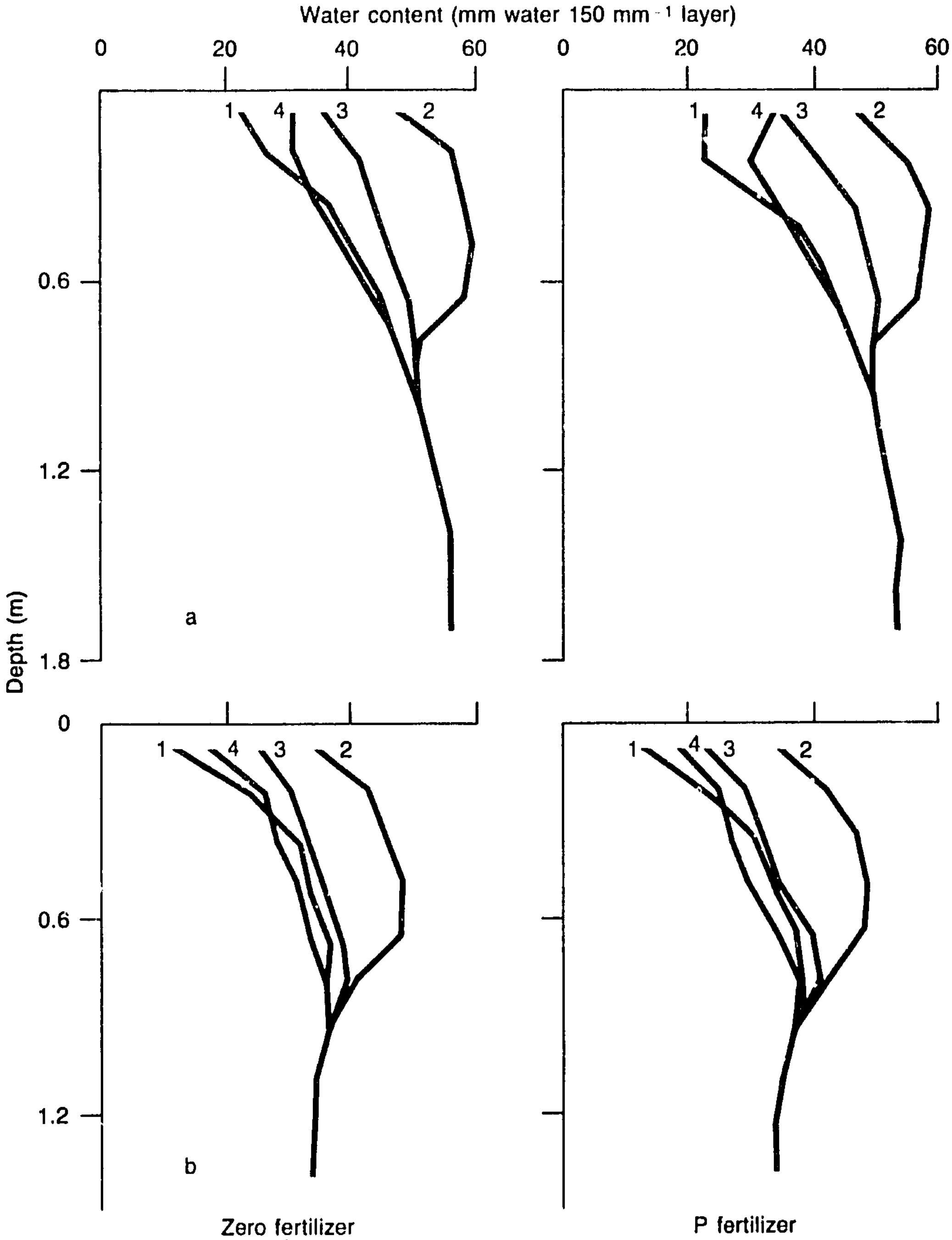


Figure 4. Changes in Water Content under Barley Crops at a) Jindiress and b) Breda during the 1981/82 Growing Season. Water Measured (1) before Sowing, (2) at Maximum Profile Recharge, (3) Anthesis and (4) Physiological Maturity (Gregory *et al.*, 1984).

Increasing T Relative to E

Soil evaporation is a very important component of the total water use of crops grown in Mediterranean environments. Cooper *et al.* (1983) have shown that E is about 35 and 55 percent of the seasonal ET for crops of barley at Tel Hayda and Breda in northern Syria, respectively. Similarly, French and Schultz (1984), working with wheat on a range of soil types in south Australia, calculated that E was 33 percent of ET. In Mediterranean climates it is common for winter-sown crops to commence their growth in cool, damp conditions with a moist soil surface and to complete their reproductive growth under conditions of depleted soil water and an increasing atmospheric demand for water.

One means of reducing E is to use a mulch. Mulching materials, however, are usually scarce in dry areas because of low dry matter production and they are used as fodder for livestock, fuel, and building materials. Mulching on a large scale is therefore unlikely although stubble-mulching may be appropriate where livestock are not kept.

Trials at ICARDA have shown that applications of fertilizer increase barley yields and also increase WUE (Table 4). The principal reason for the increased WUE was that fertilizer increased the early growth of barley by allowing more rapid growth of the leaves (see Gregory *et al.*, 1984 and Cooper *et al.*, 1987 for details). The increased leaf area shaded the soil surface intercepting more of the incident radiation so that water which would otherwise have evaporated instead was transpired. In the cold winter months, saturation deficits are small so that as Fischer (1981) concluded "growth during the cool winter months is cheap in terms of the transpiration cost." The additional growth, then, resulted from changing the balance of E and T thereby increasing the WUE.

It is uncertain at present whether fertilizers may also change the transpiration efficiency. Kallsen *et al.* (1984) grew spring barley on a sandy loam in New Mexico, United States for two years with rates of nitrogen fertilizer ranging from 30 to 300 kg N ha^{-1}. They found that grain yield and transpiration were linearly related irrespective of the rate of nitrogen application. Similarly, Walker and Richards (1985) have shown no effects of potassium deficiency on the transpiration efficiency of alfalfa and maize. In contrast, Tanner and Sinclair (1983) concluded that increases in transpiration efficiency occurred as long as dry matter production was less than 50 percent of that possible when nutrients were nonlimiting.

One other effect of fertilizers on WUE is noteworthy. Applications of phosphorus fertilizer on severely P-deficient soils in northern Syria generally advance the date of anthesis and maturity by up to 10 days depending upon the season. This provides a mechanism of drought avoidance but also means that the crop experiences lower saturation deficits at any given developmental stage and thus has a higher transpiration efficiency. The data of Cooper *et al.* (1983) and Cooper *et al.* (1987) show slightly higher transpirational efficiencies for crops given fertilizer (an increase of between 0 and 9 kg ha^{-1} mm^{-1}), though the errors associated with their calculations are uncertain.

Differences between varieties in the distribution of roots and timing of water extraction may also contribute to differences in WUE. Brown *et al.* (1987) showed that a local landrace barley, Arabic Abiad, had a longer root system below a 15 cm soil depth than the variety Beecher after early stem elongation (Figure 5). This longer root system was associated with earlier and slightly greater water use from the deeper soil layers and resulted in higher grain yields of Arabic Abiad.

Establishing the optimum plant population provides another way of maximizing WUE. Populations should be high enough to ensure that the maximum amount of water is transpired without all available water being used before grain-filling commences. In areas with high variability in the seasonal rainfall, achieving the optimum population to maximize transpiration may be, in practice, very difficult. For example, Anderson (1984) showed that the optimum population of triticale (the population giving maximum grain

Table 4. Effects of Fertilizer on Yield and Water Use of Barley (cv. Beecher) Grown at Two Sites on Northern Syria.

Site Year	Breda (35° 55′ N, 37° 10′ E)								Jindiress (36° 23′ N, 36° 41′ E)							
	1979/80		1980/81		1981/82		1982/83		1979/80		1980/81		1981/82		1982/83	
Rainfall (mm)	268		299		318		254		367		454		319		360	
Fertilizer	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+
Total shoot dry wt (t ha^{-1})	3.2	6.3	3.8	7.5	3.9	6.2	2.0	3.4	3.8	6.6	5.4	12.5	4.4	8.7	6.6	11.0
Grain dry wt (t ha^{-1})	1.5	2.8	1.6	2.6	1.3	2.2	0.9	1.5	1.7	2.9	2.3	5.0	1.4	2.9	3.1	4.7
Total water use (evapotranspiration, mm)	259	285	234	225	225	232	227	240	272	322	323	376	323	316	333	356
WUE (kg ha^{-1} mm^{-1})	12.4	22.1	16.2	33.3	17.3	26.7	8.8	14.2	14.0	20.5	16.7	33.2	13.6	27.5	19.8	30.1

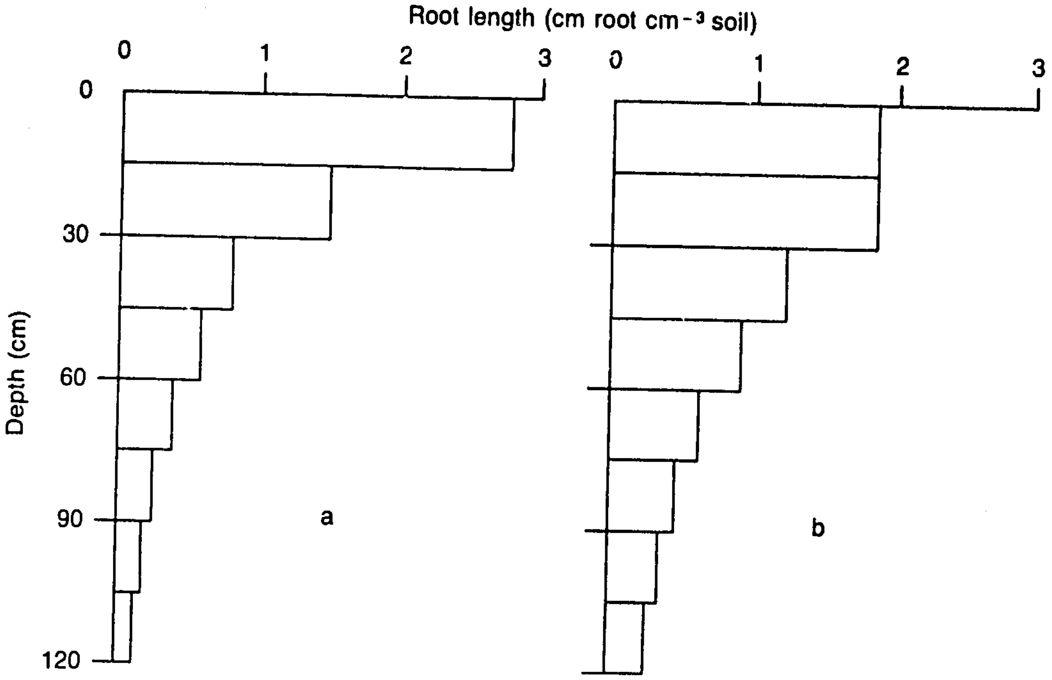


Figure 5. Distribution of Root Length Between Anthesis and Maturity for Two Varieties of Barley. a) Beecher and b) Arabic Abiad Grown at Jindiress (Brown *et al.*, 1987).

yield) varied between 80 and 190 plants m^{-2} (corresponding to seeding rates of 30 to 150 kg ha^{-1}) for grain yields ranging from 2.1 to 6.9 t ha^{-1}. However, yield at the optimum population was closely related to the water supply available for the growing season. Without prior knowledge of the rainfall, then, it is difficult to optimize plant population in a particular season.

Conclusions for Mediterranean-Type Environments

Dry matter production in arid regions may be increased in two ways. Either the total amount of crop available water stored in the soil profile must be increased by tillage or conservation practices or the amount of water transpired must be maximized by crop management practices.

Currently fallowing is used as the major water conservation practice (also tending to conserve soil nitrogen; Seligman *et al.*, 1985) but this generally conserves a small proportion of the total rainfall for a subsequent season. As human populations increase, the amount of fallowing decreases, contributing to the recent decline in cereal yields in the dry regions.

Application of fertilizer increases WUE by promoting early leaf growth; this reduces evaporative loss from the soil surface. It might also be possible to select varieties with rapid early leaf growth to enhance this effect. It is important to adopt early varieties and practices which ensure that grain-filling is completed before saturation deficits and temperatures become very large. Optimizing plant population will be difficult without knowledge of the probability of various amounts of rainfall.

References

Anderson, W.K. 1984. Plant populations for triticale in a Mediterranean environment. Field Crops Res. 8:281-295.

Arar, A. 1980. The role of rainfed agriculture in the Near East region: Summary of present situation, potential and constraints. p. 10-21. *In* Rainfed agriculture in the Near East and North Africa. FAO, Rome, Italy.

Bierhuizen, J.F., and R.O. Slatyer. 1965. Effect of atmospheric concentration of water vapour and CO2 in determining transpiration-photosynthesis relationships of cotton leaves. Agric. Meteorol. 2:259-270.

Bolton, F.E. 1981. Optimizing the use of water and nitrogen through soil and crop management. p. 231-247. *In* J.L. Monteith and C. Webb (ed.), Soil water and nitrogen in Mediterranean-type environments. Martinus Nijoff/Junk, The Hague.

Briggs, L.J., and H.L. Shantz. 1913. The water requirements of plants. USDA Bureau Plant Ind. Bull. 285. U.S. Gov. Print. Office, Washington, DC.

Brown, P.L. 1971. Water use and soil water depletion by dryland winter wheat as affected by nitrogen fertilization. Agron. J. 63:43-46.

Brown, S.C., J.D.H. Keatinge, P.J. Gregory, and P.J.M. Cooper. 1987. Effects of fertilizer, variety and location on barley production under rainfed conditions in northern Syria. I. Root and shoot growth. Field Crops Res. 16:53-66.

Caprio, J.M., G.K. Grunwald, and R.D. Snyder. 1985. Effect of standing stubble on soil water loss by evaporation. Agric. For. Meteorol. 34:129-144.

Cooper, P.J.M. 1983. Crop management in rainfed agriculture with special reference to water use efficiency. p. 63-79. *In* Proc. 17th Coll. Int. Potash Inst. Bern, Switzerland.

Cooper, P.J.M., P.J. Gregory, J.D.H. Keatinge, and S.C. Brown. 1987. Effects of fertilizer, variety and location on barley production under rainfed conditions in Northern Syria. II. Soil water dynamics and crop water use. Field Crops Res. 16:67-84.

Cooper, P.J.M., J.D.H. Keatinge, and G. Hughes. 1983. Crop evapotranspiration - a technique for calculation of its components by field measurements. Field Crops Res. 7:299-312.

Day, W., D.W. Lawlor, and A.T. Day. 1987. The effect of drought on barley yield and water use in two contrasting years. Irrig. Sci. 8:115-130.

Dennett, M.D., J.A. Rodgers, and J.D.H. Keatinge. 1983. Simulation of a rainfall record for the site of a new agricultural development: An example from Northern Syria. Agric. Meteorol. 29:247-258.

Fischer, R.A. 1980. Influence of water stress on crop yield in semiarid regions. p. 323-339. *In* N.C. Turner and P.J. Kramer (ed.) Adaptation of plants to water and high temperature stress. John Wiley, New York.

Fischer, R.A. 1981. Optimizing the use of water and nitrogen through breeding of crops. p. 249-278. *In* J.L. Monteith and C. Webb (eds.) Soil water and nitrogen in Mediterranean-type environments. Martinus Nijhoff/Junk, The Hague.

French, R.J., and J.E. Schultz. 1984. Water use efficiency of wheat in a Mediterranean-type environment. I. The relation between yield, water use and climate. Aust. J. Agric. Res. 35:743-764.

Gregory, P.J., M. McGowan, P.V. Biscoe, and B. Hunter. 1978. Water relations of winter wheat. I. Growth of the root system. J. Agric. Sci. Camb. 91:91-102.

Gregory, P.J., K.D. Shepherd, and P.J.M. Cooper. 1984. Effects of fertilizer on root growth and water use of barley in Northern Syria. J. Agric. Sci. Camb. 103:429-438.

ICARDA. 1983. International Center for Agricultural Research in the Dry Areas, annual report 1982. p. 41. Aleppo, Syria.

ICARDA. 1985. International Center for Agricultural Research in the Dry Areas, annual report 1984. p. 8. Aleppo, Syria.

Kallsen, C.E., T.W. Sammis, and E.J. Gregory. 1984. Nitrogen and yield as related to water use of spring barley. Agron. J. 76:59-64.

Kilewe, A.M., and L.G. Ulsaker. 1984. Topographic modification of land to concentrate and redistribute runoff for crop production. E. Afric. Agric. For. J. 44:257-265.

Lawes, J.B. 1850. Experimental investigation into the amount of water given off by plants during their growth; especially in relation to the fixation and source of their various constituents. J. Hort. Soc. London. 5:38-63.

Pearcy, R.W., and J. Ehleringer. 1984. Comparative ecophysiology of C3 and C4 plants. Plant Cell and Environ. 7:1-13.

Penman, H.L., and R.K. Schofield. 1951. Some physical aspects of assimilation and transpiration. Symp. Soc. Exp. Biol. 5:115-129.

Rijtema, P.E., and G. Endrodi. 1970. Calculation of production of potatoes. Neth. J. Agric. Sci. 18:26-36.

Seligman, N.G., S. Feigenbaum, R.W. Benjamin, and D. Feinerman. 1985. Efficiency of fallow as a store for fertilizer nitrogen in a semi-arid region. J. Agric. Sci. Camb. 105:245-249.

Tanner, C.B. 1981. Transpiration efficiency of potato. Agron. J. 73:59-64.

Tanner, C.B., and T.R. Sinclair. 1983. Efficient water use in crop production: research or re-search? p. 1-27. *In* H.M. Taylor, W. R. Jordan and T.R. Sinclair (ed.) Limitations to efficient water use in crop production. ASA, Madison, WI.

Walker, G.K., and J.E. Richards. 1985. Transpiration efficiency in relation to nutrient stress. Agron. J. 77:263-269.

de Wit, C.T. 1958. Transpiration and crop yields. Versl. Landbouwk. Onderz. No. 64.6. S'Gravenhague, The Netherlands.

Wong, S.C., I.R. Cowan, and G.D. Farquhar. 1979. Stomatal conductance correlates with photosynthetic efficiency. Nature, London. 282:424-426.

Data Acquisition and Processing Tec' ˜iques for Agricultural Research

A.A. Jaradat
Jordan University of Science and Technology, Irbid, Jordan

ABSTRACT. Developments in the field of data acquisition and processing are occurring at a rapid pace, with the use of computers at the core. Automated data capture and computer processing promise to facilitate agricultural research in developing countries. Microcomputer software packages necessary to integrate research design, management, and data analysis functions are available and flexible enough to handle any experimental design. This paper attempts to give the reader an idea about data acquisition and processing techniques, using computers at varying levels of sophistication from simple data storage and retrieval to complex statistical analysis and modeling.

Introduction

Today, the management of large volumes of data by computers has become necessary and commonplace. The need to deal with large and more complex data sets is widespread. Many, if not most, research projects in agronomy, soils, horticulture, and other disciplines are complemented by computers. The corresponding development of database management systems and other data handling tools is becoming increasingly important as information needs grow.

Microcomputers simplify the work of agricultural researchers in many parts of the world, especially in developing countries. Developments in the field of data acquisition and processing techniques are occurring rapidly, with the use of computers at the core (National Research Council, 1986). It is possible, today, to perform functions ranging from the collection and processing of agricultural survey data to the statistical analysis of experimental field data and the building of sophisticated simulation models of agricultural systems (Michigan State University, 1985; O'Toole and Jones, 1986).

This paper presents data acquisition and processing techniques using the computer at varying levels of sophistication, from simple data storage and retrieval to complex statistical analysis and modeling.

Steps in Experimentation

The work of researchers in any agricultural discipline is information intensive. Research experiments are designed to generate enough data which can be translated into information. The new information could be used to bring about a more productive agricultural system or one of its components.

Generally, there are five recognized steps in agricultural research (Michigan State University, 1985):

1) The researcher characterizes a certain practice (e.g. a farmer's practice), identifies a problem, lists priorities, and recommends solutions to the problem.
2) Experiments are designed to test and/or verify a new technology, based on known or projected requirements of the end users (e.g. extension agents, farmers, policy makers).
3) For the recommendations to be applicable in a range of environments or situations, a number of experiments must be conducted and managed systematically.
4) Accurate and appropriate techniques are required to collect and analyze the normally large body of data.
5) Results of the research are reported or communicated to the end users (e.g., farmers).

Planning Experiments

Agricultural research has traditionally been in research stations where facilities for experimentation are excellent and accessibility to researchers is favorable. However, selection of the best technology for farmers cannot be based only on experimental results obtained in research stations. This is mainly because of the inconsistency in technology performance between research stations and farmers' fields.

Two major types of experiments can be recognized. These are (Gomez and Gomez, 1984):

1) Technology-generation experiments, and

2) Technology-verification experiments.

Planning of Technology-Generation Experiments

This kind of experiment can be initiated in a research station or a farmer's field. Special care should be taken in selecting a test site, experimental design, and layout of such experiments, especially if these are to be conducted in a farmer's field. The test site is selected such that it provides a set of physical and biological conditions under which the experiment is to be developed.

A suitable experimental design and layout of the experiment are necessary prerequisites for obtaining reliable results. The design of experiments in a farmer's field must aim at keeping the size of the experiment small. This can be done by keeping the number of treatments and number of replicates at a minimum, thus minimizing the experimental error. However, in a research station the need may arise for large experiments, both in size and number of treatments (e.g., varieties) tested (Gomez and Gomez, 1984; Little and Hill, 1978).

Planning of Technology-Verification Experiments

The main objective of verification experiments is to compare the performance of a farmer's technology and a newly developed technology in a farmer's field. The most important parameters for comparison are biological yield and profitability.

For the purpose of technology-verification, test farms should adequately represent the farms in the target area. This makes it necessary to choose the appropriate sampling technique for farm selection. Certain criteria, such as farm size and cropping pattern should be taken into consideration (Gomez and Gomez, 1984).

Computerized Planning of Experiments

The researcher who designs an experiment and collects the data is basically concerned with formulating hypotheses, working out an appropriate research design, and interpreting the results (Figure 1). Once a hypothesis is formed, the next step is to design a procedure for its verification. This usually involves (Brand, 1970; Mead and Curnow, 1983):

1) Selecting the appropriate material to be tested;

2) Specifying the characters to be measured;

3) Selecting the procedure to measure those characters; and

4) Specifying the procedure to determine whether the measurements made support the hypothesis.

The last two points constitute most of what is generally termed the design of experiments. Experimental design has the following components:

1) Estimate and control of error, and

2) Proper interpretation of results.

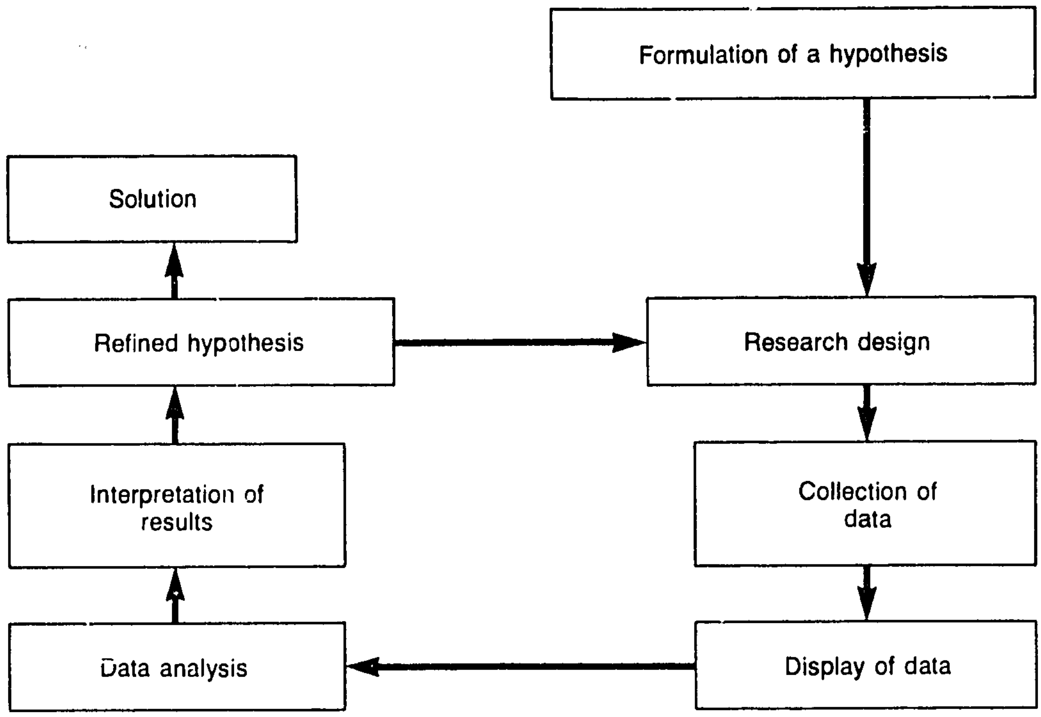


Figure 1. A Flow Chart Showing the Procedure of Hypothesis Testing as a Part of the Scientific Method of Research.

Computers, in general, and microcomputers, in particular, have simplified the work of researchers in agriculture. Microcomputers are now used to perform several functions in agricultural experimentation, ranging from the design of experiments to the statistical analysis of such experiments.

Experimental Design Generation

A number of specific software programs have been developed to support the multidisciplinary applied research which agronomists, plant breeders, agricultural economists, etc. conduct to develop improved production technologies.

These software programs (e.g., MSTAT, MSUSTAT, SYSTAT, and CRISP) have the capability of generating experimental designs for field and laboratory experiments. Most software programs share the following steps in generating experimental design (ICARDA, 1985a, 1985b; Michigan State University, 1985; SYSTAT, 1986):

1) Initializing and performing randomization for the required experimental design;
2) Converting the randomization file, created in the first step, to a data file for data input; and
3) Generating and printing field books, field maps, and labels.

Two general types of experimental designs are used in agriculture. These are:

1) Randomized block designs, and
2) Statistical designs for varietal testing or for verifying technologies.

The latter type includes, but is not limited to, lattice, augmented, and nearest neighbor designs.

After a certain experimental design has been generated, treatments (e.g., varieties and entries) have to be randomized and factors and variables have to be defined before data entry.

File Management

A wide range of file management options is available to researchers using specialized statistical software programs. A data file can be updated at anytime after it has been created. Factors, levels of factors, variables, and observations can be added to the original list.

Factor-setting for data can be generated automatically by invoking a special option, or can be entered manually by the researcher. Factors, factor levels, variables, or observations can also be deleted from a file as desired.

Researchers can check the data stored in a file using specific minimum and maximum allowable values for each variable in the data file.

The need may arise, in some experimental situations, to select rows of data from an input file. This can be performed by using a logical combination of data-related conditions. One example is selecting varieties with yield greater than a specified value.

A built-in calculator enables researchers to perform complex arithmetic operations using data of existing variables and a set of valid operators (e.g., addition, division, multiplication, etc.) (ICARDA, 1985a,b; Michigan State University, 1985).

Data Acquisition

Conventional Data Collection

Until recently, data generated in research station experiments used to be collected manually. This procedure involves a maximum of five steps, starting with manual data collection and ending with computer processing (Figure 2).

Data in field books is primarily arranged for ease of measurements in the field. At times, this may not be the form most convenient for computer processing and statistical analysis. Thus transcribing the data from field books to the form required for data analysis may be necessary. The number of times data are transcribed depends on the complexity of the computations desired. It is strongly recommended that researchers who collect their data by a conventional method should minimize the number of times those data are transcribed. This minimizes the chances of making errors during transcription.

Several types of data are normally collected for technology-generation experiments. One example is the detailed data on agronomic traits, i.e., yield and yield components of field crops such as wheat, lentils, sorghum, and corn. However, for technology-verification experiments, these detailed measurements are not necessary. Data collection for technology-verification experiments is designed primarily to compare the new technology and the farmer's practice and to determine the potential for adoption of the new technology. Because of such a specific objective, the type of data to be collected generally differs from that of technology-generation experiments (Gomez and Gomez, 1984; Sokal and Rohlf, 1981).

Data Collection in Digital Form

Microcomputers, in particular, have changed the methods by which research data are collected. With the advent of data loggers and sensors, researchers are collecting data directly from field experiments in digital form.

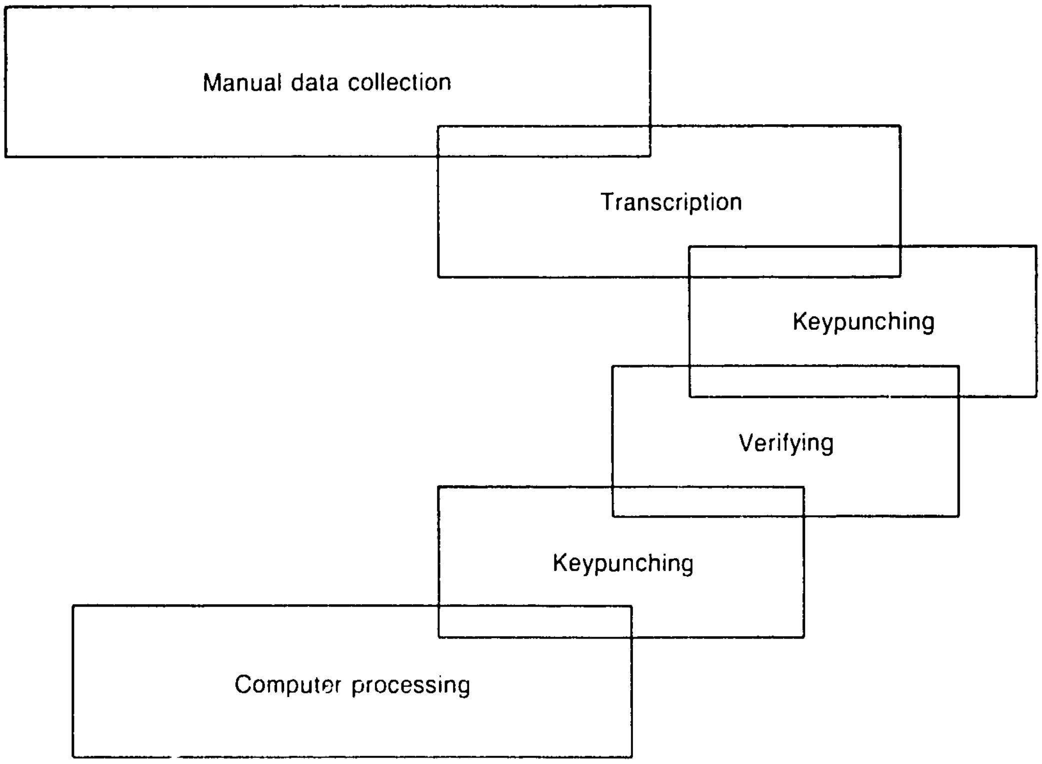


Figure 2. Steps in Manual Data Acquisition.

The weakest links in the whole data collection-preparation-reporting cycle are the data preparation steps: transcribing, key punching, editing, and verifying. Researchers are able to eliminate these weak links and create a two-link chain that takes them from data collection to computerized summaries.

A researcher using data loggers (e.g., Omnidata) can review, edit, and mathematically process data in the field. Again, data stored in data loggers can be transmitted directly to a computer or a printer.

Certain types of sensors allow the researcher to collect and record a large number of observations on a number of variables. For example, in 20 to 30 seconds a photosynthesis-measuring device automatically records up to 10 observations each of CO_2 concentration, relative humidity, chamber air temperature, leaf temperature, and photosynthetically active radiation. Data storage capacity of certain data loggers and sensors can typically be over 100 pages.

Most data acquisition systems are sold as complete systems to end users and are configured for particular applications. Some of the sophisticated instruments mentioned earlier are microprocessor-based but do not have the capability of running any applications programs except those supplied by the manufacturer. However, there are a number of excellent software programs that can be used with data acquisition systems. The combination of dBASE III for storing and arranging data, Lotus 1-2-3 for spreadsheet analysis and graphics, and Turbo Pascal for computations is appropriate for data acquisition systems (Munasinghe *et al.*; National Research Council, 1986).

Data Processing (Analysis)

The skillful and expeditious handling of data is essential to the successful practice of agricultural research. The first stage in a statistical analysis, after the data has been filed, is a descriptive presentation of the data, often in the form of tables. It is recommended that a summary of basic statistics is produced and printed at this stage. Examples of basic statistics are: means, variances, standard deviations, minimum and maximum values, etc. At this point of statistical analysis, it is possible to create new variables from existing ones. The new variables can be produced by calculations performed on basic data and these, in turn, can be subjected to further statistical analysis (Sokal and Rohif, 1981).

Single-Factor Experiments

Experiments in which only a single factor varies while others are kept constant are called single-factor experiments. In such a situation, the treatments consist only of the different levels of the single variable factor. All other factors are applied uniformly to all experimental units (or plots) at a single level. An example of a single-factor experiment is a crop variety experiment where the single variable factor is variety and the levels are the different varieties being compared. Other examples are fertilizer experiments where the application of a single fertilizer element is varied; insecticide experiments where several insecticides are tested; and plant population experiments where a range of plant densities are compared.

There are two groups of experimental designs that are applicable to a single-factor experiment. The first is the family of complete block designs. This group includes the completely randomized design, the randomized complete block design, and the latin square design. These designs are suitable for experiments with a small number of treatments and are characterized by blocks, each of which contains at least one complete set of treatments.

The second family of designs is the incomplete block design. This group includes, but is not limited to, lattice and group balanced block designs. These are suited for experiments with large numbers of treatments and are characterized by blocks, each of which contains only a fraction of the treatments under consideration (Little and Hill, 1978; Michigan State University, 1985; Sokal and Rohlf, 1981).

Two-Factor Experiments

In agricultural and biological experiments, organisms are simultaneously exposed to many growth factors during their lifetime. Because an organism's response to any single factor may vary with the level of the other factors, single-factor experiments are not applicable. Thus, when response to the factor of interest is expected to differ under different levels of the other factors, researchers should use factorial experiments which are designed to handle simultaneously two or more factors.

A two-factor experiment can be expanded to include a third factor and so on. However, when more factors are added to an experiment:

1) There will be a rapid increase in the number of treatments to be tested, and

2) There will be an increase in the number and type of interaction effects.

Although a large experiment is usually not desirable because of its high cost and complexity, the information gained from interactions among factors can be very valuable (Gomez and Gomez, 1984; Little and Hill, 1978).

Regression and Correlation

In characterizing the relationships among variables, statistical procedures that can simultaneously handle several variables are needed.

Analysis of variance (using any one of the experimental designs mentioned earlier) can evaluate treatment effects on one variable at a time, even when one variable affects another.

Regression and correlation analyses allow a researcher to examine associations among:

1) Dependent variables, which represent the biological and physical features of the experimental units that are expected to be affected by the treatments being tested;

2) Dependent and independent variables, e.g., fertilizer rates, varieties, and weed control methods, which are generated from one or more management practices and are the primary focus of the experiment; and

3) Dependent variables and environment, e.g., factors such as rainfall, solar radiation, and temperature, which represent the part of the environment that is not within the researcher's control.

It is necessary that selected variables be expressed quantitatively for the proper use of this type of analysis.

Regression analysis describes the effect of one or more variables (independent) on a single variable (dependent) by expressing the latter as a function of the former. Correlation analysis provides a measure of the degree of association between the variables under consideration. Regression and correlation analyses can be classified according to the number of variables involved and the form of the functional relationship between the dependent and the independent variables. These include:

1) Simple linear regression and correlation,

2) Multiple linear regression and correlation,

3) Simple nonlinear regression, and

4) Multiple nonlinear regression.

The simple linear regression analysis deals with the estimation and test of significance concerning the intercept and the regression coefficient in the linear regression equation. It should be noted here that because simple linear regression analysis is performed with the assumption that there is a linear relationship between the independent and the dependent variables, it does not provide any test as to whether the best functional relationship between the two variables is indeed linear. On the other hand, simple linear correlation is used to measure the degree of association between two variables with or without a well-defined cause and effect relationship.

The simple nonlinear regression is used in cases where the response to a treatment is not linear (e.g., response of wheat yield to N fertilization), or in situations where plant response is not constant over a specific range of the independent variable (e.g., pattern of plant growth with time). This technique has a wide application in agricultural research and most of the nonlinear responses found in agricultural and biological systems can be linearized through variable transformations or creation of new variables from existing ones.

With the increasingly accepted perception of interdependence of factors of production in agricultural systems, and with the availability of experimental procedures that can simultaneously evaluate several factors, the use of factorial experiments is increasing and there is a corresponding increase in need for use of regression procedures that can simultaneously handle several independent variables.

Multiple linear regression is the most appropriate technique to be used in situations where a number of independent variables are assumed to affect the dependent variable in a linear fashion, and independently of one another. However, when the relationship between the dependent variable and one or more of the independent variables does not follow the multiple linear relationship, a multiple nonlinear regression technique should be used (Gomez and Gomez, 1984; Little and Hill, 1978; Michigan State University, 1985).

A danger inherent in modern data processing procedures is that the user entering the data into a computer may simply obtain the final statistical results without observing the distribution of the variables. In the past, such distributions were necessary to facilitate computations. This is no longer necessary. But such distributions could lead to interesting new insights into the nature of the data, to the rejection of some outlying observations, or suggest that the data do not conform to the assumptions of a particular statistical test. However, there are now numerous data analysis programs available that carry out just such displays (Sokal and Rohlf, 1981).

Data Analysis

Data analysis is a recent development in the area of biometry and experimental design. It involves the systematic search through a set of data to reveal information and relationships of interest. The procedures of data analysis, although essentially numerical, are also experimental.

Data analysis consists of such techniques as transformations, robust estimation, and graphics techniques. Transformation techniques are used to see what effect they have on the distribution of a sample or the relationships between two variables in a sample. Robust estimation is carried out to minimize the effects of a certain percentage of an extreme observation. Graphics techniques are used to look for (and probably suggest) interesting patterns in the data.

In fact these techniques are not new. They have been used by researchers and statisticians for many years. Yet the development of high speed computers allowed researchers to ask many more questions and obtain instantaneous answers for them.

Data analysis is looked at as the systematic and largely automated scrutiny of sets of data to yield both summaries and fresh insights into the relationships in a given study. However, one of the problems encountered in data analysis is that the longer the researcher spends adjusting the data and checking various models, the less reliable the final statistical inferences become for those data. Some researchers apply various statistical tests to the same data and choose the test results that suit them best. Such procedure is analogous to selecting data to fit models and then presenting the results as if they emerged from a random sample (Sokal and Rohlf, 1981).

Other Statistical Techniques

Statistical analysis of data generated by experiments that are conducted at several sites and over a number of years or crop seasons, can be handled by one or more of the statistical procedures outlined in the previous sections. However, in certain situations, a combined analysis of variance, regression analysis, and/or covariance analysis could be used.

In certain experimental situations, results of the classical analysis of variance procedures could be misleading. Examples are: competition effects of border plots, different fertilizer rates of adjacent plots, and varietal competition. There are special statistical techniques available to detect the degree of competition and corrections can be made to results of classical analysis (ICARDA, 1985a; Mead and Curnow, 1983; Sokal and Rohlf, 1981).

Modeling and Simulation

Mathematical modeling is the art of describing biological or physical systems with equations, usually for the purpose of planning and decision-making. One broad class of models is for simulating biological or physical systems, i.e., for predicting the outcome of a system based on its characteristics. Once a model has been developed, it can be used for simulation by inserting hypothetical or real data and calculating system output.

Models can be classified into two broad groups: stochastic or statistical models and process or physical models (IBSNAT, 1986).

Stochastic models can only be used within the limits of the universe in which they have been developed. Within these limits they commonly give reasonably realistic results. On the other hand, a process model can be used anywhere where the processes used in the model describe the system that is being modeled.

The availability of software programs for data base management (DBM) enabled researchers to use large data bases for model building and validation or calibration.

The recent advances in data base management systems (DBMS) and other fields of information technology, enabled researchers in different agricultural fields to organize large quantities of data to simulate complex processes in agricultural systems. Crop growth and production models, for example, allow researchers to predict and/or estimate (O'Toole and Jones, 1986; Ritchie, 1986):

1) Phasic development or duration of growth stages as influenced by genotype and environmental factors,

2) Biomass production and partitioning of photosynthates,

3) Root system dynamics, and

4) Effect of soil water deficit and nitrogen deficiency on photosynthesis and partitioning of photosynthates in the plant system.

Another group of models which are soil-oriented allow researchers to predict and/or estimate (Saxton, 1983; Williams *et al.*, 1984):

1) Soil moisture regimes,

2) Effects of alternative management practices on chemicals and runoff in the soil profile,

3) The effect of erosion on potential soil productivity, and

4) Economic costs of erosion for designated kinds of soils and the costs and benefits of various conservation alternatives.

With the development of complex agricultural models, researchers were able to identify some major voids in their research data. As the models have been constructed, it was common to find that many of the parameters and coefficients needed by the model were not contained in the research data base. Researchers in different agricultural disciplines learned two facts from this. First, it is possible to construct models even without all the research data desired. By using alternative structural equations in the models, many of the problems facing researchers can be solved. Second, constructing these models gave researchers insights into the deficiencies in their research programs and they were able to allocate future resources better (National Research Council, 1986).

References

Brand, S. 1970. Statistical and computational method in data analysis. North Holland, Amsterdam, The Netherlands.

Gomez, K. and A. Gomez. 1984. Statistical procedures for agricultural research. John Wiley & Sons, New York.

IBSNAT. 1986. Experimental design and data collection procedures for IBSNAT. Tech. Report 1.

ICARDA. 1985a. CRISP reference manual. ICARDA. Aleppo, Syria.

ICARDA. 1985b. ICADET database management systems (Users Manual). ICARDA, Aleppo, Syria.

Little, T.M. and F.J. Hill. 1978. Agricultural experimentation. Design and analysis. John Wiley & Sons, New York. Mead, R. and R.N. Curnow. 1983. Statistical methods in agriculture and experimental biology. Chapman & Hall, London, UK.

Michigan State University. 1985. MSTAT: Microcomputer statistical program. Experimental design, data management, data analysis (Users Manual). Michigan State Univ., East Lansing, MI.

Munasinghe, M., M. Dow and J. Fritz (ed.). Microcomputers for development: Issues and policy. The Department of Government Printing, Sri Lanka.

National Research Council. 1986. Microcomputers and their applications for developing countries. Westview Press, Boulder, CO.

O'Toole, J.C. and C.A. Jones. 1986. Crop modelling: Applications in direction and optimization of rainfed rice research. Proc. Impact of Weather Parameters on Growth and Yield of Rice. IRRI, Los Banos, Phillipines. 7-10 April 1986.

Ritchie, J.I. 1986. CERES-WHEAT: A general documentation. p. 159-175. *In* W.O. Willis (ed.). ARS wheat yield project. USDA-ARS, U.S. Gov. Print. Office, Washington, DC.

Saxton, K.E. 1983. Soil water hydrology: Simulation of water balance computations. Proc. Hamburg Workshop, August 1983.

Sokal, R. and J. Rohlf. 1981. Biometry, the principles and practices of statistics in biological research. W.H. Freeman & Co., San Francisco, CA.

SYSTAT. 1986. The system for statistics (Users Manual).

Williams, J.R., C.A. Jones and P.T. Dyke. 1984. A modelling approach to determining the relationship between erosion and soil productivity. Trans. ASAE 27:129-144.

Soil Spatial Variability and Methods of Analysis

D.J. Mulla
Washington State University, Pullman, Washington, USA

ABSTRACT. The variation in soil properties is rarely random. Usually soil properties are more similar when measured in small areas and are more variable when measured in larger areas. When soil properties are spatially variable, it is essential to determine the nature and pattern of variability in order to efficiently manage the soil. Geostatistical techniques are discussed for optimal design of sampling schemes in spatially variable soils. Use of efficient sampling patterns optimizes labor and equipment demands, while facilitating quantitative understanding of the nature and pattern of variability. A linear, unbiased, estimator technique known as kriging can be used to produce survey maps of spatially variable soil patterns using a minimum number of field samples. Maps of spatially variable soil properties can be used for efficient management of many problems, including soil salinity, plant available water, and low soil fertility. Methods of describing spatially variable soil properties are illustrated using an example involving soil test phosphorus levels on a commercial farm in the Columbia Basin of Washington State.

Introduction

Soils are inherently variable. In situations where this spatial variation is controlled by topographic patterns, differences in soil color, vegetative growth, or surface wetness may indicate the extent of heterogeneity. In most cases, however, patterns of spatial variability in soil properties are not visually apparent. Researchers often make the mistake of assuming that soil properties are relatively homogeneous in fields which are flat and have no obvious visual evidence of heterogeneity. In situations such as this, the extent of spatial variability in soil properties such as hydraulic conductivity (Vieira *et al.*, 1981), moisture content (Wierenga, 1985), soil test phosphorus levels (Dow and James, 1973), A-horizon depth (Wilding, 1985), or exchangeable sodium percentage (Uehara *et al.*, 1985) may be appreciable.

In order to determine the nature and pattern of soil variability some type of field sampling or field measurements are needed. Generally, the magnitude of variability that exists in the field is greater than the errors that arise in typical laboratory or field analytical measurements. Therefore, it is important to devise a sampling scheme which accurately measures the range of variability encountered at different locations in the sampling area (de Gruijter, 1985). Sampling schemes which involve too few sampling locations will be inadequate for management and mapping requirements. Sampling schemes which are too dense may involve high labor and equipment costs, and are also undesirable. An efficient sampling scheme is one in which a minimum number of sample locations are obtained to sufficiently characterize the magnitude and pattern of soil heterogeneity.

If the variation in soil properties occurs randomly, so that sample variance is not a function of sample separation distance, classical statistics can be used to analyze the data. These are standard techniques for analyzing soil samples, and are well known to soil scientists (Petersen and Calvin, 1965). The sample mean, $\bar{x}$, is estimated from the expression:

$$\bar{x} = (1/n) \sum_{i=1}^{n} z(x_i), \qquad [1]$$

where n is the number of samples and $z(x_i)$ is the value of the measured soil property at a location x_i. The sample variance, s^2, is:

$$s^2 = [1/(n-1)] \sum_{i=1}^{n} [z(x_i)-\bar{x}]^2, \qquad [2]$$

where s is the sample standard deviation. In order to estimate the number of samples required to estimate the sample mean within a given level of precision, the following expression can be used:

$$n = t_{\alpha}^2 s^2 / D^2 \qquad [3]$$

where t_{α}^2 is the Students t value statistic based upon a given confidence level and the number of samples used to evaluate s^2, and D is the desired maximum difference between the field means and the means of the samples. Finally, the extent of variability can also be assessed using the coefficient of variation, CV, which is usually expressed as a percent:

$$CV = (s/\bar{x}) \times 100\%. \qquad [4]$$

Typically, in most soils, the variance in measured soil properties depends upon separation distance. In such a situation, samples which are obtained from closely separated locations are more similar in value than samples separated by a larger distance. Patterns in spatial variability for samples exhibiting such spatial correlation are not accurately described using classical statistics. Instead, an analysis technique known generally as geostatistics is more useful.

The purpose of this paper is to show how models of soil spatial variability can be used to design sample schemes, to map the nature and pattern of soil variability using a minimum of input data, and to devise efficient management procedures for crop production. An example involving soil test phosphorus levels will be used to illustrate the geostatistical methodology.

Methods

Dow and James (1973) measured soil test phosphorus on a commercial farm in the Columbia Basin of Washington using a systematic sampling grid. At intervals of 100 ft, 5 soil cores within a 6 ft diameter circle were collected to a depth of 10 in. These samples were oven-dried at 70° C, combined to form one composite sample, and screened. Each composite sample was extracted with sodium bicarbonate and analyzed for phosphorus (Olsen *et al.*, 1954). In the present study, statistical and geostatistical analyses of the data were conducted using a Hewlett Packard 9816S computer and 7470A plotter.

Results and Discussion

To illustrate the use of geostatistical methods, consider an example involving soil test phosphorus values from a commercial field in the Columbia Basin of Washington. Data for this example come from a leveled, visually homogeneous area studied by Dow and James (1973), and are representative of typical results for the area. Figure 1 illustrates the variation in soil test phosphorus values on a regular grid with 40 sample locations separated by 100 ft. Note that soil test phosphorus values do not vary randomly with distance, but are generally similar in value over short distances.

The sample mean, variance, and coefficient of variation from Eq. [1], [2], and [4], respectively, are 6.3 ppm, 14.8 ppm^2, and 60 percent. A frequency distribution of soil test phosphorus and its best-fitting normal curve shown in Figure 2 were compared using a Chi-square test and found to be significantly different. Thus, soil test phosphorus values are not normally distributed. The use of Eq. [3] requires that the data be normally distributed, so it is a misapplication to use Eq. [3] for predicting sampling size. Note, however, that Eq. [3] predicts that 27 soil samples are required to estimate soil test phosphorus levels to within 2 ppm of the mean value using a confidence interval of 99 percent and n-1=39 degrees of freedom.

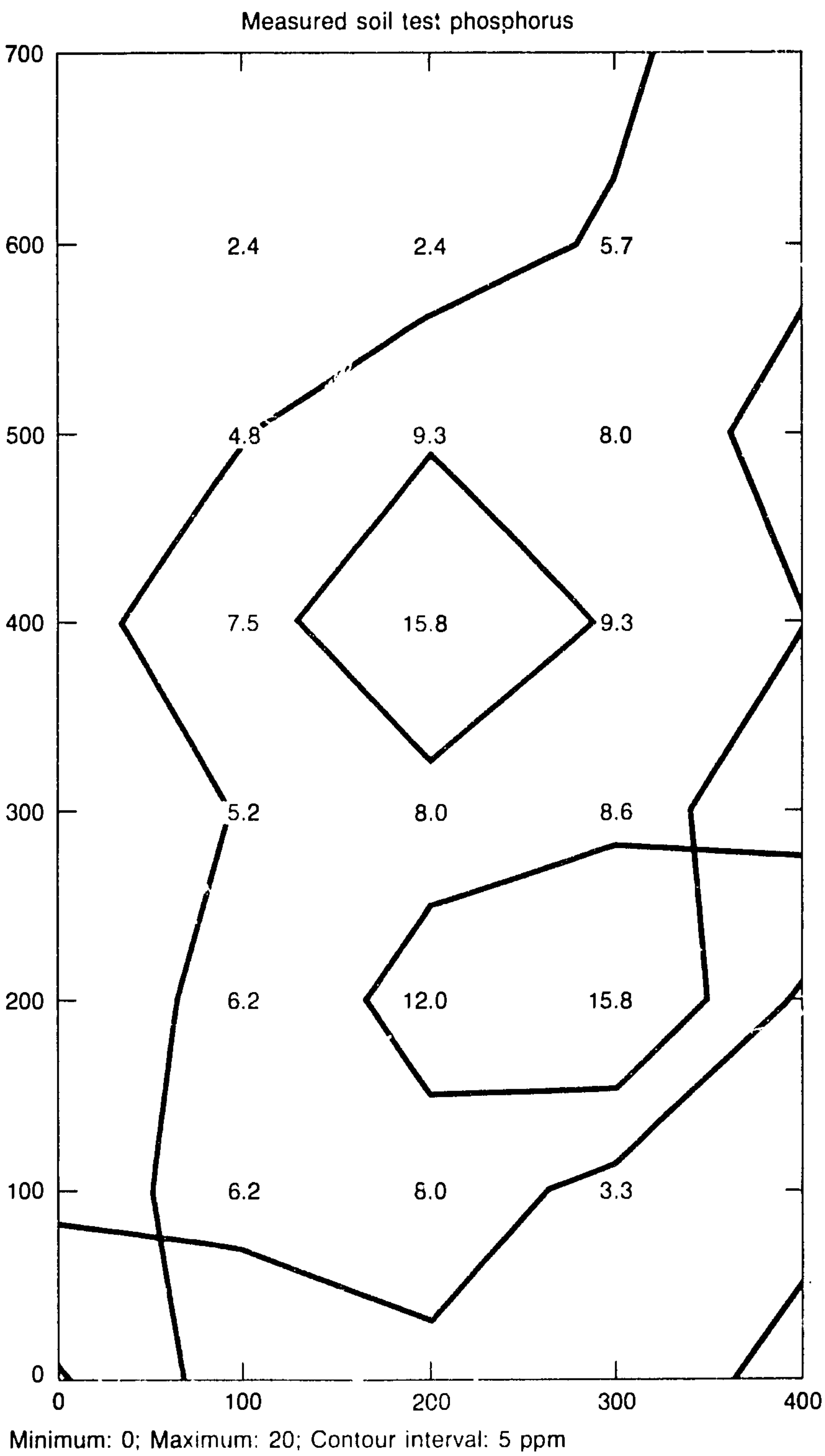


Figure 1. Soil Test Phosphorus Levels (ppm) at 40 Sampling Sites Located at 100 Ft Intervals on a Commercial Farm in the Columbia Basin of Washington.

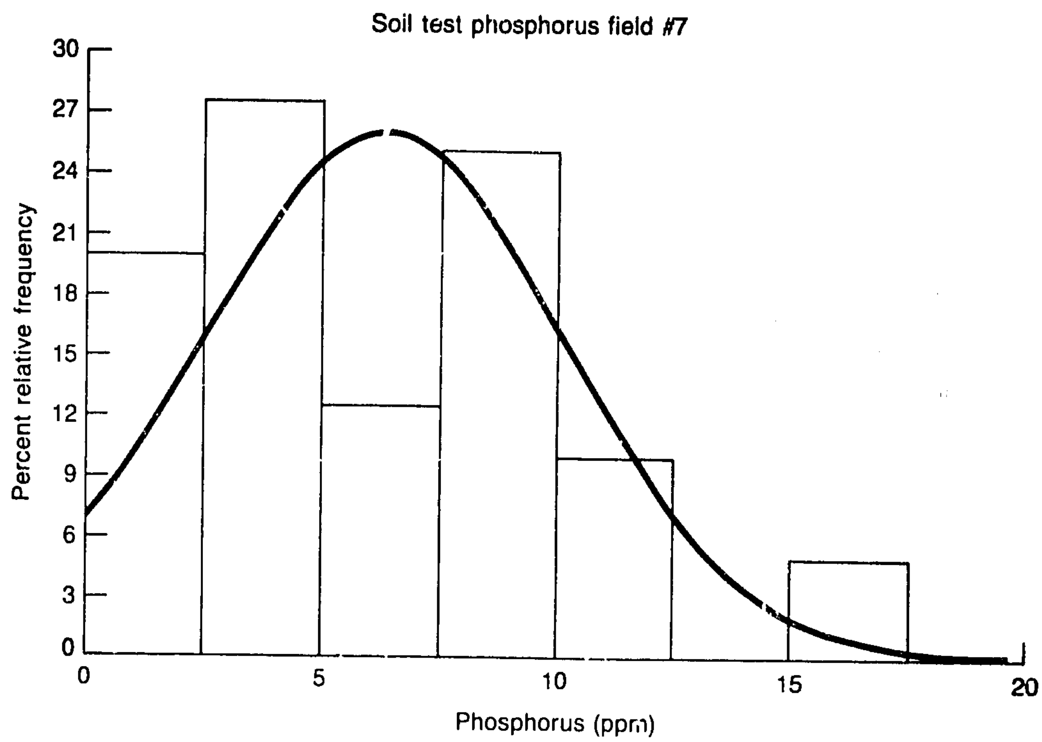


Figure 2. Frequency Distribution Diagram of Soil Test Phosphorus Levels (ppm) at 40 Sampling Sites on a Commercial Farm in the Columbia Basin of Washington.

The results in Figure 1 could be used to design an approximate fertilizer management scheme for crop production. Clearly, however, additional mapping detail is desirable. Since labor and equipment constraints are often important in field experimentation, the researcher may also want to know if less than 40 samples can be collected without sacrificing accuracy. Geostatistical methods can be applied to provide the latter information.

Geostatistics is useful for interpolating between measured data points to provide additional data for detailed mapping. This procedure involves computing the semivariance function of the data, fitting semivariogram models to the semivariance data, and using an interpolation scheme known as kriging. These procedures have been outlined by Burgess and Webster (1980) and Vieira *et al.* (1983), but are described in detail below for readers who may be unfamiliar with these sources.

The Semivariogram

As stated previously, if sample variation occurs randomly in space, the total sample variance will not depend upon the separation distance between samples. Samples which are correlated in space, however, will have lower sample variance at smaller separation distances than at larger separation distances. Therefore, one method for assessing the spatial correlation of the samples is to compute sample variance as a function of sample separation distance. For interpolation and mapping purposes, it will be useful to compute a quantity known as semivariance, $\gamma(h)$, instead of computing variance. The expression for semivariance is:

$$\gamma(h) = [1/2n(h)] \sum_{i=1}^{n(h)} [z(x_i)-z(x_{i+h})]^2, \qquad [5]$$

where n(h) is the number of samples separated by a distance of h; $z(x_i)$ is the value of the measured property at location x_i; and $z(x_{i+h})$ is the value of the measured property at location x_{i+h}. Table 1 lists values of semivariance for the soil test phosphorus levels in Figure 1 as a function of separation distance. Note that the number of pairs of data used in the computations at each separation distance are always greater than 20, and hence, are large enough to insure statistical accuracy of semivariance values (Journel and Huijbregts, 1978).

Table 1. Number of Pairs at Each Average Separation Distance Used in Computing the Semivariance for Soil Test Phosphorus Levels in Figure 1.

Avg. Distance	Number of Data Pairs
ft	
118.9	123
228.4	180
326.8	163
421.2	130
522.6	91

Theoretically, the semivariance equals zero if h=0 because there should be no variation in sample values measured at the same location. As separation distance increases, the semivariance will increase; the correlation between samples is lower as the distance between samples increases. When the separation distance reaches a large critical value (known as the range), the sample pairs lack any statistical correlation to one another and variations occur in a truly random fashion. Only if the semivariance is relatively constant with separation distance and varies randomly at a value approximately equal to the total sample variance can the researcher conclude that the sample population is adequately described by classical statistical models.

Once the semivariance function for the data is computed, standard semivariogram models can be fit to the data by least squares techniques. This allows the researcher to quantitatively model spatial variations which occur in the data. Weighted least squares curve-fitting techniques (Cressie, 1985) take into account the fact that semivariance values computed from a large number of sample pairs should be weighted more heavily than those that are computed using a smaller number of sample pairs. Although the weighted least squares technique is more accurate than the least squares technique, only the latter approach is used here. Three common semivariogram models are:

1. Linear model:

$$\gamma(h) = C_0 + B\,h \qquad 0 \leqslant h < a \qquad [6]$$

$$\gamma(h) = C_0 + C_1 \qquad h \geqslant a;$$

2. Spherical model:

$$\gamma(h) = C_0 + C_1[1.5(h/a)-0.5(h/a)3] \qquad 0 \leqslant h < a \qquad [7]$$

$$\gamma(h) = C_0 + C_1 \qquad h \leqslant a;$$

3. Exponential model:

$$\gamma(h) = C_0 + C_1[1-\exp(-h/a_0)] \qquad 0 \leqslant h; \qquad [8]$$

where h is the separation distance between observations; a is a model parameter known as the range; $(C_0 + C_1)$ is a model parameter known as the sill; and C_0 is a model parameter known as the nugget. The nugget is nonzero whenever sampling error occurs due to measurement error or when sample spacing is too large to detect spatial correlation occurring at small separation distances. In ideal situations where measurement errors are absent and sample spacing is small, the nugget will equal zero.

For the linear model, B is simply the slope of the line for a plot of semivariance versus separation distance. For the exponential model, a_0 is approximately equal to a/3. Physically, the sill is approximately equal to the total sample variance in Eq. [2], and is the maximum value of semivariance which the model attains at large separation distances. Physically, sample observations separated by distances smaller than the range are statistically correlated to one another, while measurements separated by a greater distance than the range are not correlated. Classical statistical methods can be applied to the data only if the range has a value which is smaller than the closest sampling distance.

The soil test phosphorus values in Figure 1 were used to calculate values for the semivariance. Presented in Figure 3 are the sample semivariance values computed from Eq. [5], as well as the best-fitting exponential semivariogram model from Eq. [8]. Note that the values of the sill (C_1), range (a), and nugget (C_0) for this model are approximately equal to 18.3 ppm^2, 397.5 ft, and 0, respectively. The sill is only somewhat higher than the total sample variance, and the range of spatial correlation is approximately 400 ft. Thus, the soil phosphorus levels exhibit substantial spatial correlation, and classical statistical analyses would only be useful if samples had been collected at distances separated by about 400 ft or more.

Kriging

The data presented in Figure 1 is somewhat deficient for the purposes of constructing a detailed two-dimensional map of soil test phosphorus levels. A geostatistical technique known as kriging can be applied to the data to produce a detailed map. This procedure is described below.

Kriging is an interpolation technique which uses the semivariogram model in Figure 3 and the measured data to estimate values at specified locations where no measured data are available. Estimated values, $z^*(x_0)$, are obtained from the linear interpolation scheme:

$$z^*(x_0) = \sum_{i=1}^{N} \lambda_i \, z(x_i) \qquad [9]$$

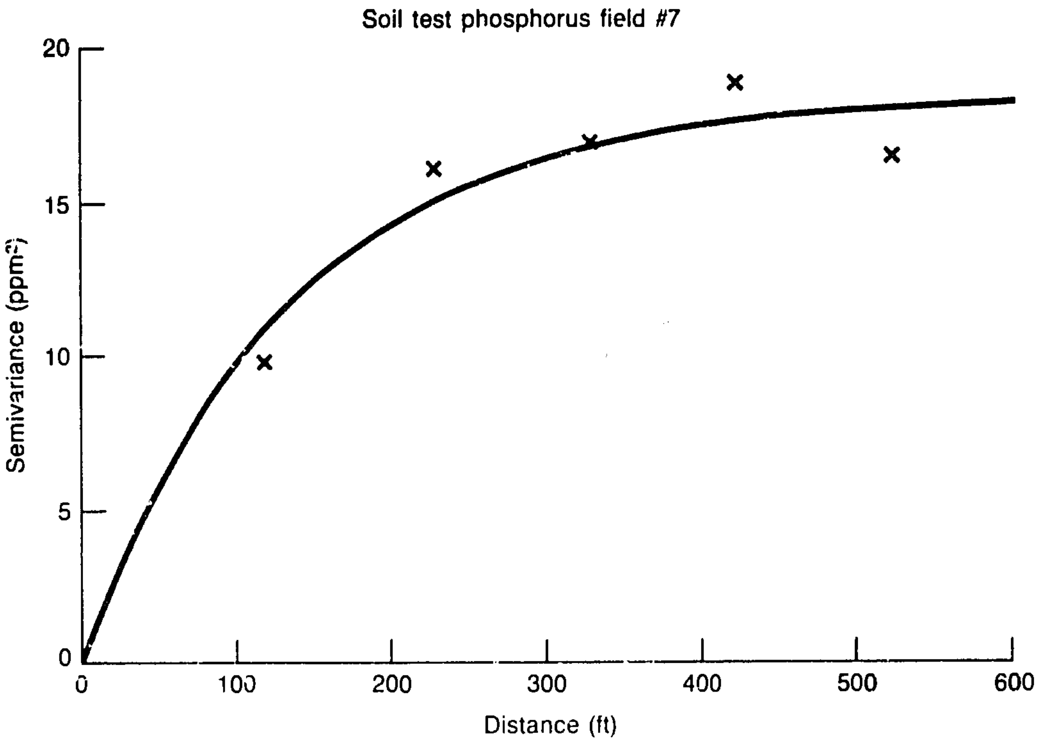


Figure 3. Semivariance Values and Exponential Semivariogram Model for 40 Soil Test Phosphorus Values on a Commercial Farm in the Columbia Basin of Washington.

where x_0 is a location where no samples were collected; N is the number of neighboring measured datum points used in the interpolation scheme; λ_i is a weighting factor for the measured data which is yet to be determined; and $z(x_i)$ is the measured datum at location x_i. Thus, kriging is a method which uses N nearest-neighbor measured data points and their associated weighting factors to estimate values at locations where data were not actually measured.

An advantage of the kriging method is that when Eq. [8] is used to estimate values at a location where actual measured data are available, the method always generates an estimated value which is equal to the actual datum. This occurs because, for such a situation, the weighting factor is unity for the observation located at the same place as the estimated value, while the weighting factors for all other neighboring data are zero. Mathematically, when x_0 is a location where an actual measured value exists the following expressions apply:

$$z^*(x_0) = z(x_0) \text{ and}$$

$$\sum_{i=1}^{N} \lambda_i = 1 . \qquad [10]$$

Many other interpolation schemes are in use but commonly, at locations where actual measured observations are available, these do not return an estimated value which is equal to the measured datum. An example of such an interpolation scheme is the linear regression line, which may have a high correlation coefficient, but does not pass through all measured points.

The kriging technique also yields a minimum estimation variance, $\sigma^2(x_0)$, which can be computed from the expression:

$$\sigma^2 (x_0) = \mu + \sum_{i=1}^{N} \lambda_i \gamma(x_i, x_0) \quad [11]$$

where μ is an undetermined multiplier; and $\gamma(x_i, x_0)$ is the value of the semivariogram model in Figure 2 corresponding to the separation distance between the kriged point at x_0 and the neighboring measured point at x_i. Lower values of the estimation variance correspond to higher accuracies in interpolation, since the estimation variance is a measure of uncertainty in the estimation procedure.

In order to compute the interpolated value in Eq. [10] and the estimation variance in Eq. [11], values must be obtained for the weighting factors, λ_i, and the undetermined constant, μ. It can be shown that these values can be computed from a system of N+1 unknowns in N+1 simultaneous algebraic equations having the form:

$$\sum_{j=1}^{N} \lambda_j \gamma(x_i, x_j) + \mu = \gamma(x_i, x_0), \text{ for } i=1 \text{ to } N, \text{ and}$$

$$\sum_{j=1}^{N} \lambda_j = 1 \quad [12]$$

where $\gamma(x_i, x_j)$ is the value of the semivariogram model in Figure 2 corresponding to the separation distance between two neighboring observations at locations x_i and x_j.

To illustrate the use of the kriging Eq. [9] to [12] for interpolation and mapping purposes, consider the 40 soil test phosphorus values in Figure 1 and the associated semivariogram in Figure 3. For simplicity, estimate soil test phosphorus at the sampling location with coordinates x=175 ft, y=425 ft, from the four neighboring measured values shown in Figure 4. Once the locations of neighboring observations have been specified, the set of simultaneous equations in Eq. [12] must be solved for the weighting factors, λ_i, and the undetermined multiplier, μ. Expressing the set of N+1 simultaneous equations (N=4 in this example) using matrix notation gives:

$$[F][L] = [B] \quad [13]$$

where

$$[F] = \begin{vmatrix} \gamma(x_1,x_1) & \gamma(x_1,x_2) & \gamma(x_1,x_3) & \gamma(x_1,x_4) & 1 \\ \gamma(x_2,x_1) & \gamma(x_2,x_2) & \gamma(x_2,x_3) & \gamma(x_2,x_4) & 1 \\ \gamma(x_3,x_1) & \gamma(x_3,x_2) & \gamma(x_3,x_3) & \gamma(x_3,x_4) & 1 \\ \gamma(x_4,x_1) & \gamma(x_4,x_2) & \gamma(x_4,x_3) & \gamma(x_4,x_4) & 1 \\ 1 & 1 & 1 & 1 & 0 \end{vmatrix}$$

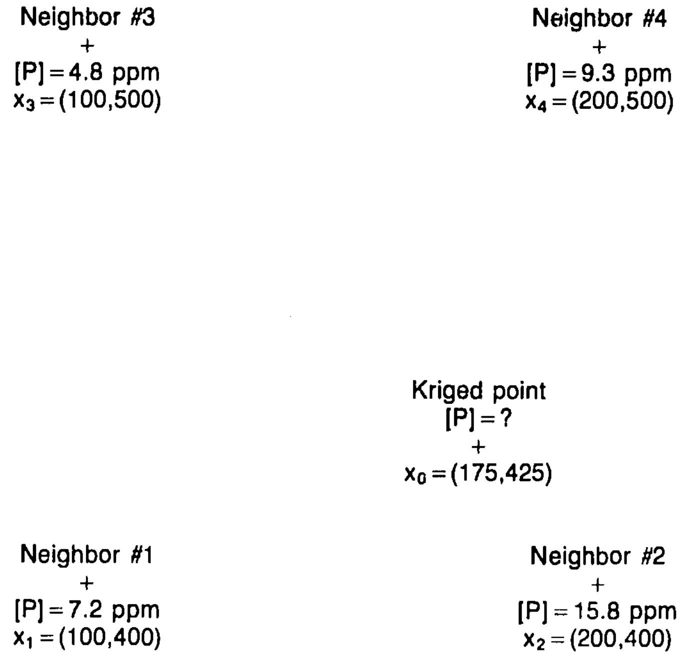


Figure 4. Locations and Soil Test Phosphorus Levels (ppm) of Four Neighboring Observations Around a Location Where Soil Test Phosphorus Level is to be Estimated by Kriging.

$$[L] = \begin{vmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \\ \mu \end{vmatrix} \qquad \text{and } [B] = \begin{vmatrix} \gamma(x_0,x_1) \\ \gamma(x_0,x_2) \\ \gamma(x_0,x_3) \\ \gamma(x_0,x_4) \\ 1 \end{vmatrix}$$

From these definitions it is evident that [F] is an N+1 by N+1 matrix of the semivariances corresponding to the separation distances between all possible pairs of neighboring observations. [B] is an N+1 by 1 column matrix of the semivariances corresponding to the separation distances between the location of the kriged point (x=175, y=425) and all neighboring observations. Values for the semivariances in these matrices are obtained from calculations with the specified semivariogram model, which in this example is given in Eq. [8] and plotted in Figure 3. The N+1 by 1 column matrix [L] is the matrix of unknown constants which needs to be determined.

The solution to Eq. [13] is obtained by matrix inversion using the expression:

$$[L] = [F]^{-1}[B] \qquad [14]$$

where $[F]^{-1}$ is the inverse of [F]. For this example the values for each entry in [F] and [B] can be obtained from the semivariogram model in Figure 3 and the appropriate separation distances. These values are given below:

$$[L] = \begin{bmatrix} 0.0 & 9.7 & 9.7 & 12.0 & 1.0 \\ 9.7 & 0.0 & 12.0 & 9.7 & 1.0 \\ 9.7 & 12.0 & 0.0 & 9.7 & 1.0 \\ 12.0 & 9.7 & 9.7 & 0.0 & 1.0 \\ 1.0 & 1.0 & 1.0 & 1.0 & 0.0 \end{bmatrix}^{-1} \begin{bmatrix} 8.2 \\ 4.3 \\ 10.1 \\ 8.2 \\ 1.0 \end{bmatrix} \qquad [15]$$

The solution to Eq. [15] is:

$$[L] = \begin{bmatrix} 0.18 \\ 0.56 \\ 0.08 \\ 0.18 \\ -0.15 \end{bmatrix} \qquad [16]$$

This solution shows that the weighting factor for the closest-neighbor observation (15.8 ppm) is the largest (0.56), and the weighting factor for the farthest-neighbor observation (4.8 ppm) is the smallest (0.08). The value of the undetermined multiplier, μ, is -0.15.

It is now possible to use Eq. [9] to estimate the soil test phosphorus level at location x=175, y=425, and to calculate the estimation variance using Eq. [11]. Substituting the values for the appropriate constants into Eq. [9] and [11] yields: $z^*(x_0) = (0.18)7.5 + (0.56)15.8 + (0.08)4.8 + (0.18)9.3 = 12.27$ ppm; and $\sigma^2(x_0) = (0.18)8.2 + (0.56)4.3 + (0.08)10.1 + (0.18)8.2 + (-0.15)1.0 = 6.01$ ppm^2.

The previous example illustrates how kriging is used to estimate soil test phosphorus from four neighboring observations at the location x=175, y=425. This procedure was used with a computer to estimate soil test phosphorus values at 493 locations separated by 25 ft increments in the study area represented by Figure 1. The results have been used to produce a detailed contour map of soil test phosphorus levels, shown in Figure 5. A detailed contour map of the estimation variances at locations in the study area is shown in Figure 6. Note that estimation variances are zero at locations where actual measurements were obtained. This shows that the kriged value at a location where an actual observation was made is always equal to the measured value.

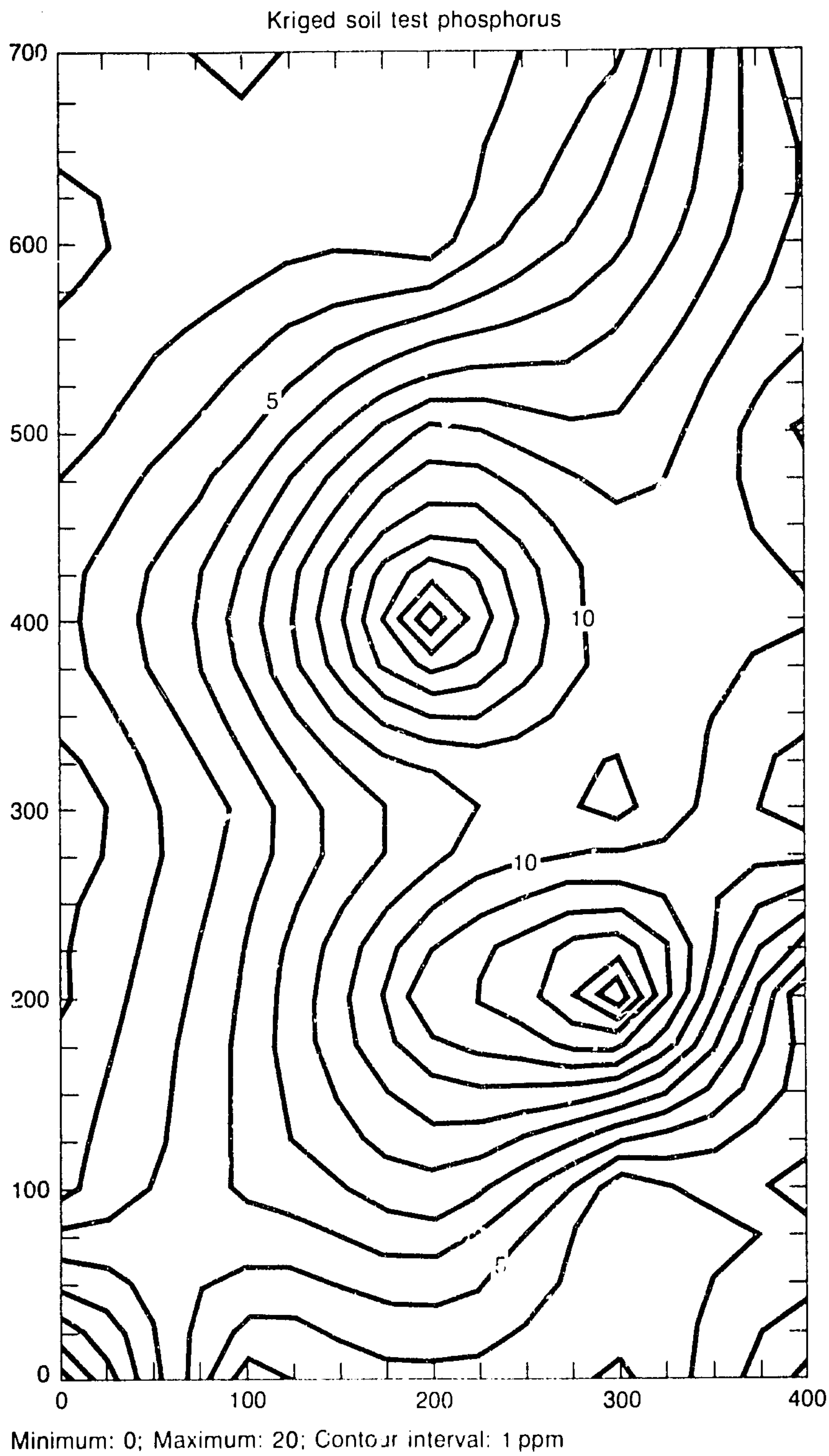


Figure 5. Contour Map of 493 Soil Test Phosphorus Values (ppm) Derived From 40 Soil Samples and Kriging at 25 Ft Increments on a Commercial Farm in the Columbia Basin of Washington.

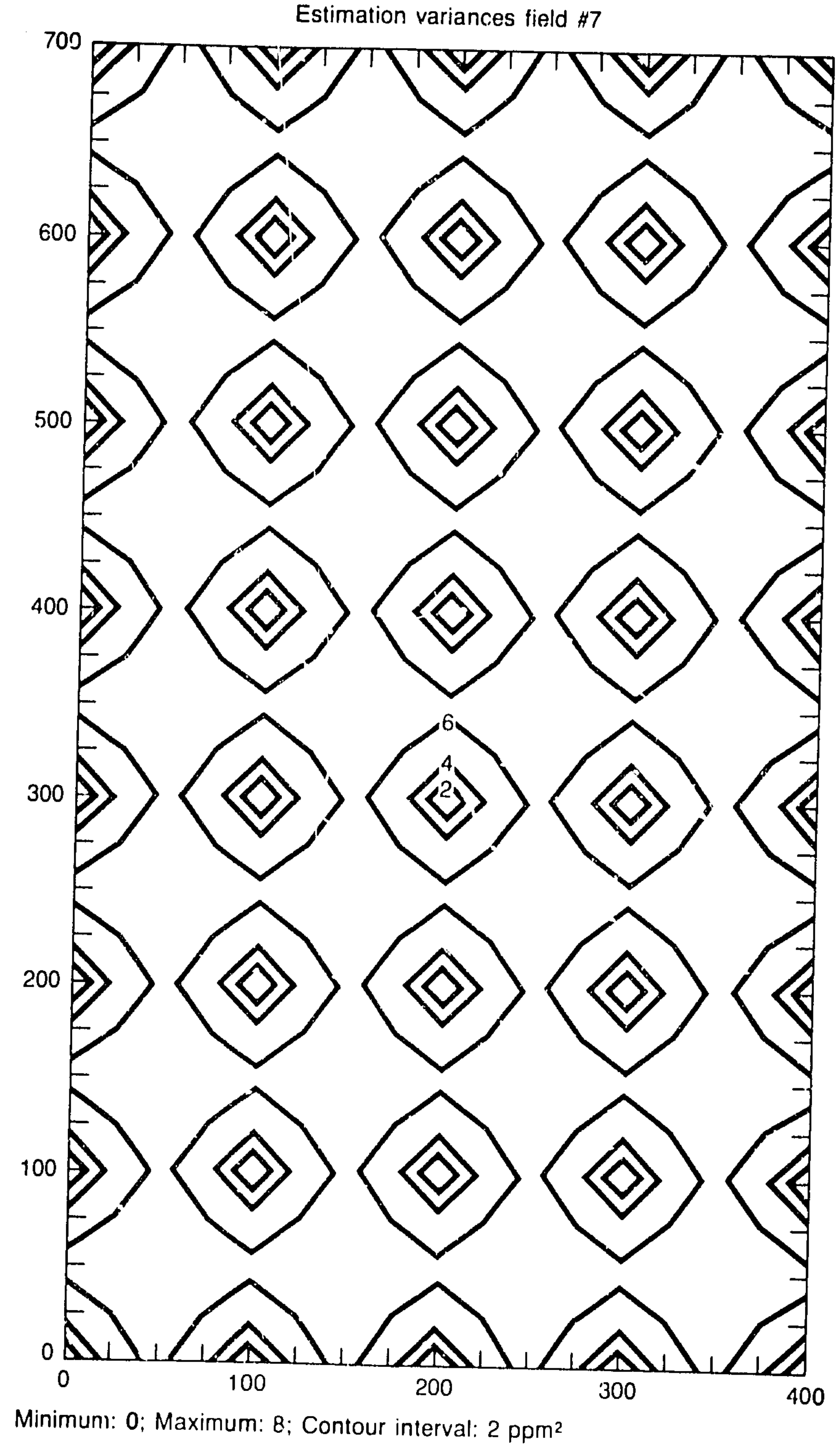


Figure 6. Contour Map of Estimation Variances (ppm^2) Derived from 40 Soil Samples and Kriging at 25 Ft Increments on a Commercial Farm in the Columbia Basin of Washington.

Table 2. Percent of Maximum Crop Yield, P_2O_5 Fertilizer Requirement, and % of Area for Five Soil Test Phosphorus Categories of a Commercial Field in the Columbia Basin of Washington.

	Soil Test Phosphorus Category (ppm)				
	0-2.5	2.6-5.0	5.1-7.5	7.6-10.0	10.1+
% of maximum yield	50	80	95	98	100
P_2O_5 needed (lb acre^{-1})	275	206	137	69	0
% area affected	7	31	22	23	17

Management Application

The soil test phosphorus levels in Figure 5 can be used to plan a fertility management program for the commercial field where the samples were obtained. To achieve this, the relation between soil test levels and suggested phosphorus fertilizer application rates must be determined from fertility trials as described in Dow (1984). The latter information for the Columbia Basin of Washington is given in Table 2, along with the percent of maximum crop yield which could be expected if no fertilizer was added (Dow and James, 1973). Also shown is the percent of the area in Figure 5 which lies in each soil test phosphorus category. These areal percentages were computed from the frequency distribution plot of kriged soil test phosphorus values shown in Figure 7.

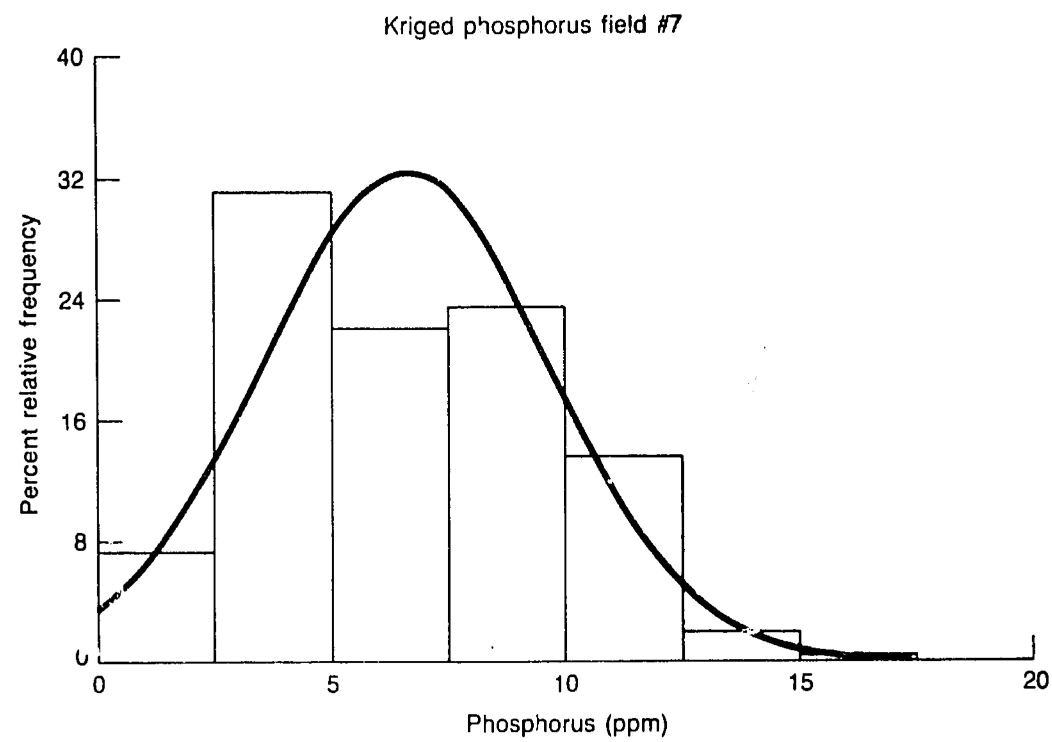


Figure 7. Frequency Distribution Diagram of 493 Kriged Soil Test Phosphorus Levels (ppm) on a Commercial Farm in the Columbia Basin of Washington.

Three distinct types of fertility management programs can be devised. These include 1) applying fertilizer based on the mean soil test phosphorus value (6.6 ppm) for the entire field, 2) applying fertilizer based on the lowest soil test phosphorus value (1.6 ppm) for the entire field, or 3) applying fertilizer according to the spatial patterns in soil test phosphorus which exist in different portions of the field. If method 1 is used, the recommended rate of P_2O_5 application from Table 2 is 137 lb acre^{-1} for the entire field. This approach obviously results in underproduction on approximately 38 percent of the farm. If method 2 is used, the recommended rate of P_2O_5 application is 275 lb acre^{-1} for the entire field. Using this approach, maximum yields would be obtained, but yield increases may be offset by increased fertilizer cost.

The third method involves using the known spatial patterns in soil test phosphorus to manage fertilizer applications. Figure 8 shows a contour map of kriged soil test phosphorus levels with a 5 ppm contour interval. This map is identical to that in Figure 5, except that fewer contour lines are drawn. The most efficient fertilizer application program for this field probably involves applying 275 lb P_2O_5 acre^{-1} to all areas having from 0 to 5 ppm soil test phosphorus levels, and applying 137 lb P_2O_5 acre^{-1} to all areas having from 5 to 10 ppm soil test phosphorus levels. No fertilizer is applied to portions of the field having greater than 10 ppm soil phosphorus. An approach such as this is not difficult to implement, and results in efficient use of fertilizer resources as well as optimum crop production.

Sampling Strategies

In the example used here, 40 soil samples were used to obtain a basic understanding of the spatial patterns in soil phosphorus levels. A kriging analysis in which some of the measured observations are omitted can be used to determine if adequate mapping detail can be obtained with fewer than 40 samples.

Consider the situation if only 20 soil samples were collected from the field using four transects and the sample design shown in Figure 9. Eq. [5] and [8] could be used to obtain the semivariance and semivariogram model, respectively, for these 20 samples. The latter results are plotted in Figure 10. Note that the semivariorgram model for 20 samples is similar to that for 40 samples shown in Figure 3. The result of kriging 493 soil test phosphorus values on a regular grid at 25 ft increments using the data in Figures 9 and 10 is shown in Figure 11. Note the qualitative similarity between the results in Figure 11 and those in Figure 5. Kriging allows the researcher to obtain detailed information concerning spatial patterns with reduced sample sizes. Estimation variances for the kriged soil phosphorus levels are shown in Figure 12. In general, these variances are larger than those shown in Figure 6. The decrease in sample number is accompanied by an increase in estimation errors. It has been noted by Webster and Burgess (1984) that kriging estimation errors are usually much less than errors predicted using classical statistics. Hence, fewer samples can be collected when a geostatistical analysis is conducted than when a classical statistical analysis is performed.

Conclusions

Soil properties usually vary in a systematic rather than random fashion in the natural environment. Geostatistical methods provide a quantitative understanding of this variability using a minimum number of field samples. Optimal management decisions can be formulated once these spatial patterns are understood.

The basic steps involved in the geostatistical approach include: 1) collecting soil samples on transects or regular grids; 2) data analysis using the semivariogram model; 3) data interpolation by the technique of kriging; 4) display of spatial patterns using contour maps of the kriged soil property; and 5) application of knowledge concerning spatial variations for management decisions. These steps are illustrated using an example involving phosphorus fertility management of a commercial farm in the Columbia Basin region of Washington.

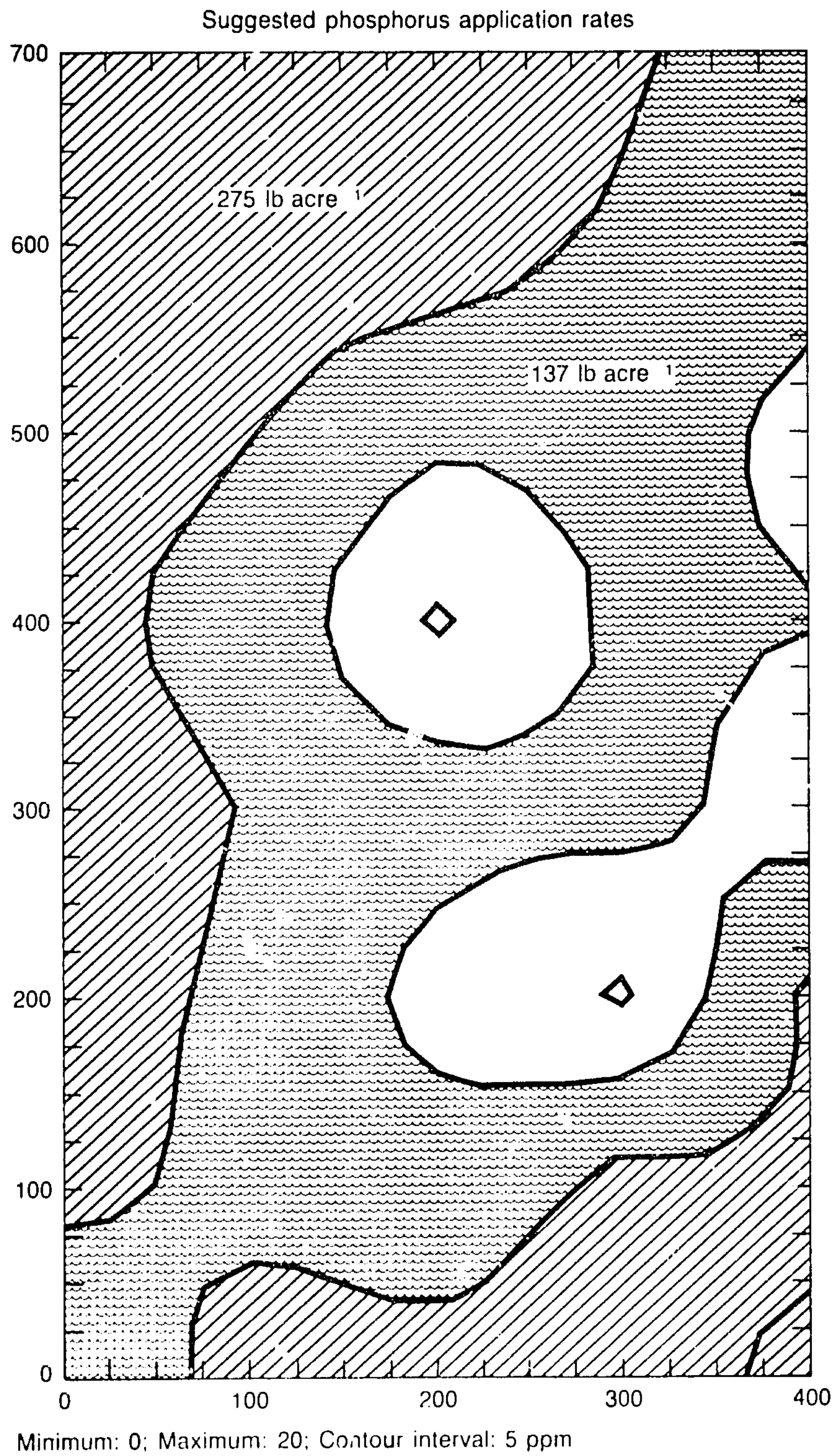


Figure 8. Suggested P_2O_5 Fertilizer Application Rates on a Spatially Variable Commercial Farm in the Columbia Basin of Washington.

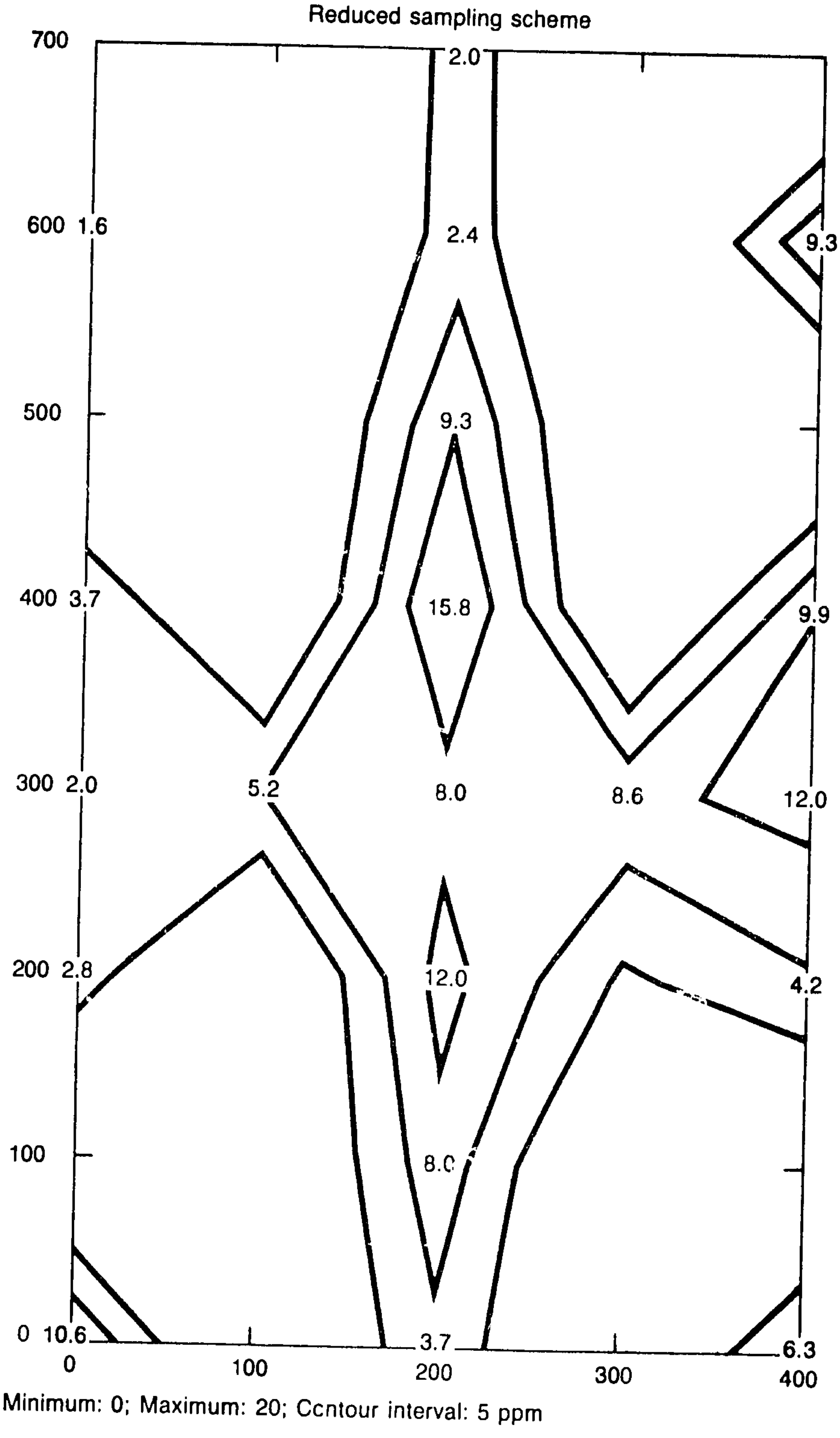


Figure 9. Reduced Intensity Sampling Design for Phosphorus Levels on a Commercial Field in the Columbia Basin of Washington.

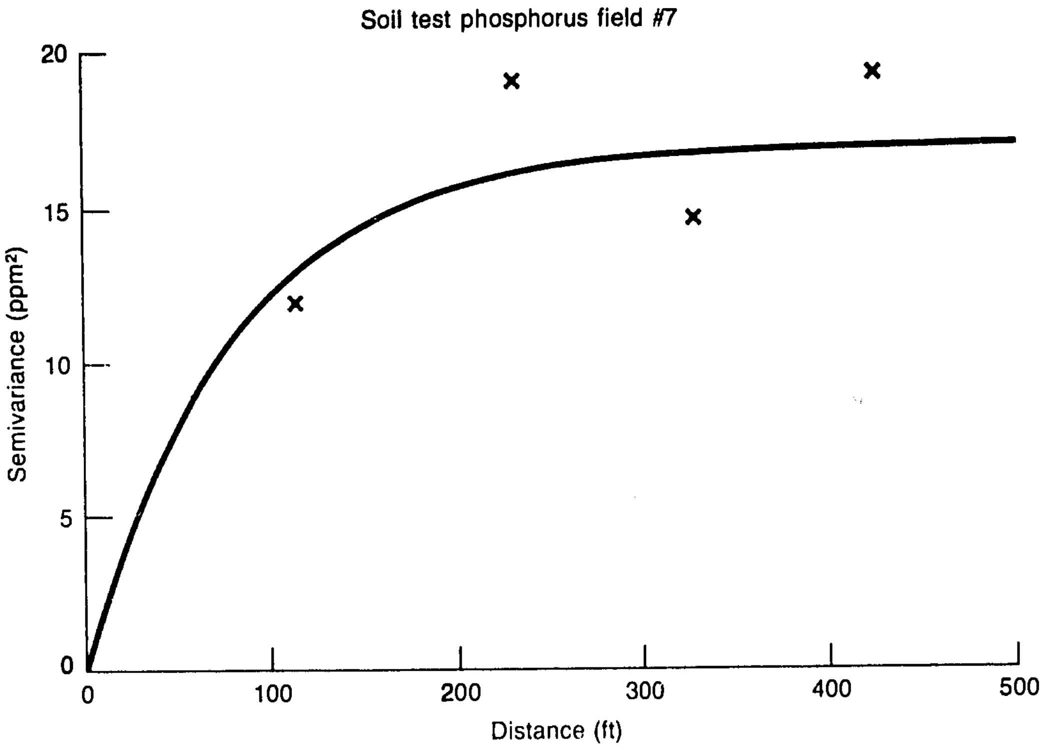


Figure 10. Semivariance Values and Exponential Semivariogram Model for 20 Soil Test Phosphorus Values on a Commercial Farm in the Columbia Basin of Washington.

The consequences of not considering spatial patterns in soil properties when conducting and designing field experiments are as follows. First, the interpretation of fertility trials or breeding trials may be inconclusive because classical statistical analyses cannot compensate for the effects of systematic spatial variability in soil properties. Second, management decisions based upon insufficient soil data will contribute to inefficient use of soil, water, crop, and fertilizer resources. Third, if sampling strategies are based upon classical concepts, excessive inputs of labor and equipment may be required. Thus, significant benefits can be expected from the application of geostatistical methods to field experimentation.

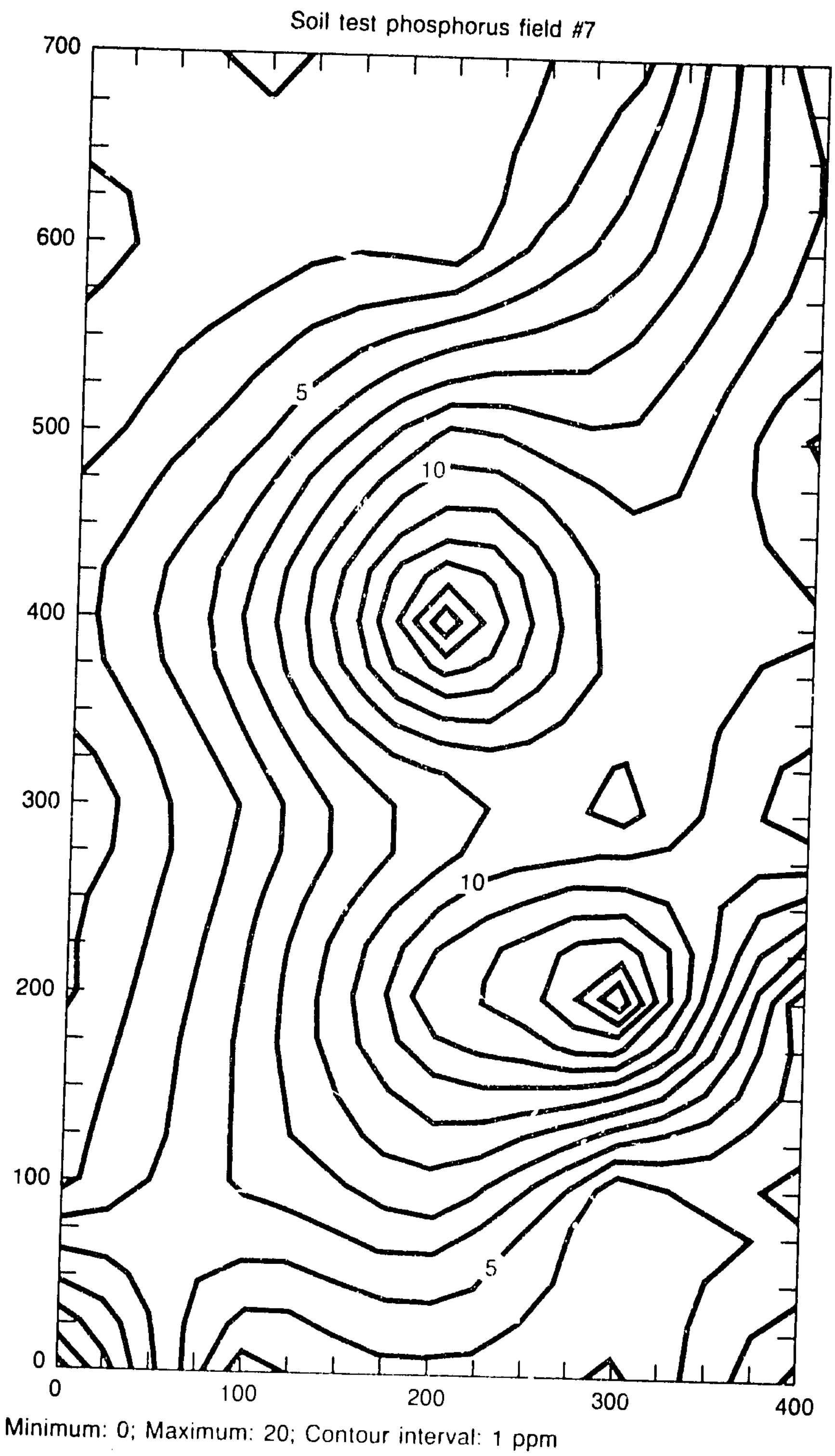


Figure 11. Contour Map of 493 Soil Test Phosphorus Values (ppm) Derived from 20 Soil Samples and Kriging at 25 Ft Increments on a Commercial Farm in the Columbia Basin of Washington.

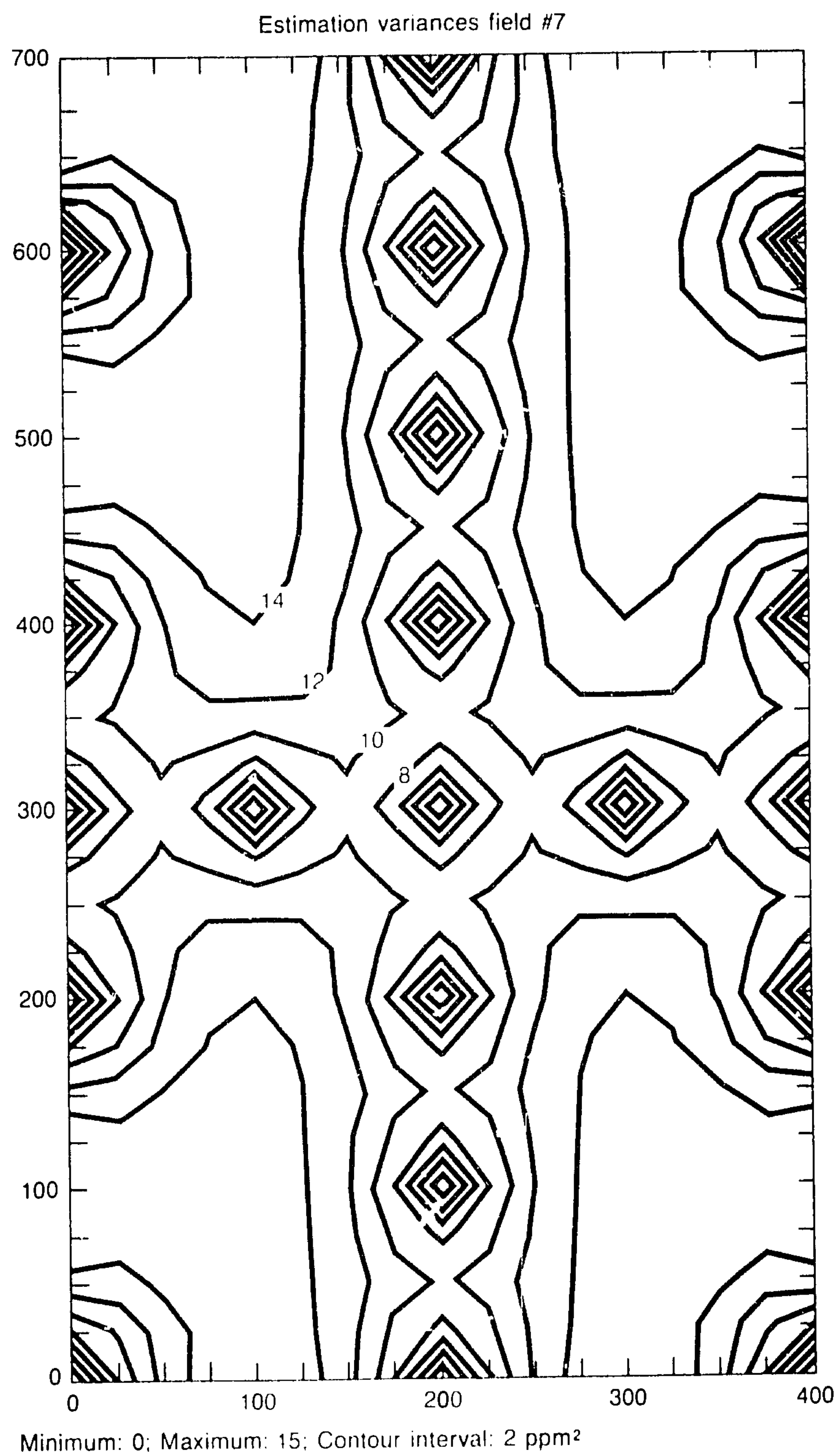


Figure 12. Contour Map of Estimation Variances (ppm^2) Derived from 20 Soil Samples and Kriging at 25 Ft Increments on a Commercial Farm in the Columbia Basin of Washington.

References

Burgess, T.M., and R. Webster. 1980. Optimal interpolation and isarithmic mapping of soil properties: I. The semivariogram and punctual kriging. J. Soil Sci. 31:315-331.

Cressie, N. 1985. Fitting variogram models by weighted least squares. Mathematical Geology 17:563-586.

de Gruijter, J.J. 1985. Transect sampling for reliable information on mapping units. p. 150-163. *In* D.R. Nielson and J. Bouma (ed.) Soil spatial variability. Pudoc, Wageningen, The Netherlands.

Dow, A.I. 1984. Soil and water management guide for the Jordan Valley. Jordan Valley Agricultural Services Project No. 278-0241.

Dow, A.I., and D.W. James. 1973. Intensive soil sampling. Washington Agricultural Experiment Station Bull. 781.

Journel, A.G. and C.J. Huijbregts. 1978. Mining geostatistics. Academic Press, London, UK.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular No. 939. U.S. Gov. Print. Office, Washington, DC.

Petersen, R.G., and L.D. Calvin. 1965. Sampling. *In* C.A. Black (ed.) Methods of soil analysis. Part 1. Agronomy 9:54-72.

Uehara, G., B.B. Trangmar, and R.S. Yost. 1985. Spatial variability of soil properties. p. 61-92. *In* D.R. Nielson and J. Bouma (ed.) Soil spatial variability. Pudoc, Wageningen, The Netherlands.

Vieira, S.R., D.R. Nielson, and J.W. Biggar. 1981. Spatial variability of field-measured infiltration rate. Soil Sci. Soc. Am. J. 45:1040-1048.

Vieira, S.R., J.L. Hatfield, D.R. Nielson, and J.W. Biggar. 1983. Geostatistical theory and application to variability of some agronomical properties. Hilgardia 51:1-75.

Webster, R. and T.M. Burgess. 1984. Sampling and bulking strategies for estimating soil properties in small regions. J. Soil Sci. 35:127-140.

Wierenga, P.J. 1985. Spatial variability of soil-water properties in irrigated soils. p. 112-125. *In* D.R. Nielson and J. Bouma (ed.) Soil spatial variability. Pudoc, Wageningen, The Netherlands.

Wilding, L.P. 1985. Spatial variability: Its documentation, accommodation and implication to soil surveys. p. 166-187. *In* D.R. Nielson and J. Bouma (ed.) Soil spatial variability. Pudoc, Wageningen, The Netherlands.

Economic Analysis of Conservation Practices

D. Colacicco and A. Barbarika
U.S. Department of Agriculture, Economic Research Service, Washington, DC, USA

ABSTRACT. Conservation practices must be evaluated by what they offer to the farmer in terms of net income or risk management and what they offer to the public in terms of net social benefits. In order to determine the net value of conservation practices, costs and benefits can be analyzed by either a cost-effectiveness or a benefit-cost analysis. Costs are of two types: resource costs in labor, supplies and equipment, and opportunity costs, that is, profits lost by employing a conservation practice. The most cost-effective practices in terms in annual cost and erosion reduction benefits to the farmer are, in order: conservation tillage, contouring, and winter cover crops. Other practices may be recommended depending on the desired level of erosion control and the funds available. Farmers benefit from reduced erosion by maintenance of their crop yields over the long-term and reduced fertilizer costs. The water conservation benefits of reduced soil erosion can also be substantial, particularly in dry areas where they can be six times the soil conservation benefits. Other benefits of erosion control occur off the farm and can easily exceed the benefits to the farmer. But the dollar value of these social benefits is difficult to quantify. Determination of the most cost-effective conservation practice or set of practices requires more information than is often available. Simulation models have tremendous potential to aid in these evaluations, but for the time being, guesstimates will probably dominate the conservation practice selection procedure of farmers.

Introduction

Any discussion of the economics of conservation practices must begin with the observation that conservation per se has no economic value. Conservation practices must be evaluated by what they offer to the farmer in terms of net income or risk management and what they offer the public in terms of net social benefits. This paper reviews the items that must be considered in estimating the costs and benefits of erosion control practices and determining the best level of erosion control. Few generalities are made on the circumstances associated with high returns to investment in soil conservation. One generality is that the return is determined by specific site circumstances that are hard to generalize. Emphasis is on the costs and benefits to farmers, but the public perspective is also recognized.

Examples of the benefits and costs of erosion control practices will be used to demonstrate the concepts under discussion. The data used in the examples are drawn from the authors' experience analyzing the economics of soil conservation in the United States and are representative of the ideal data required for private or public analyses of conservation practices.

This paper begins with a discussion of data and procedural needs. The analyst must recognize the intended audience, the type of required analysis, and then scramble to collect available data. The costs of erosion control are discussed in the second section. The costs are easier to estimate than the benefits because the farmer sees most of the costs as expenses or demands on his time and equipment. However, some of the costs may not represent consumed resources, but rather foregone profit or opportunity costs. Adding less erosive crops that are less profitable to the rotation is an example of an opportunity cost. The cost of a practice can be negative. For example, conservation or reduced tillage has been found to be cheaper than conventional clean tillage in many parts of the United States. A procedure to determine the lowest cost practice or set of practices for a given level of erosion reduction follows the cost section.

The benefits from installing soil conservation practices are discussed next. A major benefit to farmers is a reduction in the negative impacts of soil erosion on farm profits. An economic analysis of conservation practices must recognize the long term and cumulative nature of these benefits. A procedure is developed and used to estimate the productivity value of a ton of topsoil. Many practices that are considered soil conservation practices actually improve the farm's profitability more by conserving water than soil. In addition to these on-farm benefits which must also be incorporated into all economic analyses of conservation practices, public analyses of conservation practices must also recognize as benefits the reduction in damages suffered by the users of waters polluted by agricultural activities. These offsite benefits of erosion control can be greater than the on-farm benefits.

The fifth section of this paper discusses the procedures to select the best set of conservation practices for a particular site. An example is used to demonstrate the optimal selection process. The final section makes a few general conclusions and summarizes the paper.

Procedural and Data Needs

Evaluation of the impacts of the practices is dependent on whether the analysis is for the farmer or for the government as the representative of the public. In the presence of full information, a well functioning land market, and efficient capital markets, the only difference in the conservation choices of a farmer and a wise social planner would be due to consideration of offsite benefits (McConnell, 1983). However, the real world has imperfectly functioning markets and neither farmers nor social planners have all the information needed for wise decision-making.

In an efficient capital market, the interest rate will be both the farmers' price of capital and the social rate of discount used in public-oriented analyses. Selection of an interest rate is important because of the long-term nature of the benefits. To use any rate other than the opportunity cost of capital will result in an unreliable analysis.

Some economists have argued that the planning horizon of farmers is not long enough for wise planning. A well functioning land market makes this argument irrelevant. An efficient land market will capitalize the productivity of the soil into the land price. Therefore, any improvements to soil productivity made by a farmer installing conservation practices will increase the selling price of land. The recognition of this effect by the farmer will result in the correct consideration of the value of future soil productivity in the farmer's soil conservation choice.

A farmer must use the prices paid for resources in calculating costs. A public-oriented analysis would use estimated opportunity costs of resources in lieu of market prices if the prices are not determined by competitive markets. Deviation from the assumptions of perfectly functioning markets by a public analyst must be made with care since they will, as a minimum, increase the complexity of the analysis and can greatly increase its controversy.

After the recipient of the analysis has been identified, the analyst must determine the type of analysis. If the recipient has already determined to set aside a fixed amount of money for conservation, or if the benefits cannot be estimated, a cost-effectiveness analysis is sufficient. A complete economic analysis such as benefit-cost analysis is performed if the recipient wants to determine the optimal level of erosion control or to determine the return on investment in erosion control.

Cost-effectiveness measures the benefits of practice installation in physical units, such as tonnes of soil saved per dollar of expenditure. The procedure implicitly assumes that the eroded soil has the same value in all situations. A centimeter of soil from a thin soil in one area is worth the same as a centimeter of deep fertile soil in another area. Also, a tonne of soil affecting a salmon fishery is assumed to inflict the same damage to society as a tonne of soil eroding into a farm pond.

A more complete economic analysis such as benefit-cost analysis has two principal advantages over a cost-effectiveness analysis. First, a benefit-cost analysis can incorporate more objectives than a cost-effectiveness analysis in determining the best distribution of investment by geographic areas, soil groups, land uses, etc. Multiple objectives, such as the maintenance of rural water quality, agricultural productivity, or farm income, can be incorporated into the analysis if these can be defined in dollar terms.

The second principal advantage of benefit-cost analysis of soil conservation is its potential to evaluate the worth of the investment relative to other nonconservation investments. The benefits of erosion control are primarily the damages avoided by reducing erosion. A benefit-cost analysis that results in a high benefit/cost (B/C) ratio may be demonstrating that a greater investment in erosion control is warranted. However, economic analyses in general are only meant to be used as one piece of information, albeit an important one, among other pieces that are required to make responsible investment decisions. Attitudes by the analysis recipient toward risk, equity, and the ethics of conservation will affect the decision to adopt conservation practices. For example, this paper will not incorporate any analysis of the risk to the food system of continued erosion. It's clear that the current level of erosion has reduced the productive potential of United States agriculture. Some may feel that there is a level of productivity reduction which is unacceptable in terms of the risk to our future food system regardless of what any B/C analysis result may show.

The quality and completeness of an economic analysis of conservation practices will be largely determined by the available data. The economist, farmer, or extension agent seldom have the resources, time, or inclination to develop primary data for the economic analysis. Appropriate, scientifically valid data needed for a specific analysis are rarely available and the analyst always faces the question of how to rationally extrapolate relevant data to the needs of the analysis. Mathematical models are an excellent way for a sophisticated analyst to adapt existing scientific knowledge to a specific analysis. Recent development of yield/soil loss models will greatly facilitate estimation of the soil productivity benefits of conversation and an example of their use is presented in this paper. The type of data used as examples in this paper will not be available or appropriate for many analyses. In those cases, alternative data or professional judgement will have to be used to complete the analysis.

Costs of Soil Conservation

The costs of controlling erosion are much easier to estimate than the benefits. Conservation practices can incur two types of costs which must be included in economic analyses. Resource costs are the conventional costs of the inputs used to install the practices. The equipment rental and labor costs of installing a terrace are examples of resource costs. The profit sacrificed because of using a practice is called an opportunity cost. The reduction in profit caused by taking land out of production in a grassed waterway or by adding hay to a crop rotation are examples of opportunity costs.

Erosion control practices can be categorized as either management practices or structural practices. The net cost of a conservation management practice is estimated by budgeting its costs and returns and comparing these to the cost and return without the practice. Available data sources are used to estimate the price and quantities of the inputs and the output commodity. There is no substitute for this laborious chore.

Table 1 is an example of a conventional fall tillage budget for soybeans in Iowa. In comparison, Table 2 is a sample budget for soybeans in Iowa when conservation tillage is used. Both tillage practices are assumed to have identical yields of 2427 kg ha^{-1}. In many instances conservation tillage, which disturbs less soil, results in yield changes and changes in revenues. In our sample case, the only difference was assumed to be in the tillage applied. The reduced tillage results in lower costs for all items associated with pre-harvest machinery such as fuel, repairs, labor, interest, and ownership costs. The conservation tillage budget shows a cost savings of \$21.77 ha^{-1} over fall tillage.

Table 1. Sample Conventional Tillage Budget.†

	Unit	Price or Cost/Unit	Quantity	Value or Cost per Ha
		.. $ ..		.. $ ..
1. Gross receipts from production:				
Soybeans	kg	0.27	2427.30	664.47
Total receipts				664.47
2. Variable costs:				
Preharvest:				
Seed	kg	0.44	67.24	29.80
Nitrogen	kg	0.40	11.21	4.42
Phosphate	kg	0.62	56.03	34.47
Potash	kg	0.24	56.03	13.47
Lime	t	10.83	0.50	5.42
Pre-emerge herb	ha	26.81	1.00	26.81
Post emerge herb	ha	23.48	0.30	7.04
Herbicide appl.	ha	7.14	3.00	21.42
Mach fuel & lube	ha			18.95
Mach repairs	ha			13.37
Machinery labor	hr	3.84	3.56	13.67
Interest on op. cap.	$	0.14	80.69	10.89
Total preharvest				199.73
Harvest				
Mach fuel & lube	ha			7.39
Mach repairs	ha			6.82
Machinery labor	hr	3.84	1.85	7.09
Interest on op. cap.	$	0.14	0.00	0.00
Total harvest				21.30
Total variable costs				221.03
3. Income above variable costs				436.72
4. Ownership costs (replacement, taxes, interest, ins.)				
Tractors				25.99
Machinery				89.40
Total ownership costs				115.37
5. Other costs				
Land charge (no charge)				0.00
General farm overhead				0.00
Total other costs				0.00
6. Total of above costs				343.12
7. Return to risk and management				321.35

† Prepared by the Center for Agricultural and Rural Development, Iowa State University, in cooperation with SCS, for the RCA analyses.

Table 2. Sample Conventional Tillage Budget.†

	Unit	Price or Cost/Unit	Quantity	Value or Cost per Ha
		.. $ ..		.. $ ..
1. Gross receipts from production:				
Soybeans	kg	0.27	2427.30	664.47
Total receipts				664.47
2. Variable costs:				
Preharvest:				
Seed	kg	0.44	67.24	29.80
Nitrogen	kg	0.40	11.21	4.42
Phosphate	kg	0.62	56.03	34.47
Potash	kg	0.24	56.03	13.47
Lime	t	10.83	0.50	5.42
Pre-emerge herb	ha	26.81	1.00	26.81
Post emerge herb	ha	23.48	0.30	7.04
Herbicide appl.	ha	7.14	3.00	21.42
Mach fuel & lube	ha			15.00
Mach repairs	ha			10.60
Machinery labor	hr	3.84	2.94	11.31
Interest on op. cap.	$	0.14	73.19	9.88
Total preharvest				189.64
Harvest				
Mach fuel & lube	ha			7.39
Mach repairs	ha			6.82
Machinery labor	hr	3.84	1.85	7.09
Interest on op. cap.	$	0.14	0.00	0.00
Total harvest				21.30
Total variable costs				210.93
3. Income above variable costs				446.81
4. Ownership costs (replacement, taxes, interest, ins.)				
Tractors				20.29
Machinery				84.56
Total ownership costs				104.84
5. Other costs				
Land charge (no charge)				0.00
General farm overhead				0.00
Total other costs				0.00
6. Total of above costs				322.51
7. Return to risk and management				341.96

† Prepared by the Center for Agricultural and Rural Development, Iowa State University, in cooperation with SCS, for the RCA analyses.

Some of the conservation management practices such as green manuring, critical area planting, and pasture and hayland planting may reduce revenues in the short-term if they cause lower valued crops such as hay to be substituted into the crop rotation.

Most of the costs of structural practices such as terraces, waterways, and windbreaks are incurred at installation, but all have operation and maintenance costs. These practices also reduce the acreage available for crop production and this opportunity cost must be included in the cost analysis.

Table 3 presents the average cost per ha of the most common conservation practices in the United States. The costs can vary widely between sites and are dependent on site characteristics, management practices, and other factors. Table 3 also shows the average soil savings for the practices. In general, the structural practices save more soil but cost enough more per ha to make them more costly per t of soil saved (less cost-effective) than most management practices.

Table 3. Average Cost of Various Conservation Practices in the United States.

Conservation Practices	Average Cost per Ha†	Average Erosion Reduction per Ha‡	Cost per Metric Ton of Erosion Reduction
	. $.	t	. $.
Structural Practices			
Diversion and water ctr str	165.01	108.12	1.52
Grassed waterway	445.27	213.72	2.08
Terrace	208.40	211.28	1.08
Windbreak	39.39	112.58	0.35
Management Practices			
Conservation tillage	-3.63	30.26	-0.12
Contour and stripcropping	13.32	85.34	0.15
Cover and green manure	25.99	8.38	3.10
Critical area planting	65.31	108.54	0.61
Emergency tillage	36.57	32.36	1.12
Grasses and legumes	195.63	93.21	2.09
Pasture and hayland mtg	60.38	76.16	0.87
Pasture and hayland plt	111.91	129.43	0.95

† Present value of costs over the life of the practices.

‡ Erosion reduction over the life of the practice.

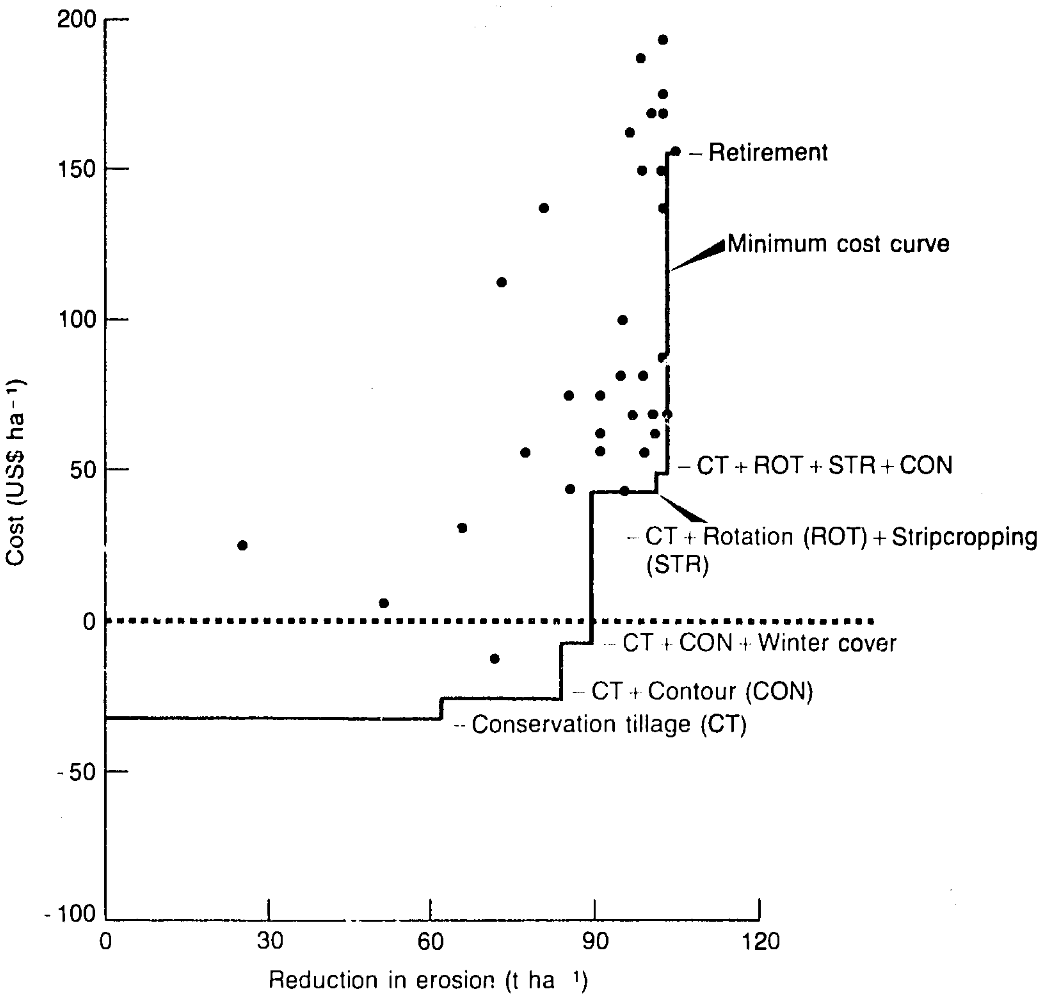


Figure 1. Sample Cost Curve for Erosion Reduction for Soybean Land in Northern Missouri (Raitt, 1981).

Identifying Cost-Effective Practices

Soil savings of a number of practice combinations can be estimated for a specific area and then the cost-effective combinations can be identified (Raitt, 1981; Reisen *et al.*, 1986). Figure 1 shows an example of this procedure. The annual costs and erosion reduction for many possible combinations of practices are shown (as circles) for a soybean operation in northern Missouri on a specific soil group. The solid line shows the minimum costs of achieving a given erosion reduction. The most cost-effective practice to apply first is conservation tillage which has a negative cost and saves about 63 t ha^{-1}. The next most cost-effective practices to add to conservation tillage are contouring and then a winter cover crop. All the cost-effective combinations of practices are identified in Figure 1 with land retirement conserving the most soil. While terraces were an option, none of the cost-effective combinations included terraces. The particular practice chosen under a cost-effectiveness analysis will depend on the desired level of erosion control or the funds available. The minimum cost curve will have the general shape shown in Figure 1, with average cost increasing with greater erosion control. A more complete economic analysis requires an estimation of the dollar benefits as well as the costs of erosion control.

Benefits of Soil Conservation

Benefits to Farmers from Reduced Erosion

The loss of topsoil will cause reduced yields under a given management scheme due to the reduction of nutrients, water-holding capacity, water infiltration, organic matter, and other beneficial characteristics of topsoil. However, a farm operator can be expected to change his management of the land in response to the reduced soil quality. Depending on the specific effects of erosion on his soil. the farmer may increase purchased nutrients such as fertilizer to maintain yields or, alternatively, the farmer may reduce his input application rate because of the reduced yield potential. Thus, the benefits to the farmer from conserving topsoil are the sum of the value of the yields maintained plus the cost savings from not changing the application rate of fertilizer or other inputs.

The farmer receives benefits from maintaining topsoil long after the erosion control practice has been discontinued. For example, suppose a farmer currently has a 6000 kg ha^{-1} crop and is continually losing 30 kg of yield per year due to an erosion rate of 20 t ha^{-1} y^{-1}. This situation is shown in Figure 2. If the farmer used conventional tillage, his yield would fall to 5970 kg ha^{-1} the first year and drop 30 kg per year thereafter.

If the farmer tried reduced tillage in year 1, there would be no yield drop and the farmer would have that annual 30 kg advantage for as long as he was growing a crop, even if he decided not to use reduced tillage again. In this case, the yield would be 5940 kg ha^{-1} in year 2 without having tried reduced tillage in year 1, but the yield in year 2 is 5970 kg ha^{-1} with having tried reduced tillage in year 1. Any commensurate change in fertilizer costs would also continue as long as the farmer grew a crop.

In the above example, a yield benefit of 30 kg ha^{-1} was created by a one time savings of 20 t of soil. Thus there would be a 30/20 or 1.5 kg per year saving per t. If the crop were corn worth \$0.10 kg^{-1}, the value of the annual yield benefit per t of soil savings would be 1.5 × \$0.10 or \$0.15.

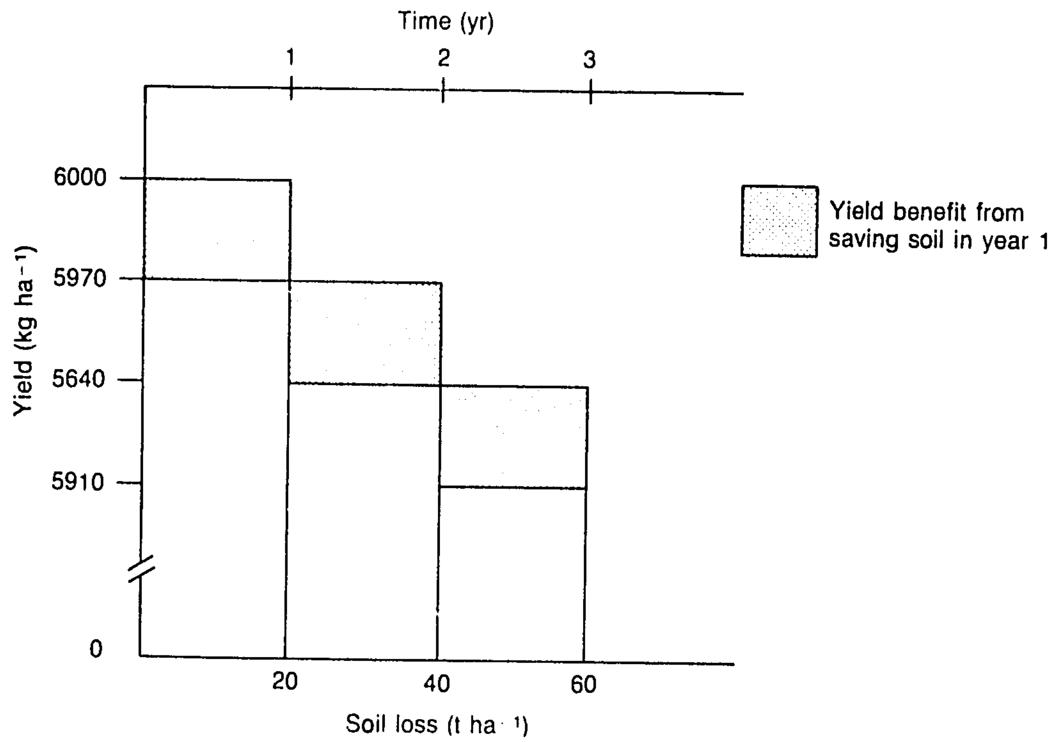


Figure 2. Benefits over Time from Adoption of a 1-Year Practice.

The present value of a stream of annual yield benefits would be the annual value ($0.15 t^{-1}) times an annuity factor, which is dependent on the number of years the benefits last and a discount rate. If we assume that the land will be in crop production forever, then the annuity factor is just the multiplicative inverse of the discount rate. A discount rate of 4 percent, which approximates the real return to capital, yields an annuity factor of 25. The present value of a stream of yield benefits of a one time savings of a tonne of soil in the above example would be worth 25 × $0.15 or $3.75.

Any benefits from saving fertilizer or lime could be subjected to the same procedure to determine the present value of these benefits. Obviously, the total present value of saving a tonne of soil would be the sum of the present values of the yield, fertilizer, and lime benefits. If the fertilizer and lime effects were not present in the above example, the value per t would remain at $3.75. The present value of the benefits from the installation of a conservation practice is the total present value per t of soil times the number of t of soil saved by the conservation practice, assuming that the yield response to soil loss is linear. Thus, the total present value of benefits from the adoption of 1 year of reduced tillage in the above example is 20 times $3.75 ha^{-1} or $75.00.

The annual benefits from the soil savings generated by practices that last more than one year accumulate as long as the practices continue in use and then last as long as the farmer grows a crop. For example, the yield effects from installation of a conservation practice that saves 20 t soil per year and lasts three years is depicted in Figure 3. After the first year's impacts, a second year of the practice saves another 20 t soil and maintains

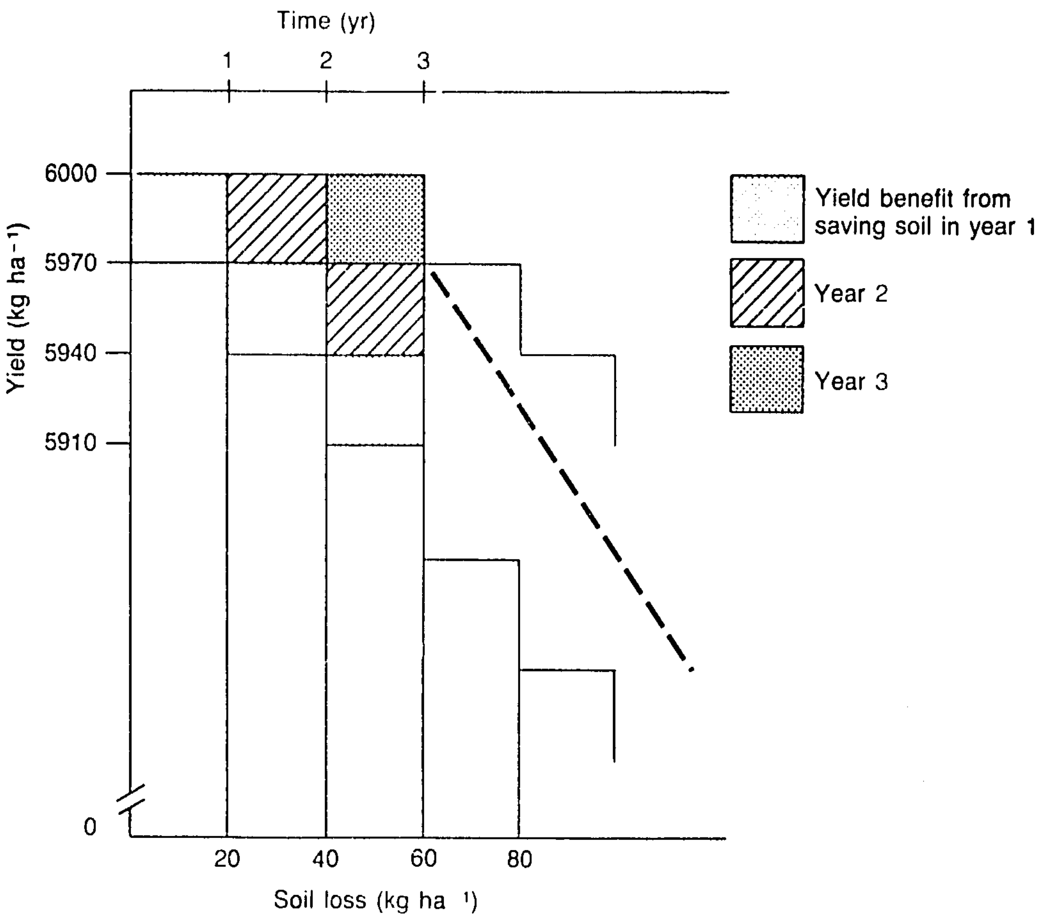


Figure 3. Benefits over Time from Adoption of a 3-Year Practice.

another 30 kg crop production. This 30 kg of yield is added to the half bushel produced by the soil savings the previous year, summing up to yield 60 kg more in the 2nd year than would have existed without the conservation practice. By the 3rd year, the annual yield would be 90 kg ha^{-1} over what it would otherwise be and remains that much higher as long as the land is farmed.

We have assumed no yield effect due to exogenous technology changes. Technology could increase productivity, thereby reducing commodity prices and the benefits of erosion control. However, technological advances could also be complementary to soil quality in crop production, which would make the yield reduction due to erosion and the benefits of erosion control even greater than without such advances.

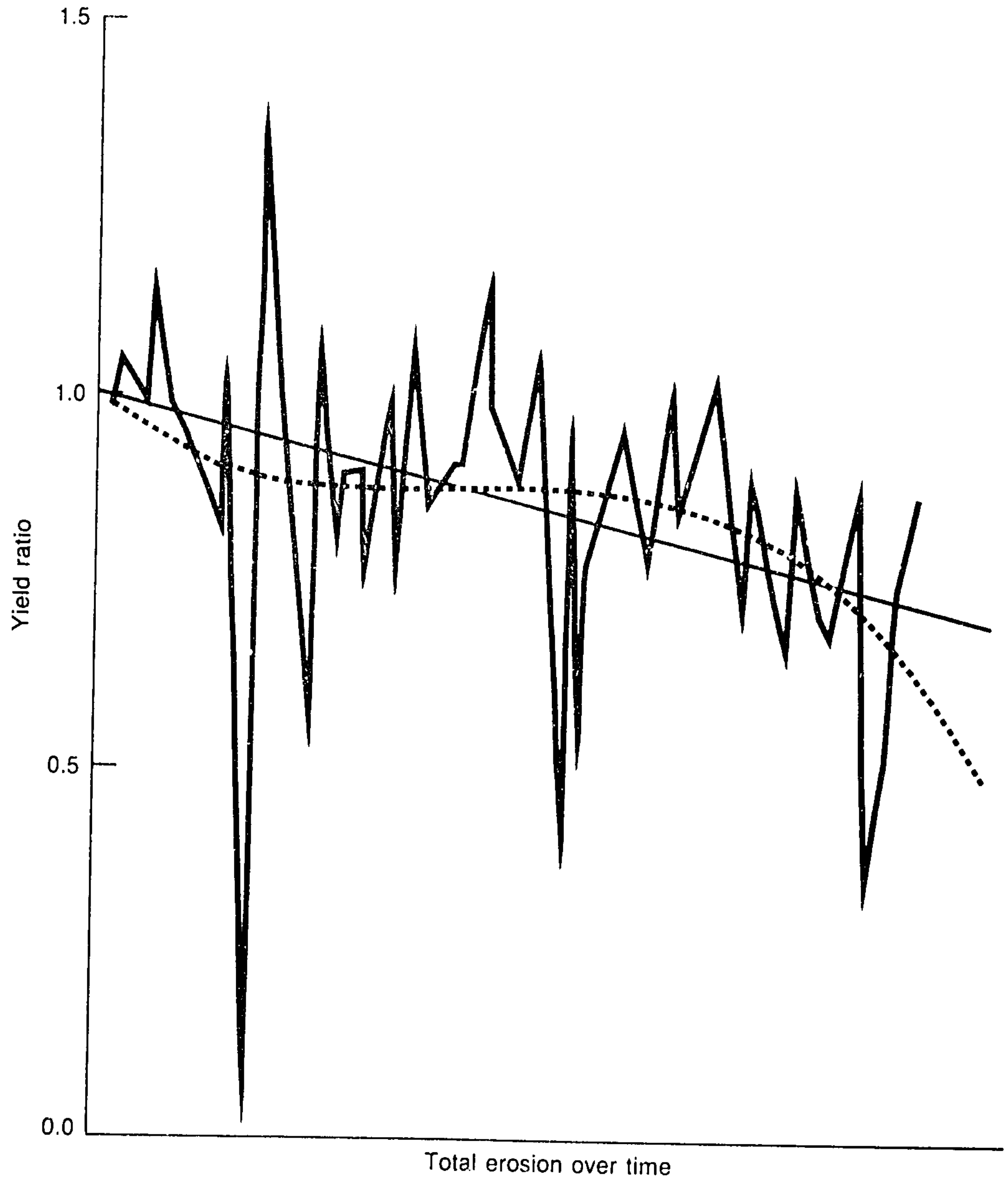


Figure 4. Sample Data and Regression of Yield Ratio (Eroded Yield/Uneroded Yield) as a Function of Soil Loss.

Table 4. The Value of Average Yield and Input Losses due to Erosion.†

Region	Yield	Nitrogen	Phosphorus	Lime	Total‡
			$\$ t^{-1}$		
Appalachian	0.29	0.02	0.03	0.01	0.35
Corn Belt	0.42	0.03	0.07	0.01	0.53
Delta States	0.09	0.01	0.03	0.01	0.14
Lake States	0.45	0.03	0.07	0.01	0.56
Mountain	0.12	0.11	0.04	0.02	0.30
Northeast	0.95	0.04	0.04	0.01	1.05
Northern Plains	0.22	0.09	0.04	0.03	0.39
Pacific	0.12	0.04	0.03	0.00	0.20
Southeast	0.08	0.01	0.03	0.01	0.13
Southern Plains	0.10	0.12	0.02	0.03	0.28
United States	0.25	0.06	0.04	0.02	0.37

† 4 percent discount rate; weighted by acres in combination of (crop × soil group × major land resource area).
‡ Totals may not add to sum of column or row due to rounding.

Even if the loss of topsoil has only a small effect on average yield, it may have a large effect on the year to year variation in yield. If the water-holding capacity and water infiltration rate are reduced by removal of topsoil, then the yield decline caused by low precipitation will be greater than otherwise. This increased variation in yield will cause increases in costs to the farmer and society which are not included in the above presentation.

The estimate of productivity benefits from a conservation practice is sensitive to the chosen discount rate because the benefit stream is very long. For example, a discount rate of 8 percent would cut the benefits in half from what they would be if a 4 percent rate were chosen. Economic analysis should recognize that discount rates vary. A farmer facing survival will have a much higher discount rate than other farmers or than government.

Productivity Benefits Per Tonne of Soil Saved

Based on the concepts discussed above, we developed a procedure to estimate the economic value of the productivity benefits per t of representative soils in the United States. The relative yield and fertilizer effects of erosion on each representative soil were estimated by a simulation model reflecting the relationships between yield, weather, hydrology, crop management, and soil characteristics (Williams *et al.*, 1984). The simulation was run for 100 years using representative weather data. Subsequently, the ratio of yields on eroded to uneroded soil was regressed on soil loss to estimate the marginal effect of soil loss on yield (Putman *et al.*, 1984). Only simple linear regression was used in the analysis because unrealistic results occurred when higher order polynomials were tried. Simple regression resulted in a straight line, as shown in Figure 4, and presumes a constant marginal productivity of soil, which may not be realistic in all cases. Relative fertilizer effects were obtained from the simulation model in the same fashion. Prices, crop and soil distributions, starting yields, and fertilizer application rates were obtained from various sources.

Table 4 presents some preliminary estimates of the average yield and input damages per t per ha of soil loss nationally and regionally for the United States. The average value of productivity damages in the United States is \$0.37 t^{-1}. The regional averages vary from a high of \$1.05 t^{-1} in the Northeast where soils are very sensitive to soil loss, to \$0.13 t^{-1} in the Southeast and Delta states where yields are lower and soils less sensitive to erosion. Two-thirds of the damages came from yield losses and one-third from higher fertilizer costs. The relatively low values may be surprising but are consistent with other estimates (Benbrook *et al.*, 1984).

Water Conservation Benefits

Significant moisture conservation benefits often accrue to farmers with soil conservation practices in arid and semiarid regions, or in humid regions subject to frequent droughts. In cool, humid areas, the benefits may be negative if yields are decreased because of excess moisture or reduced soil temperatures caused by the conservation practices. Table 5, based mostly on Unger (1984) indicates the effect that soil conservation practices can have on moisture and crop yields. It shows that practices often have a significant impact on moisture, by increasing infiltration, reducing runoff, increasing water storage, or reducing evaporation and transpiration, and may result in increased as well as decreased yields. In addition, adoption of soil conservation practices on irrigated land can lead to reduced water withdrawals (Troeh *et al.*, 1978, Ch. 18).

The water conservation benefits of the conservation practices can easily be worth more to the farmer in dry areas than the erosion control benefits. For example, Table 5 shows significant and consistent yield improvements due to contour farming in dry areas. A farmer averaging 363 kg cotton ha^{-1} at \$1.32 kg^{-1}, who realized only a 10 percent increase in yields due to contouring, would have an increase in profit of over \$48 ha^{-1}. If the farmer had a rapidly eroding soil that was losing 50 t ha^{-1} before contouring and 25 t ha^{-1} after contouring, the value of the soil conserved would be under \$8 ha^{-1}. Thus, in this example, which is probably common in dry areas, the water conservation benefits of a soil conservation practice are worth more than 6 times the soil conservation benefits.

Other Benefits to Farmers

The soil productivity and water conservation benefits discussed above are not the only possible benefits to farmers from adopting conservation practices. Windbreaks have generally been observed to increase short-term yields, sometimes as much as 20 percent (Baldwin and Johnston, 1984). Windbreaks improve short-term yields by reducing seed and seedling loss and improving the microclimate. Several conservation practices offer benefits by lowering certain costs of production but these effects are defined as negative practice costs and were discussed in the cost section.

The damages from gully erosion affect the returns from farming differently than sheet, rill, and wind erosion. Gully erosion may remove land from production and can reduce tillage efficiencies by breaking up fields. Thus, the benefits generated by gully control practices are the opportunity cost of land retained in production and the reduced costs of production from maintaining field size efficiencies.

Benefits to Society

The public receives substantial benefits from the adoption of conservation practices on the farm. The reduction in sediment loadings to streams improves the water quality for swimmers, fishermen, water supply systems, reservoirs, and other users of the water. The increased water storage in the watershed can reduce flash flood damage. In the United States the public benefits of conservation practices appear to be greater than the productivity benefits the farmer receives. A recent study by the U.S. Department of Agriculture estimated that the value of improved water quality from installation of erosion control practices under the major conservation programs of the United States government was almost twice the value of the soil productivity maintained (ERS, 1986).

Table 5. Effect of Some Soil Conservation Practices on Moisture and Crop Yields.

Practice	Location	Crop	Effect on Moisture	Effect on Yields	Reference
Contour farming	Texas (USA)	Cotton	Runoff decreased 29%	Increased 61%	Fisher and Burnett, 1953
	India	Potato	Runoff decreased 44%	Increased 6%	Singh, 1974
	India	Maize	Runoff decreased 78%	Increased 46%	Singh, 1974
	Various (USA)	Various	Increased available moisture	Equivalent or increased yields noted in 99% of 600 sets of comparisons	Troeh *et al.*, 1988 (p. 306)
Stubble mulch tillage	Texas (USA)	Wheat	Increased available moisture	Increased 17% and .5%	Johnson and Davis, 1972
	Great Plains (USA)	Wheat	Increased soil moisture at 7 locations by 28%	N.R.	Smika, 1976
Conservation tillage	Indiana (USA)	Maize	N.R.	No difference in 7 year average yields	Griffith *et al.*, 1977
	Iowa (USA)	Maize, soybeans	N.R.	No significant effect	Amemiya, 1977
	Kansas (USA)	Sorghum	Increased soil water	Increased by 46% to 65%	Phillips, 1969
	Nebraska (USA)	Wheat	Increased soil water by 28% to 48%	Increased by 6% to 9%	Smika and Wicks, 1968
Zero or no-tillage	Indiana (USA)	Maize	N.R.	Decreased 5 year average yields 14% and 34%	Griffith *et al.*, 1977
	Nebraska (USA)	Maize	N.R.	Increased 3 year average yields 6%	Amemiya, 1977
	Kansas (USA)	Sorghum	N.R.	Increased 4 year average yields 4%	Phillips, 1969
	Nebraska (USA)	Wheat	Increased soil water by 20% and 75%	Increased by 21% and 15%	Smika and Wicks, 1968
	Iran	Barley	N.R.	Decreased 3 year average yields by 29%	Hakimi and Kachru, 1976
Terraces	Northern Plains (USA)	Alfalfa	Increased 5 year average water storage by 243% to 550%	Increased 5 year average yields by 113% to 185%	Haas and Willis, 1971
	Iowa (USA)	Maize	Decreased runoff	Decreased 3 year average yields by 4%	Spomer *et al.*, 1973
	Texas (USA)	Cotton, sorghum	No decrease in runoff during critical period	Decreased yields in 3 of 4 years	Armbrust and Welch, 1966
	Texas (USA)	Cotton	N.R.	Increased by 24% and 59%	Burnett and Fisher, 1956
	Colorado (USA)	Wheat	Water use efficiency increased by 14%	Increased by 15%	Greb, 1979

Determining the Best Set of Practices

A profit maximizing farmer will control erosion to the point where it ceases to pay. This can be illustrated by going again to the example of soybean land in northern Missouri. The soil in the analysis has a productivity value of \$0.34 t^{-1} (ERS, 1986). Figure 5 shows the productivity benefits relationship along with the minimum cost curve. A farmer receiving only the productivity benefits would not install any conservation practices above the benefits line because all practices above the line cost more than the benefit he would receive. Of the five practice combinations below the benefits line only three are on the minimum cost curve and worthy of consideration.

The profit maximizing farmer would select conservation tillage on the contour. As shown in Table 6 the farmer would certainly practice conservation tillage because he could reduce costs by \$33.85 ha^{-1}. The farmer would also farm on the contour because it only costs an extra \$6.42 (marginal cost) but increases benefits by \$6.86 (marginal benefits). The farmer would not be inclined to adopt the winter cover practice with the other practices because the marginal cost of \$22.24 exceeds the \$2.29 of increased benefits. If the average value of offsite benefits per t of erosion controlled from the USDA study (\$0.60) were used (ERS, 1986), winter cover would still not be practiced. Total benefits for winter cover would only increase to \$6.49. Obviously the farmer would adopt more practices if the government shared costs or if water conservation or other benefits were received from the practices other than the long-term productivity benefits discussed here.

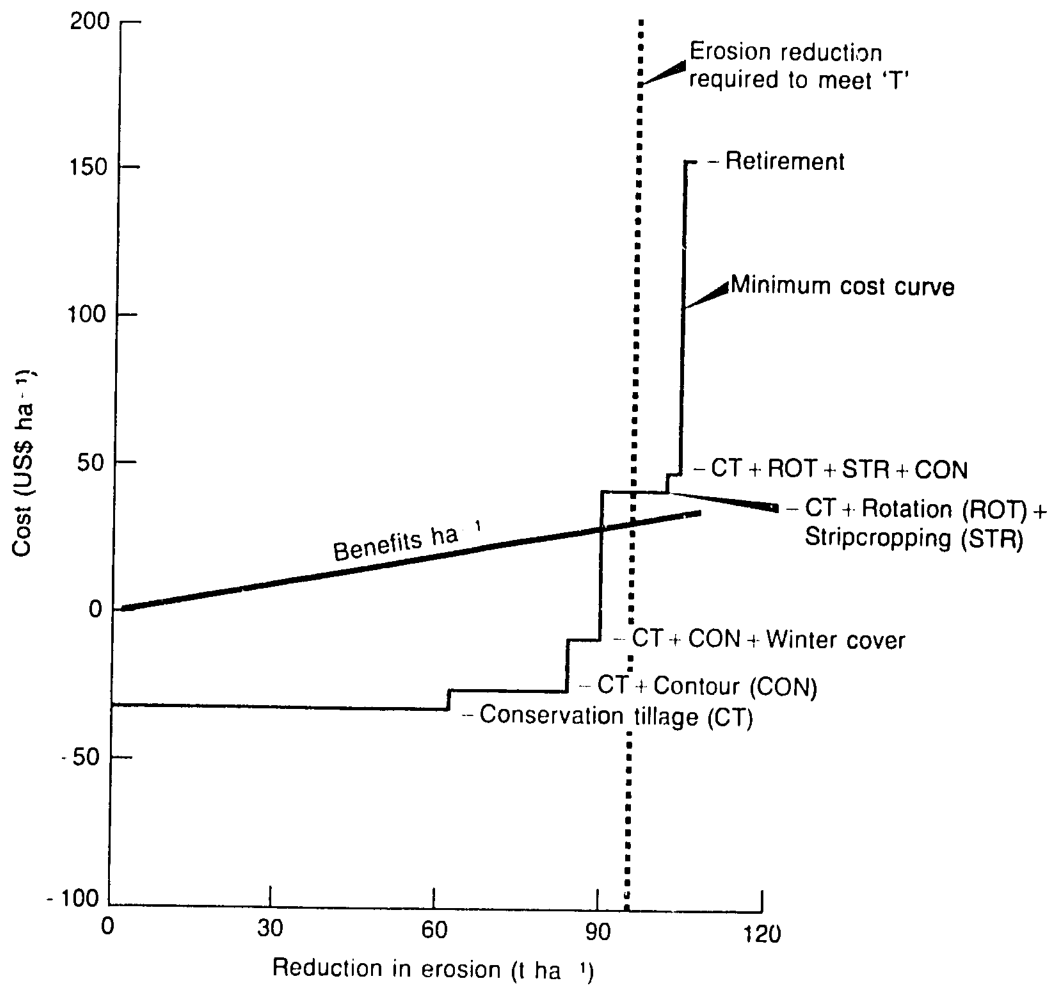


Figure 5. Best Combination of Conservation Practices (Raitt, 1981).

Table 6. Farm costs and Benefits of Minimum Cost Practices on Soybean Land in Northern Missouri (Raitt, 1981).

Conservation Practices	Erosion Reduction	Marginal Erosion Reduction	Cost	Marginal Cost	Marginal Cost per T	Total Benefits	Marginal Benefits	Marginal Benefits per T
	t ha⁻¹	*t ha⁻¹*	*$*	*$*	*$ t⁻¹*	*$*	*$*	*$ t⁻¹*
None	0	0	0.00	0.00	0.00	0.00	0.00	0.00
Conservation Tillage (CT)	63	63	-33.85	-33.85	-0.54	21.34	21.34	0.34
CT + Contour (CON)	83	20	-27.43	6.42	0.32	28.19	6.86	0.34
CT + CON + Winter Cover	90	7	-5.19	22.24	3.31	30.48	2.29	0.34
CT + Rotation + Strip-cropping	99	9	45.47	50.66	5.65	33.53	3.05	0.34

Conclusions

Economic analyses of conservation practices must consider the goals of the decision-makers. Farmers seeking to maximize profits are not interested in the offsite benefits of conservation practices that may be a very important part of the benefits in a public analysis. Benefit and cost estimation for a farmer must reflect the input prices the farmer pays and commodity prices the farmer receives. The planning horizon and the discount rate can generally be assumed to be the same for both farmers and the general public unless land or capital market failures are clearly present. The soil productivity benefits from erosion control last over the long-term and are cumulative, thus the present value of these benefits is very sensitive to the chosen discount rate.

Simulation models provide a feasible method to estimate the yield and fertilizer changes caused by erosion. These effects of erosion are needed to estimate the economic value of the productivity benefits from erosion control. The water conservation benefits of conservation practices can be more important to profitability in dry climates than the erosion control benefits. However, these water conservation benefits are not as well documented for use in economic analyses as the productivity benefits of erosion control. Other benefits, such as increased tillage efficiencies from the elimination of gullies, are possible and when present must be included in all economic analyses of conservation practices. Public analyses of conservation practices must include benefits occurring off the farm such as improvements in recreational opportunities, reduction in flood damage, and reductions in dredging costs. The offsite benefits of erosion control can easily exceed the benefits to the farmer.

The costs of conservation as required in an economic analysis are generally easier to estimate than the benefits because of the available cost data. All the cost of the resources used to install the practices must be included along with the opportunity costs of any foregone profits.

The determination of the best set of practices to install and the optimum level of erosion control at a particular site requires development of a minimum cost curve. The minimum cost curve relates the cost of control to the erosion reduction and portrays the least cost combination of practices for a given level of reduction. An incremental comparison of the benefits to the costs of the practices should reveal the point at which it does not pay to control more erosion.

As we have pointed out, selection of the best practice or set of practices requires much information. The use of microcomputers will make estimation of a customized minimum cost function a reality for many farmers in the near future. However, most farmers will be lucky if they can take advantage of generic analyses to limit their budgeting to a few rationally selected alternatives. Estimation of the benefits a farmer will receive from his specific installation of a practice is made more difficult than cost estimation by the lack of data. Efforts are currently underway in the United States to develop yield/soil loss simulation models that may be useful to individual farmers, but they are expected to be very data intensive. Large amounts of soil, weather, crop, and other data are required and it is not clear whether the detailed effort will be cost-effective. Best *guesstimates* will likely predominate the conservation practice selection procedure for some time to come.

References

Amemiya, M. 1977. Conservation tillage in the western corn belt. J. Soil Water Conserv. 32:29-36.

Armbrust, D.W., and N.H. Welch. 1966. Evaluation of Zingg conservation bench terraces on Amarillo fine sandy loam soil. J. Soil Water Conserv. 21:224-226.

Baldwin, C.S., and E.F. Johnston. 1984. Windbreaks on the farm. Ontario Ministry of Agriculture and Food. Publication 527. Ontario, Canada.

Benbrook, C., P. Crosson, and C. Ogg. 1984. Resource dimensions of agricultural policy. *In* Proc. Agricultural and Food Policy Conference, Berkeley, CA, 11-12 June 1984.

Burnett, E., and C.E. Fisher. 1956. Land leveling increases dryland cotton production. Texas Agricultural Experiment Station Bulletin. SB-19.

ERS. 1986. Benefits and costs of major USDA erosion control programs. USDA, Natural Resource Economics Division. U.S. Gov. Print. Office, Washington, DC.

Fisher, C.E., and E. Burnett. 1953. Conservation and utilization of soil moisture. Texas Agricultural Experiment Station Bulletin. B-767.

Greb, B.W. 1979. Reducing drought effects on croplands in the West-Central Great Plains. USDA Information Bulletin No. 420. U.S. Gov. Print. Office, Washington, DC.

Griffith, D.R., J.V. Mannering, and W.C. Moldenhauer. 1977. Conservation tillage in the eastern corn belt. J. Soil Water Conserv. 32:20-28.

Haas, H.J., and W.O. Willis. 1971. Water storage and alfalfa production on level benches in the Northern Plains. J. Soil Water Conserv. 26:151-154.

Hakimi, A.H., and R.P. Kachru. 1976. Response of barley crop to different tillage treatments on calcareous soil. J. Agric. Eng. Resour. 21:399-403.

Johnson, W.C., and R.G. Davis. 1972. Research on stubble-mulch farming of winter wheat. USDA-ARS Conservation Resources Report No. 17. U.S. Gov. Print. Office, Washington, DC.

McConnell, K. 1983. An economic model of soil conservation. Am. J. Agric. Econ. 65:83-89.

McMartin, W., A.B. Frank, and R.H. Heintz. 1974. Economics of shelterbelt influence on wheat yields in North Dakota. J. Soil Water Conserv. 29:87-91.

Phillips, W.M. 1969. Dryland sorghum production and weed control with minimum tillage. Weed Sci. 17:451-454.

Putman, J., P. Dyke, and G. Wistrand. 1984. Erosion-Productivity Index Simulator (EPIS). USDA-ERS. Unpublished Report.

Raitt, D.D. 1981. A computerized system for estimating and displaying shortrun costs of soil conservation practices. USDA-ERS, Natural Resource Economics Division, Technical Bulletin No. 1659. U.S. Gov. Print. Office, Washington, DC.

Reisen, J.H., L.L. Bull, and D.E. Kugler. 1986. Crop budget generator: A personal computer model for analysis of soil conservation economics. USDA-ERS, Natural Resource Economics Division. U.S. Gov. Print. Office, Washington, DC.

Singh, G. 1974. The role of soil and water conservation practices in raising crop yields in dry farming areas of tropical India. FAO/UNDP International Expert Consultation on the Use of Improved Technology for Food Production in Rainfed Areas of Tropical Asia. FAO, Rome, Italy.

Smika, D.E. 1976. Mechanical tillage for conservation fallow in the semiarid Central Great Plains. *In* Conservation tillage, Proc. Great Plains Workshop, Ft. Collins, CO. August 1976. Great Plains Agricultural Council Publication No. 77.

Smika, D.E., and G.A. Wicks. 1968. Soil water storage during fallow in the Central Great Plains as influenced by tillage and herbicide treatments. Soil Sci. Soc. Am. Proc. 32:591-595.

Spomer, R.G., W.D. Shrader, P.E. Rosenberry, and E.L. Miller. 1973. Level terraces with stabilized backslopes on loessial cropland in the Missouri Valley: A cost-effectiveness study. J. Soil Water Conserv. 28:127-131.

Troeh, F.R., J.A. Hobbs, and R.L. Donahue. 1978. Soil and water conservation for productivity and environmental protection. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Unger, P.W. 1984. Tillage systems for soil and water conservation. FAO Soils Bulletin No. 54. FAO, Rome, Italy.

Williams, J.R., P.T. Dyke, and C.A. Jones. 1984. A modeling approach to determining the relationship between erosion and soil productivity. Trans. ASAE, 27:129-144.

Woodruff, N.P., R.A. Read, and W.S. Chepil. 1959. Terrace benching to save potential runoff for semiarid land. Agron. J. 51:289-292.

Small-Scale Water Harvesting Techniques

E.R. Perrier
International Center for Agricultural Research in the Dry Areas, Aleppo, Syria.

ABSTRACT. The implementation of small-scale water harvesting techniques is examined using the concepts of probability and water balance techniques. An example is developed using data and information from the El Haseke Province, Syria to demonstrate the methods available for technical and economical evaluation. A general discussion describes the catchment basin, conveyance device, storage facility, and cultivated field type of water harvesting systems as well as direct runoff systems using tied-ridges and micro-catchment basins.

Introduction

The old saw that "everyone talks about the weather but no one does anything about it," is only partially true for water harvesting systems. These systems are only as reliable as the weather because they depend upon the stochastic nature of rainfall. Water harvesting does not change the nature of weather but weather's impact on dryland agriculture is less devastating using these techniques. A well-designed water harvesting system can help in the establishment of agriculture in most arid climates. Nonetheless, when mean annual rainfall is less than 50 mm it is extremely doubtful that this technology would be economically feasible (Cooley *et al.*, 1975).

Even during years of drought, water harvesting systems can fail unless they have adequate storage facilities. Collected runoff water can be stored in soils, behind dams, in wadis, or stored in-place on terraced or tied-ridged agricultural plots. By this method, a rainfall of a few mm collected on a catchment area can be equivalent to several hundred mm of rainfall when supplied to a restricted cultivated area. The type and scale of water harvesting system to be selected depends upon the economic evaluation of the soil and the rainfall quantity, distribution, and intensity, as well as, the intended water use, site topography, availability of construction materials, and supply of skilled labor.

The objective of this paper is to review water harvesting systems for small-scale application and methods for design criteria. Water harvesting systems can be separated into two general groups:

1) Water storage in tanks or dams; and,
2) Direct application of runoff on a cultivated field.

Water harvesting is a process of collecting rain water from a modified or treated area to either maximize or minimize runoff, whichever technology is to be implemented at a specific site.

When runoff is maximized the technique collects water for distribution onto designated areas to supply an adequate amount of water for crop growth. For example, the soil surface of a rainfall catchment area could be formed into large furrows or ridges which would direct surface water into channels. The ridged soil surface could be compacted or sealed with either asphalt, oil, paraffin, salt etc., to restrict infiltration. The runoff could be collected and stored in a pond or it could be immediately redistributed onto cultivated areas. When a catchment is properly designed and constructed, runoff from light rain showers of 3 to 4 mm can be collected.

The diagrams in Figure 1 show a water harvesting system with a catchment basin to maximize runoff, conveyance device, storage facility, and cultivated field. This system provides for a multi-usage concept when collecting and storing runoff and requires high levels of management of resources and capital to provide a higher cropping intensity and ensure economic gain.

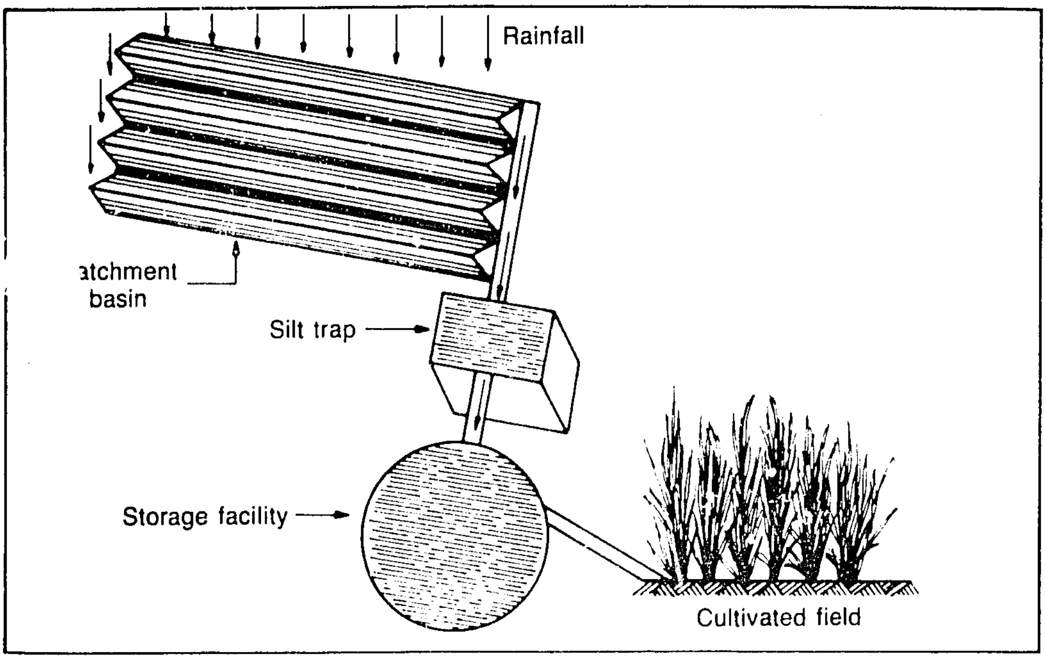


Figure 1. Diagram of Water Harvesting System with Catchment Basin, Conveyance Device, Storage Facility, and Cultivated Field.

Figure 2 shows a similar diagram but with immediate use of the runoff onto a cultivated area. This system may be less sophisticated but provides a type of system design which can be economically implemented by farmers on most fields. Cultivated fields are constructed into a sloping runoff watershed area with level conservation bench terraces (Jones, 1975). In some dryland areas contour berms are made; deep furrows are dug on the contour where soil is placed on the downhill slope to form berms which collect runoff. In general, these techniques are better applied to large or group holdings where mechanization and land-leveling equipment is available.

In other regions, capturing water and holding it in-place serves as a simple technique to minimize runoff for water harvesting. This concept of zero-runoff implies that rainfall remains on the soil surface until it infiltrates into the soil or is collected for future plant use (Perrier, 1984). Techniques which have been used in most rainfed agricultural regions for retaining rainfall in place are called tied-ridges (Hudson, 1971) or with slight modifications are called microcatchment basins (Figure 3). Tied-ridges consist of closely spaced ridges covering the soil surface in two directions at right angles, so that the ground is formed into a series of rectangular depressions.

Design Criteria

The basic criteria for designing small-scale water harvesting systems are essentially the same irrespective of the eventual use of the water. The design has to incorporate the constraints of the local environment, equipment availability, and socioeconomic conditions. In addition, separate factors which may be interrelated must be considered: precipitation, water requirements, alternative water sources, topography, labor and materials, farmer acceptance, and infrastructural parameters of water harvesting systems. Each site may have unique characteristics which can alter the eventual design of the optimal system.

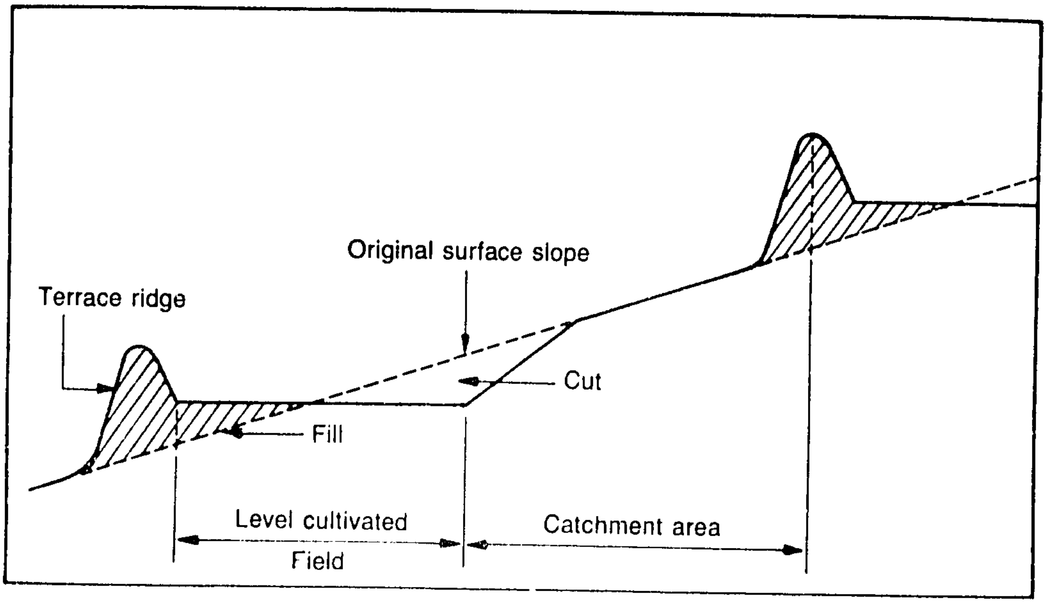


Figure 2. Diagram of Water Harvesting System with Catchment Area, Conveyance System, and Direct Application to Cultivated Field.

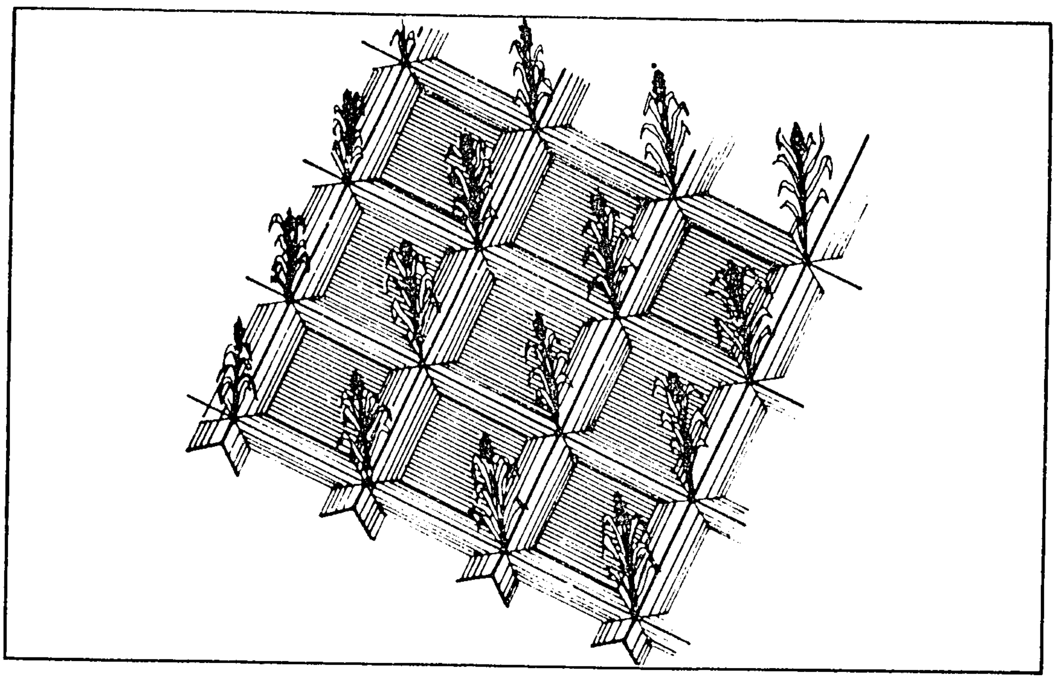


Figure 3. Schematic View of Tied-Ridges in a Field Layout.

Precipitation

Precipitation includes rainfall, as well as dew and snowfall. In the arid regions where ICARDA has principal responsibility, rainfall is the element of major concern for plant growth. Because precipitation is a stochastic variable, its quantity and timing are difficult to predict; therefore, probability techniques must be used to help the farmer evaluate the amount of risk involved before construction of a water harvesting system. The probability of the amount of rainfall and timing to meet crop requirements can be estimated from analysis of daily rainfall values, the most common data available (Perrier and Wilding, 1986). When attempting to apply various statistical methods to estimate rainfall probability, the frequency distribution of the data must be known, e.g., normal, logarithmic, or other skewed distribution. The frequency distribution does not quantify the variability of measurements but distributes the values about their relative magnitude independent of position. The mean of a data set, Y, is usually obtained by taking many samples so that the population mean can be estimated.

To illustrate various methods needed to design a water harvesting system, some analytical results from 28 years of daily rainfall data at El Haseke Province, Syria, are presented. The catchment basin, for the example, will have a compacted soil surface which requires a threshold of minimum rainfall of 6 mm before runoff occurs, i.e., 6 mm of rainfall is lost to the processes of wetting and evaporation. If the runoff surface chosen for the example had been ridged and paved with asphalt (a more efficient but costly collection system) then the threshold value would be 3 mm. For water requirement computations, wheat is the field crop chosen for the cultivated area. General statistics are computed for the runoff storms by month, y, using the following equations:

$$Y = \text{mean} = \Sigma\, y_i/n,$$

$$n = \text{number of years}$$

$$s = \text{standard deviation} = [\Sigma\,(y_i - Y)^2/n\text{-}1]^{1/2}$$

$$\%CV = \%\ \text{coefficient of variation} = 100 \times s/Y$$

$$g = \text{skewness} = \frac{n^2(\Sigma y^3) - 3n(\Sigma y)(\Sigma y^2) + 2(\Sigma y)^3}{n(n-1)(n-2)\, s^3}$$

Table 1 shows the analysis of the rainfall data from El Haseke Province, Syria, for the example catchment basin with mean rainfall, mean number of storms, and mean runoff each with the standard deviation, percent coefficient of variation and the coefficient of skewness. The mean annual rainfall for the region is 278 mm and, for the example, an annual average of 15 runoff storms yielding 108 mm of runoff.

The seasonal events (October thru May) show that January has the maximum rainfall, the highest number of runoff storms, and the largest amount of runoff. However, the months of greatest water need for wheat are in the fall at planting time (December); during the vegetative stage when fertilizer top dressing is applied (March); and during the grain filling stage (May). If these average values were repeated each year, production risks could be minimized with a catchment area of only 2:1. The percent coefficient of variation and the skewness coefficient show the stochastic nature of the 28-year data set. In particular, a maximum monthly rainfall of 223 mm (1969) and a minimum monthly rainfall of 13 mm (1970) occurred during January. The difference between the mean monthly rainfall and the mean monthly runoff is about 36 percent; therefore, 64 percent of the rainfall on the catchment basin would not be collected. If the runoff surface were ridged and sealed, then a much larger percentage of the rainfall could be collected. The months of October, November, and May are, in general, the most unstable and to design a storage facility using these data requires evaluation of the probability analysis.

Table 1. Mean Rainfall, Number of Storms, and Runoff, Each with a Statistic of Standard Deviation, mm (s), Percent Coefficient of Variation (%CV), and Skewness Coefficient (g) for 28 years of Daily Rainfall Data for El Haseke by Month.

Mean Values	Month							
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Rainfall (mm)	12	22	43	52	39	42	46	20
s (mm)	14	17	28	40	26	28	32	31
% CV	124	77	64	78	66	66	69	156
g	1.71	0.52	1.18	2.68	0.32	1.15	0.60	2.41
No. of storms	1	1	3	3	2	2	2	1
s	1	1	2	2	2	2	2	2
% CV	147	116	60	69	75	82	73	160
g	1.15	1.29	0.37	1.14	0.50	0.83	0.15	1.82
Runoff (mm)	4	7	17	21	14	15	18	8
s (mm)	10	8	20	29	13	16	18	19
% CV	234	122	116	136	98	109	104	242
g	2.91	1.08	1.95	2.98	0.70	1.47	0.94	3.34

Probabilities associated with the individual number of runoff storms by month, y, can be given by Eq. [1]:

$$y = Y + Ks, \qquad [1]$$

where K = numerical value of the frequency integral which is dependent on the skewness, g (statistical tables of Pearson type III distribution or Hjelmfelt and Cassidy, 1975).

The exceedance probability, p, is the probability that a mean value, Y, will not exceed a given p. To display the measured data using the month of December as an example, a three-step procedure can be followed:

1) Number of runoff storms for December data, y, is sorted by magnitude. The largest y is given order number m = 1, and the smallest y, order number m = n, where n is the number of years of the data set.

2) Plotting positions for the probability, p-axis, are assigned to each runoff storm value. The plotting position is determined by order number, m, and the total number of years, n, where $p = m/(n + 1)$.

3) To estimate the return runoff storm value, I, the reciprocal of the probability, p, is used. The recurrence of return interval, I, is computed by $I = 1/p$.

Table 2 shows the percent probability and recurrence values (years) for the example data set. The minimum storm included in the analysis of runoff is a daily rainfall of 6 mm or more. For a probability of 2.5 percent or a recurrence of 40 years, the number of runoff storms for the month of December would be 5 storms/year; whereas, for 10 percent probability or a recurrence of 10 years, there would be 4 storms per year. At 50 percent probability or a recurrence of 2 years, there would be 3 storms/year or the mean monthly rainfall (See Table 1).

Table 2. Percent Probability and Recurrence Values (Years) for the Means of Monthly Rainfall, mm, Number of Runoff Storms, and Runoff, mm.

Months	Mean Value	Percent Probability/Recurrence (%/Years)				
		50/2	33/3	10/10	2.5/40	1/100
Oct.	Rainfall	12	19	30	40	45
	No. of storms	1	1	1	2	2
	Runoff	4	9	16	23	26
Nov.	Rainfall	22	30	43	54	60
	No. of storms	1	2	3	4	4
	Runoff	7	11	18	23	27
Dec.	Rainfall	43	58	79	98	108
	No. of storms	3	3	4	5	6
	Runoff	17	27	42	55	62
Jan.	Rainfall	52	73	104	131	146
	No. of storms	3	4	6	7	8
	Runoff	21	37	59	79	89
Feb.	Rainfall	39	52	71	89	98
	No. of storms	2	3	4	6	6
	Runoff	14	21	31	40	45
Mar.	Rainfall	42	56	77	96	106
	No. of storms	2	3	5	6	7
	Runoff	15	24	36	47	53
Apr.	Rainfall	46	62	87	108	120
	No. of storms	2	3	4	6	6
	Runoff	18	27	41	53	60
May	Rainfall	20	37	60	82	93
	No. of storms	1	2	3	4	5
	Runoff	8	18	32	45	52

The probability analysis demonstrates that at El Haseke a design storm based on runoff at the 10 percent probability value is the most feasible to calculate volume flows and storage for the design of a water harvesting system. The design storm at 10-year recurrence is double the mean monthly runoff and sufficient to justify selection of a water harvesting system large enough to manage this volume of water. Even though storm damage to the system could be expected, design criteria for larger storms at smaller probabilities are not considered economical. The data shows that for the months of October and November there is only one low volume storm per year which is not enough for system design. Statistics for October and November do not indicate construction of a direct application water harvesting system; however, if a tank or pond storage were available then water could be stored for use during the growing season.

Water Requirements

Water requirements for designing a water harvesting system are composed of several factors such as crop and livestock production, domestic uses, and supplemental irrigation. For agronomic applications of water harvesting, the growing season is that period during which water will be needed and the supply should be adequate to support the water requirements of a crop. Water balance calculations estimate the water requirements and aid in system design by determining the magnitude and distribution of expected runoff collection. Selected crops of the Near East are presented in Table 3. These values are guidelines for estimating design requirements for a water harvesting system.

Plants respond positively when soil water is available during a sensitive growth stage. Table 4 shows the best potential use of limited water supplies for selected crops where water application can be scheduled at the moisture sensitive stages of plant growth. For these data, it is assumed that the soil profile is at field capacity at planting time.

Estimated water requirements for household use and stock water for various animals in the Near East are shown in Table 5. In general, the water requirement per farm unit falls into four classes of use with relative percentages:

Domestic purposes	10%
Farm and animals	5%
Irrigation	80%
Waste	5%

Waste is loss from the water conveyance system, e.g., open ditches, pipe joints, general leaks, and defective equipment. Seepage and evaporative losses of water from storage must also be included as part of the water requirement during the design phase of the program.

Table 3. Seasonal Evapotranspiration for Selected Crops at Minimum and Maximum Yields in the Near East.

Crop	Growth Period	Seasonal Evapotranspiration
		mm
Wheat	Nov. - May	300-655
Barley	Dec. - Apr.	200-550
Faba beans	Jan. - May	300-495
Cotton	Apr. - Nov.	550-1130
Sugar beets	Oct. - Jul.	450-1090
Maize	Mar. - Jun.	400-750
Potatoes	Feb. - Jun.	350-620

Table 4. Moisture Sensitive Stages of Growth for Selected Crops.

Crop	Moisture Sensitive Period				
	Shooting	Rooting	Heading/ Earring	Flowering	Grain/Fruit Formation
Wheat	--------		--------	--------	
Barley	--------	--------	--------		
Lentils			--------	--------	
Broad beans				--------	
Maize				--------	--------
Sorghum		- - - -	- - - -		
Millet			- - - -	- - - -	
Groundnuts				- - - -	- - - -
Tomatoes			--------	--------	--------
Cotton			--------	--------	--------
Sugar beet	. . . .	. . . .	. . . .	. . . .	. . . .
Potatoes	. . . .	. . . .	. . . .	. . . .	. . . .

---------Clearly defined sensitive phase;
- - - - -Plant insensitive but responds; and,
. . . . .No clear indication.

Table 5. Daily Water Requirements for Domestic Use and Animals in the Near East.

Use	Water Requirements
Domestic:	
Per person (includes cooking, drinking, and washing)	10-60
	l d^{-1}
Animals:	
Beef cattle	35
Dairy cattle	45
Mature sheep	4-10
Horses	45
Chickens (100 head)	8-15

To insure that there are no critical periods when water will be insufficient, the size of the catchment area and storage tank should be determined by computing an incremental water budget of collected water versus requirement (Frasier and Myers, 1983). The water budget or water balance for the design of a water harvesting system for field crop use is determined by estimating or measuring the major input and output components of water movement on a catchment area. The water balance equation can be written as:

$$R = ET + RO + S, \qquad [2]$$

where R = rainfall on the collection basin, mm; ET = evapotranspiration, mm; RO = runoff, mm; and S = soil-water storage, mm.

In general, climatic methods for predicting the water balance are used because of the difficulty in obtaining field measurements from equipment such as soil-moisture samplers, tensiometers, neutron tube apparatus, weighing lysimeters, etc., which are used for data verification. The crop water requirement to achieve optimal production refers to the timing and volume of water needed to replace moisture used by a crop growing under specific environmental conditions. As climatic conditions vary for each year (stochastic variables), a daily record is needed to estimate the water balance for design requirements of water harvesting systems.

Rainfall and water quantities are usually expressed by depth of water; therefore, it is convenient to express the water balance in similar terms, i.e., mm. Table 6 presents the computations of water balance for 11 days following germination for the required eleven variables:

1) **Daily Rainfall, mm, Rain.** Daily rainfall is measured using standard rain gauges which are monitored daily at 0800 hrs.

2) **Evaporation Data, mm, E_{pan}.** Evaporation is measured using Class A pans on nongrassed sites which are surrounded by a short crop or bare noncultivated area to provide the standard measurement for evaporation, E_{pan}. This galvanized pan, painted annually with aluminum paint, has fixed dimensions: 121 cm diameter by 25.5 cm depth. The pan must be mounted level on a 15 cm high open-frame platform (pallet) with a water level 7.5 cm below the rim. Large open screens which cover the pan discourage birds, dogs, and farm animals from drinking. Established weather stations, monitored daily, provide the most reliable data.

3) **Potential Evapotranspiration, mm, ET_0.** The pan coefficient, K_p, which is estimated for each location, is multiplied by the pan evaporation, E_{pan}, data to obtain potential evapotranspiration, ET_0. The pan coefficient, K_p, is affected by different groundcovers, relative humidity, and wind. For the El Haseke example, a pan coefficient of $K_p = 0.6$ is used; therefore,

$$ET_0 = 0.6 \times E_{pan}. \qquad [3]$$

4) **Crop coefficient, K_c.** The value of K_c is related to the various stages of plant growth but is affected by site specific factors such as crop characteristics, sowing date, plant development, length of growing season, and climate. The crop coefficient, K_c, must be determined for each study location. Figure 4 shows the crop coefficient for wheat planted in December and harvested in May at El Haseke (Doorenbos and Pruitt, 1984).

Table 6. Example Worksheet for Calculation of Water Balance Quantities with Rainfall for Spring Wheat at El Haseke, Syria, in December, 1981.

Water Component	Day 1	2	3	4	5	6	7	8	9	10	11
Rain	0.7	1.5			0.8	9.3					
E_{pan}	1.78	0.7	1.36	1.30	1.52	0.96	0.44	1.64	1.02	1.40	1.30
[illegible]	1.07	0.42	0.82	0.78	0.91	0.58	0.25	0.98	0.61	0.84	0.78
K_c	0.12	0.12	0.12	0.120	0.122	0.125	0.128	0.130	0.133	0.138	0.140
ET_{cr}	0.13	0.05	0.10	0.09	0.11	0.07	0.03	0.13	0.08	0.12	0.11
RD	0.160	0.161	0.16	0.163	0.164	0.165	0.166	0.168	0.169	0.170	0.172
RZM	36.00	36.00	36.23	36.68	36.90	37.13	37.35	37.80	38.03	38.25	38.70
WB	36.00	36.00	36.00	35.90	35.81	36.50	37.13	37.10	36.97	36.89	36.77
Net Gain	36.57	37.45	35.90	35.81	36.50	45.73	37.10	36.97	36.89	36.77	36.66
Perc/Runoff	0.57	1.45				8.60					
WD	0	0	0.33	0.87	0.40	0	0.25	0.83	1.14	1.48	2.04

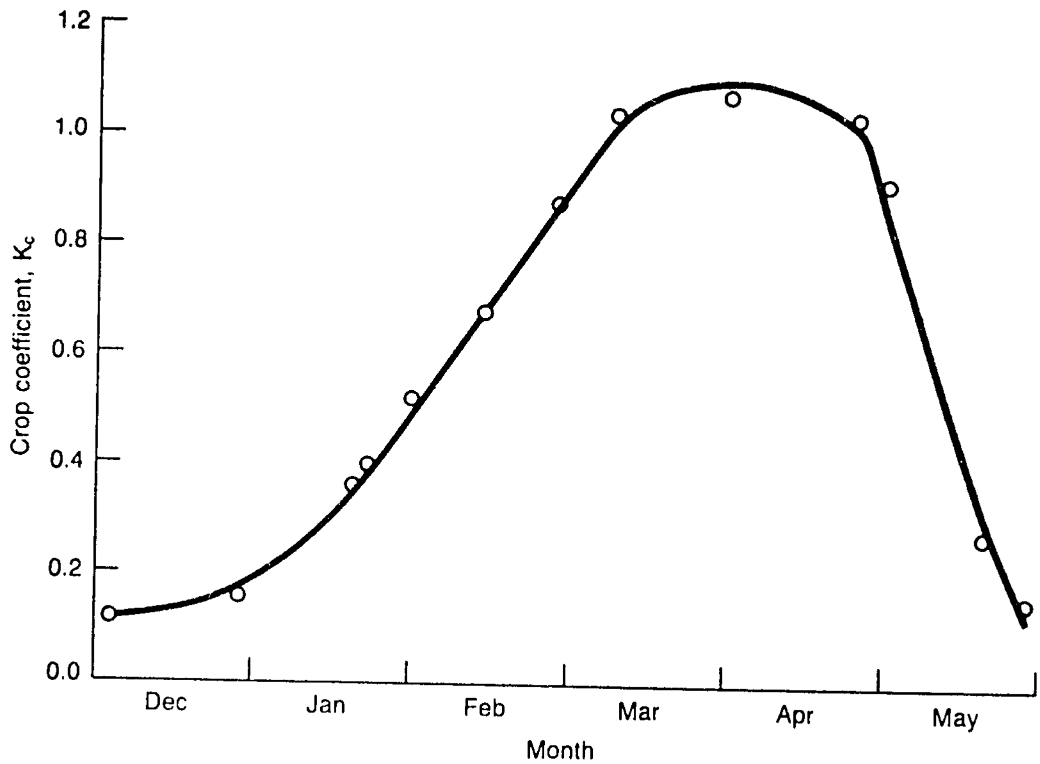


Figure 4. Crop Coefficient, Kc, for Spring Wheat Planted in December and Harvested in May.

5) **Crop Evapotranspiration, mm, ET_{cr}.** The actual amount of water used by the crop, ET_{cr}, is related to the potential evapotranspiration, ET_0, and a crop coefficient, K_c, where

$$ET_{cr} = K_c \times ET_0. \qquad [4]$$

However, at the start of the season when there are no plants (RD = 0 and RZM = 0), then ET_{cr} must be computed using K_c without a crop: K_c = 0.1 for El Haseke.

6) **Root Depth, m, RD.** The root depth in m or effective depth of water use as a function of time can be determined by: sampling roots in the soil profile; estimating from plant height measurements; or measuring moisture desorption in the soil profile. The root depth as a function of time for spring wheat at El Haseke is presented in Figure 5.

7) **Root Zone Moisture at Field Capacity, mm, RZM.** The percent available water that a soil will hold is estimated by the difference between the percent field capacity and the percent permanent wilting point on a dry weight basis (% Avail. Water = % Field Cap. - % Wilting Point). For the El Haseke clay soil, the difference between field capacity, 35.0 percent, and wilting point, 17.0 percent, gives the available water equal to 18.0 percent. When the soil profile is at field capacity the total available moisture, TA, mm m^{-1}, in the soil profile (1000 mm m^{-1}) is found by multiplying the percent available moisture by the apparent specific gravity. (Note: Soil bulk density, BD, in units of g cm^{-3} divided by the density of water which is 1.00 g cm^{-3} gives the dimensionless apparent specific gravity for soil.)

$$TA = BD \times \%\ \text{Avail. moisture} \times 1{,}000\ \text{mm m}^{-1}. \qquad [5]$$

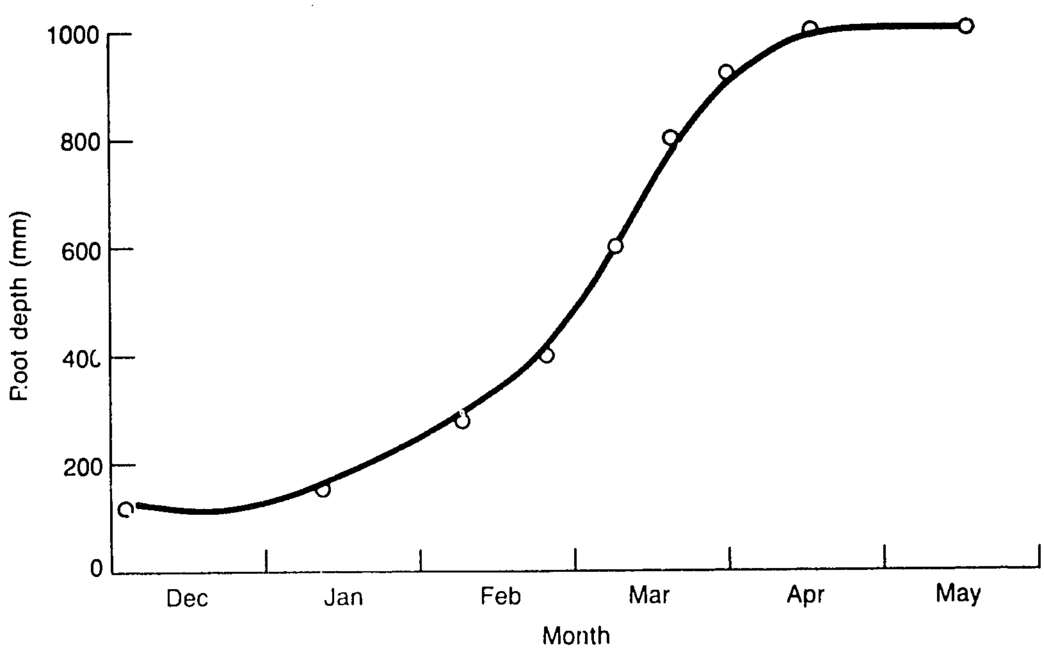


Figure 5. Root Depth as a Function of Time to a Soil Depth of 1.0 m for Spring Wheat.

For the El Haseke soils,

$$TA = 1.25 \times 18.0/100 \times 1{,}000 \text{ mm m}^{-1} = 225.0 \text{ mm m}^{-1}.$$

If the water balance is to be calculated prior to germination or if the soil profile is not at field capacity at planting time, the TA must be determined by direct measurement of soil moisture to the depth of the soil profile.

The total available moisture in the root zone, RZM, is then given by TA multiplied by the root depth, RD:

$$RZM = RD \times TA. \qquad [6]$$

For spring wheat at El Haseke, the total available water in the root zone of the soil profile at germination (root depth equal to seeding depth) which must be available for optimal crop growth is given by

$$RZM = 0.16 \times 225.0 = 36.00 \text{ mm}.$$

8) **Water Balance, mm, WB.** The daily amount of available moisture in the root zone is estimated by the water balance, WB, which can be an indication of plant water stress. At the start of computations, WB = RZM, but thereafter, WB is equal to the previous daily value for net gain. If net gain exceeds RZM, the difference between the two values is surface runoff or deep percolation; then WB becomes the previous value of RZM. For the El Haseke example, the first value of WB is 36.00 mm at germination.

9) **Net Gain, mm.** The net gain is computed from the daily value of water balance plus rainfall minus ET_{cr}. Net gain is computed as

$$\text{Net Gain} = WB + \text{Rain} - ET_{cr}. \qquad [7]$$

For El Haseke, the net gain at germination was computed as

$$\text{Net Gain} = 36.00 + 0.7 - 0.13 = 36.57 \text{ mm}.$$

10) **Deep Percolation or Surface Runoff, mm, Perc/Runoff.** The daily amount of water lost to the plant growth system is computed from the difference between RZM and the net gain.

11) **Water Deficit, mm, WD.** Amount of water needed to replenish soil moisture used by evapotranspiration is the accumulated difference between RZM and net gain for each day. If net gain is greater than RZM, then WD = 0.

To aid in the design of a water harvesting system, several years of water balance data can be computed to determine various mean values to estimate the water required for a particular crop. In addition, the data can be used to determine probability relations and evaluate the risk of a specific catchment/storage design. In the calculation of risk, economic values of construction and maintenance can be added to further evaluate an optimal design.

A simple calculation can be made to design a water harvesting system showing the rainfall equivalent which could be expected for the El Haseke region, an average of 278 mm of rainfall per year. At this level of rainfall, the ratio of catchment to cultivated area ranges from 5:1 to 15:1 with a runoff efficiency (100 × runoff/rainfall) varying from 20 percent to 90 percent. The ratio of catchment size to cultivated area and runoff efficiency is dependent upon the system design. Small-scale watersheds designed for rowcrops and small grains usually have catchment size to cultivated area ratios of 10:1 or 30:1 when the average annual rainfall is as low as 100 mm. For the El Haseke example, if a catchment area were designed with a watershed ratio of 5:1 and the total annual runoff from the catchment basin were 38.8 percent efficient (catchment basin threshold = 6 mm; therefore, 100 × mean runoff yield/mean annual rainfall = catchment basin efficiency or 100 × 108/278 = 38.8%) then the volume of water collected from 1 ha (10,000 m^2) would be:

$$5 \times 10{,}000\ m^2 \times 278/1000\ m \times 38.8/100 = 5{,}393\ m^3.$$

For each ha of cultivated land receiving the same mean annual precipitation of 278 mm, the volume of water collected would be:

$$10{,}000\ m^2 \times 278/1000\ m = 2{,}780\ m^3.$$

The total volume of rainfall, plus the catchment basin runoff reaching the cultivated area of the water harvesting system would be:

$$5{,}393\ m^3 + 2{,}780\ m^3 = 8{,}173\ m^3;\ \text{or}$$

for each ha of cultivated area the rainfall equivalent would be:

$$8{,}173\ m^3/10{,}000\ m^2 = 0.817\ m\ \text{or}\ 817\ mm.$$

Table 3 shows that for seasonal evapotranspiration this would be an adequate supply of water for most of the crops grown in the El Haseke region.

Alternative Water Sources

Alternative water sources such as wells, pumpback systems, and intermittent streams can be useful to reduce the risk of a poor harvest during periods of low precipitation. To insure that time and money are not wasted, alternative methods of water supply should be considered before installation of a water harvesting system. Using temporary or intermittent water sources may permit the installation of a smaller catchment area.

Topography

Topography such as slope, gradients of channels, extent of depressions, etc., affects both the rate and volume of surface runoff. Long, narrow catchment basins will have lower runoff rates than more compact basins of the same areal extent. The geologic or soil materials will determine the degree of compaction, infiltration rate, and the effective runoff. Detailed designs and maps must be made of the terrain with reliable figures of inputs and outputs to establish costs and returns for each design activity separately.

A topographic survey is needed at each proposed site to evaluate the potential design of a specific water harvesting system. These surveys should be sufficiently accurate for calculation of surface area and of a scale to allow easy orientation within the site. They should include the location of the catchment basin and storage facility as well as the conveyance devices needed for storm water control at the cultivated field. Wherever possible, the maps should be prepared from aerial photographs with on-site verification (ground truth). The degree of accuracy of the survey is matched to the topographic requirement of the particular location. Topographic maps are used as a foundation for canal and drainage layouts as well as site plans.

Materials and Labor

Materials and labor are of primary concern when selecting a water harvesting system. The economic factors of alternative water sources or materials to be used for catchment and storage must be considered in determining the costs of construction and maintenance. Not all catchment treatments require the same quantity and type of labor or maintenance (Frasier, 1975). For the compacted soil treatments on the catchment basin, weed growth must be eliminated and soil erosion prevented. The storage facility and conveyance device must be included in a maintenance program. This type of maintenance on small-scale water harvesting areas can require 1 to 2 man-days about 4 times per year.

Some materials and installation techniques have high capital costs and require skilled labor, especially for the catchment/storage or conservation bench terrace types of systems. In many installation designs, however, there are several combinations of catchment and storage sizes which provide the required quantity of water without high capital costs but are labor intensive, e.g., tied-ridges, micro-catchment basins, berms, etc.

Farmer Acceptance

Farmer acceptance of water harvesting concepts is an important factor in the success of any system. Farming with water harvesting always requires more physical effort than rainfed farming under comparable conditions. Farming based on small-scale water harvesting increases the food supply and does not involve the patterns of organization and social control that characterize large-scale irrigated agriculture. If the design of the water harvesting system presents the farmer with too big a burden and too little profit, the system will likely fail. In areas where water harvesting is not fully understood or accepted because of various socioeconomic factors, system design is extremely critical. The system must be designed to conform with the local labor supply and implemented with materials which have a minimum maintenance requirement and maximum effectiveness. The selected water harvesting system must support a positive economic alternative to existing conditions if farmer acceptance can be expected.

Infrastructural Parameters

Infrastructural parameters or the permanent facilities required in the support environment must be evaluated if changes which occur through implementation of small-scale water harvesting are to succeed. This implies a reassessment of markets and road networks as well as access to transportation. The availability of agricultural extension services must be altered to assist the farmer in the decisions of risk incurred by agronomic change. The reorientation of cooperative societies and realignment of services must be supported to assist those farmers whose agronomic practices are changing.

Surface Treatments of Catchment Basins for Storage Systems

There are three types of catchment basins which can be modified to increase the quantity of runoff:

1) Topographical,

2) Soil, and

3) Impermeable coverings.

A specific site should have a surface treatment designed for maximum runoff and minimum maintenance.

Topography

The simplest catchments involve some form of topographical alteration. Collection areas can be cleared of brush and rocks with small ditches cut on the slope to divert runoff water to direct field application or storage. Or, with a minimum of materials and labor, large quantities of water can be stored at low cost with the placement of rock-lined ditches at the lower edge of rock outcroppings. A more complex example of the use of topography is the roaded catchment of western Australia (similar to Figure 1) where large areas of bare land are shaped and compacted into parallel ridges (Laing, 1981).

Catchments using topographical techniques may be characterized by lower initial costs but could have low runoff efficiencies. Hollick (1982) notes that slope angles and overland flow distances must be designed to avoid water erosion damage to the catchment surface. Soil types and topographic features must be properly matched if these catchments are to be effective.

Soils

When using soil surface treatments for water harvesting catchment basins, usually the soil is rendered sterile to plant growth. Soils unsuitable for constructing surface catchments are loose sands and gravels or expanding lattice clays (self-mulching). To reduce infiltration, chemical treatments are applied to the soil surface by spraying the surface or mixing in the top 15 cm. These treatments are usually of bitumen, salt, a water repellent chemical, or paraffin wax. Potentially, soil surface treatments can provide low-cost crop water but soil surface treatments have not been totally satisfactory in the past (Frasier, 1984). These treatment designs are dependent on specific soil and climatic characteristics.

Salt treatments consist of mixing a water-soluble, sodium-based salt (NaCl) at a rate of 11 t ha^{-1} into the top 2 cm of soil to form a sodium dispersed clay system (Dutt, 1981). The salt is thoroughly mixed with the soil, wetted and compacted to a firm, smooth surface. The most effective soils are nonexpanding lattice clay of 20 percent or more (kaolinite or illite type). The sodium in the salt disperses the clay into individual particulates plugging the soil pores or holes and inhibiting water movement into the soil; the result is increased runoff.

Water repellent chemicals which coat minute soil particles change the surface tension of water absorbed to the soil particle, causing the soil to be hydrophobic or water repellent. Myers (1967) noted that a long-lasting and effective treatment of a surface for maximum runoff needed a soil binding material for water repellency and to retard erosion. When a chemical such as sodium silanolate is applied to a catchment surface where the clay content is less than 15 percent, runoff increases without soil stabilization and it has an effective life of three to five years (Frasier, 1984). Plueddemann (1975) in a laboratory screening procedure found that certain mixtures of latex and silicone emulsions do stabilize the soil surface and remain water repellant for one to three years.

Paraffin wax is used as a water repellent treatment which can be liquified by heating and sprayed as a thin layer on a prepared soil surface. Aldon and Springfield (1975) used granules or powdered paraffin wax sprinkled on the soil surface at a rate of 2.5 kg m^{-2}. The sun heats the soil surface, remelting the thin layer of wax which moves downward coating the soil particles with a water repellent wax (Fink, *et al.*, 1973). This treatment (Frasier, 1980) is best suited to soils of less than 20 percent clay content and where soil surface temperature exceeds 50°C, the melting point of paraffin.

Impermeable Coverings

Conventional construction materials such as concrete, latex rubber, black polyethylene, sheet metal, etc., have been used as coverings for catchment basins for water harvesting (Cooley, *et al.*, 1975). These materials, although expensive, may last a long time, and when properly installed and maintained may be well suited to some locations. Most thin film coverings are susceptible to mechanical damage, wind damage, and sunlight deterioration (Cluff, 1975).

Storage Facilities

A storage facility is generally required for most water harvesting systems whether it is the soil, tied-ridges or micro-catchment basins, a tank, or a check dam. Efficient water storage is the primary objective and is associated with various water uses, e.g., livestock, commercial, domestic, and supplemental irrigation for agricultural crops. Normally, the intended use of the water will influence the design. Final recommendations for the selection of system design will be dependent on cost and local conditions (Dedrick, 1975) such as:

1) Chemical and physical properties of soils;
2) Accessibility of personnel, equipment, and materials;
3) Availability of surface sealing materials;
4) Current costs; and,
5) Maintenance requirement for effective life of system.

Soil

In some designs of small-scale water harvesting the cultivated soil is the water storage container, i.e., direct runoff farming systems. The collected water is diverted or directed onto the cultivated area during rainfall. Generally, the quantity of runoff exceeds the infiltration rate of the soil and ridges are placed around the cultivated area to retain the water. Overflow from fields can be diverted by canals for storage or use on other fields. The effectiveness of this system depends on the water demands of the crop, the amount and distribution of rainfall, the soil infiltration rate and the water storage capacity. Specific designs of this type of water storage could have a high risk as crops can fail in dry years or can be badly damaged by flooding during heavy rains (UNEP, 1983).

Runoff farming systems are used extensively for the growth of trees. In Burkina Faso (French West Africa), long open slopes of denuded alfisolic soils are reforested with a continuous chain of water catchment basins (Wright, 1985). Ancient runoff farming methods have employed the collection of rocks to build low rock walls along contours to entrap eroded soil and runoff for the farming of sorghum and millet. Trees are planted behind these low walls and native grasses are seeded for stabilization (Chase, 1985).

Tied-Ridges and Micro-Catchment Basins

Ridges and depressions increase the potential for storage of water on the surface and provide for runoff trapping which increases the potential for infiltration and storage of water in the soil profile (Boa, 1966). Tied-ridges can be an effective system but they help to produce increased yields only when surface runoff occurs at a greater rate than infiltration.

There are a great many mechanical devices available for both animal traction and tractor power especially designed to make tied-ridges in a single operation. Ridges may be formed by tractor or oxen with ridgers (listers), however, ties can be constructed by hand. Usually, ridges are formed parallel to one another, planted on the tops, and tied or dammed in the furrows. Sometimes the tying, damming, or blocking of the ridges is made at the same height as the ridge. Hudson (1971) gives a word of caution about this construction technique that, if the soil becomes saturated with the depressions filling up and then overflowing, the ties or dams may break. On sloping ground, once one ridge breaks it releases a small flood which can burst the next ridge, releasing more stored water and so on down the slope. This can have a disastrous effect on soil erosion. To correct this situation, ridges should be constructed on grade with the ties lower than the ridge.

Tied-ridges can be constructed as micro-catchment basins. Figure 6 shows that the basins can be deep (30 cm) so that all the water that falls or runs into them will be captured. If the rainfall probability curve shows that the 25-year average storm is, say 80 mm, then a micro-catchment basin, if deep enough, could capture all rainfall and hold it in storage for eventual infiltration. In general, the differences between the two systems of tied-ridges and micro-catchment basins involve rainfall distribution and intensity, soil type, and slope, as well as maintenance and labor requirements. In some areas the ridges are left in-place throughout the dry season to catch early rains, minimize runoff, and permit early cultivation of the soil. Under no-till practices, the tied-ridges remain from two to three years with only minor maintenance, however, these systems are usually hand-seeded and hand-weeded.

Tanks

A water storage facility can be any container capable of holding water (Frasier, 1983). In many designs of water harvesting systems, the storage facility is the most expensive single item, and may represent 50 percent of the total system cost. There are many types, shapes, and sizes of wooden, metal, clay, and reinforced plastic water storage facilities.

Figure 7 shows a round spread-bank dam with a clay liner consisting of catchment area and tank (Laing, 1982). These have been successful in Australia because they are easy to build, suited to difficult sites, and maintenance is low (Laing, *et al.*, 1980). The compacted clay cover of the catchment area should be about 20 cm thick. The radial width of the catchment area is normally from 20 m to 75 m depending on location and size of the water harvesting catchment area. A ratio of 5 m^2 of surface area of catchment to 1 m^3 of tank storage is used with an annual rainfall of 400 mm (Stanton, 1977) or a catchment area of 2.5 ha can be used with a 5,000 m^3 dam for supplemental irrigation. The economic criterion for design should result in the most efficient dam per cubic meter of water supplied.

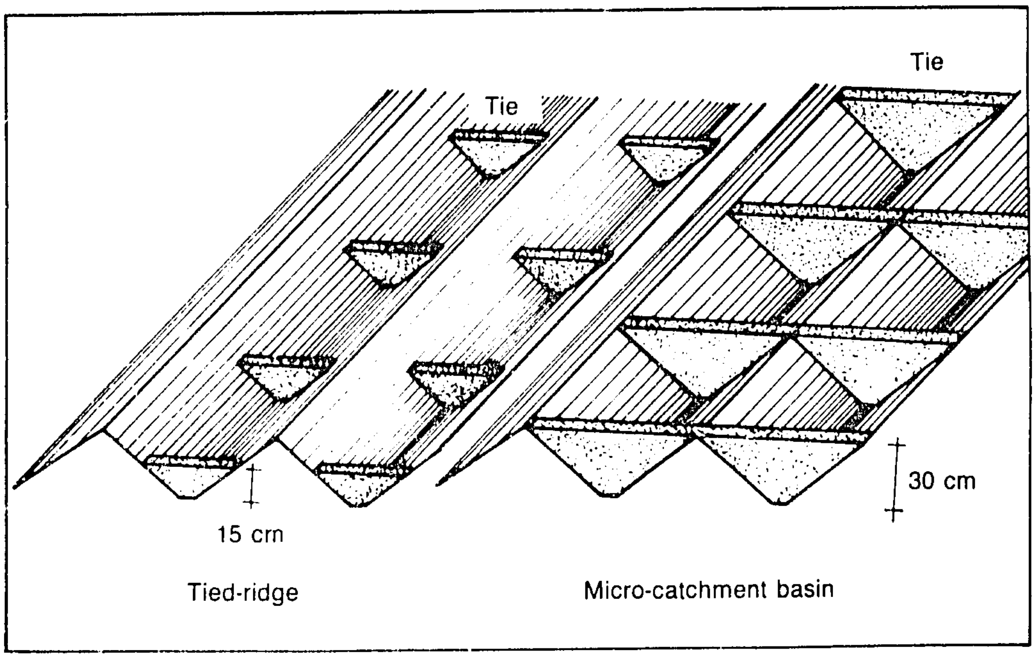


Figure 6. Schematic Diagram Showing the Cross Sections of Tied-Ridges and Micro-Catchment Basins.

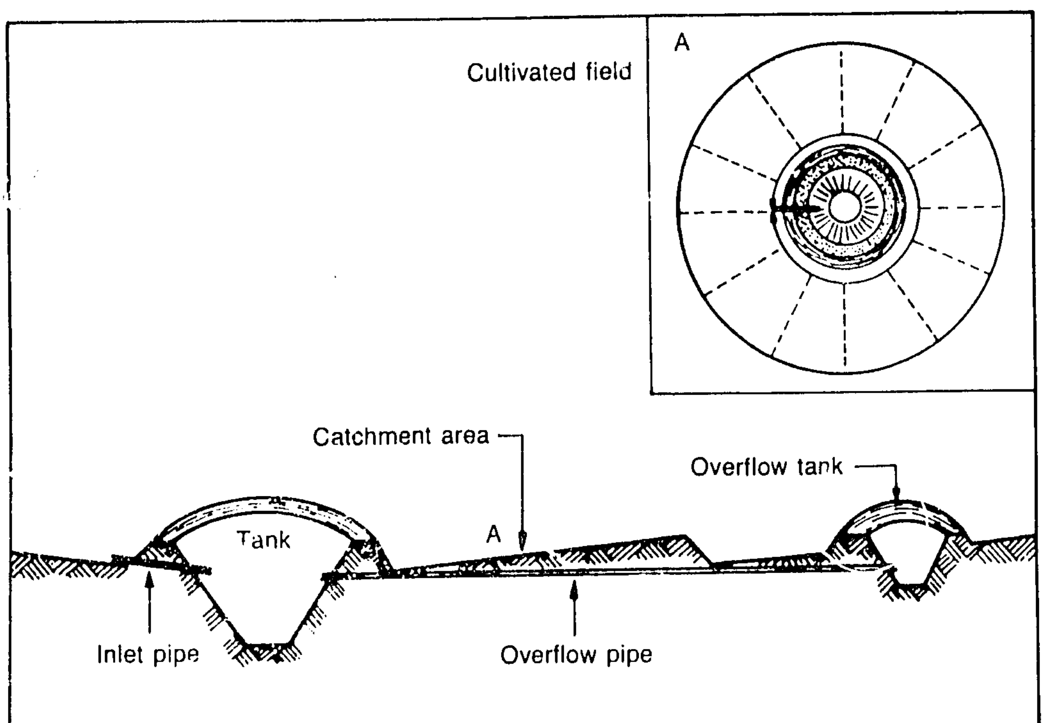


Figure 7. Cross-Section through a Spread-Bank (Flat-Batter) Dam and One Side of the Catchment Area.

Check Dams

Storage of water in small catchment ponds or reservoirs is a common technique to impound storm runoff. Small dams can be constructed across flowing and intermittent streams as well as gullies to create storage behind the dam walls. In many instances, these dams can be handmade using rock and concrete cores with a compacted clay-earth cover and gravelled spillway. In general, these types of reservoirs are used for supplemental irrigation to reduce risk and increase yield for crop production.

Summary and Conclusions

Small-scale water harvesting can economically reduce risk and increase crop production. Water harvesting to maximize or minimize runoff is a stabilizing factor for farming systems which depend on natural precipitation. Runoff can be used directly on cultivated fields or stored in soil, or used with supplemental irrigation when stored in excavated ponds or small check dams. Calculation of statistical parameters and probability analysis provide design criteria for constructing and optimizing the catchment area, conveyance device, storage facility, and cultivated field.

The performance of small-scale water harvesting depends upon the effectiveness of the catchment basin to manage soil surface conditions, e.g., inhibit infiltration, produce runoff, or increase soil water storage. Effectiveness depends on several factors including soil depth and type, surface cover, surface roughness and slope, climatic factors, labor and material costs, water balance, water quality, and availability of materials.

References

Aldon, E.R., and H.W. Springfield 1975. Using paraffin and polyethylene to harvest water for growing shrubs. *In* Proc. Water Harvesting Symposium, Phoenix, AR, 26-28 March 1974. USDA-ARS, ARS-W-22. U.S. Gov. Print. Office, Washington, DC.

Boa, W. 1966. Equipment and methods for tied-ridge cultivation. Farm Power and Machinery Informal Working Bull. No. 28, FAO, Rome, Italy.

Chase, R.G. 1985. Low-input soil/water management practices for Sahelian forest soils. Soil Sci. Soc. of Amer. Meetings. Chicago, IL, 2-5 December 1985.

Cluff, C.B. 1975. Engineering aspects of water harvesting research at the University of Arizona. *In* Proc. Watershed Management Symposium, ASCE, Irrigation and Drainage Div., Logan, UT, 11-13 August 1975.

Cooley, K.R., A.R. Dedrick and G.W. Frasier. 1975. Water harvesting: State of the art. *In* Proc., Watershed Management Symposium, ASCE Irrigation and Drainage Div., Logan, UT, 11-13 August 1985.

Doorenbos, J., and W.O. Pruitt 1984. Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper No. 24, FAO/UNDP, Rome, Italy.

Dutt, G.R. 1981. Establishment of NaCl-treated catchments. *In* Proc. Rainfall Collection for Agriculture in Arid and Semiarid Regions, Tucson, AZ, 10-12 September 1980. Commonwealth Agri. Bureaux, Farnham House, Farnham Royal, Slough, UK.

Fink, D.H., K.R. Cooley and G.W. Frasier 1973. Wax-treated soil for harvesting water. J. Range Mgmt. 26:396-398.

Frasier, G.W. 1975. Water harvesting: A source of livestock water. J. Range Mgmt. 28:429-434.

Frasier, G.W. 1980. Harvesting water for agriculture, wildlife, and domestic uses. J. Soil Water Conserv. 35:125-128.

Frasier, G.W. 1984. Water harvesting, runoff farming for collecting and conserving water supplies. *In* Alfisolic Soil Symposium, ICRISAT, December 1983. Hyderabad, India.

Frasier, G.W., and L.E. Myers 1983. Handbook of water harvesting. USDA-ARS Agric. Handbook 600, U.S. Gov. Print. Office, Washington, DC.

Hollick, M. 1982. Water harvesting in the arid lands. *In* Scientific reviews on arid zone research. Vol. 1. Scientific Publ., Jodhpur, India.

Hjelmfelt, A.T., Jr., and J.J. Cassidy 1975. Hydrology for engineers and planners. Iowa State Univ. Press, Ames, IO.

Hudson, N. 1971. Soil conservation. B.T. Batsford, Ltd., London, UK.

Jones, O. 1975. Yields and water use efficiencies of dryland winter wheat and grain sorghum production systems in the southern high plains. Soil Sci. Soc. Amer. Proc. 39:98-103.

Laing, I.A.F. 1981. Evaluation of small catchment surface treatments. Australian Water Res. Tech. Paper 61. Aust. Govt. Publ. Service, Canberra, Australia.

Laing, I.A.F. 1982. Rainfall collection in Australia. U.S.-Mexico Resource Workshop.

Laing, I.A.F., R.G. Pepper and A.L. Prout 1980. Flat batter dams suit difficult sites. Western Australian J. Agric. 4:110-112.

Myers, L.E. 1967. Recent advances in water harvesting. J. Soil Water Conserv. 22:95-97.

Perrier, E.R. 1984. Final Report: Soil-water management program. ICRISAT/SAFGRAD, Bureau de Coordination, OAU/STRC, Ouagadougou, Burkina Faso.

Perrier, E.R., and L.P. Wilding. 1986. An evaluation of computational methods for field uniformity studies. Adv. Agron. 39:265-312.

Plueddemann, E.P. 1975. Soil treatment with silicones for water harvesting. *In* Proc. Water Harvesting Symposium, Phoenix, AZ, 26-28 March 1974. USDA-ARS ARS-W-22, U.S. Gov. Print. Office, Washington, DC.

Stanton, D. 1977. Flat batter dams. Western Australian J. Agric., Farmnote AGDEX 583, October.

UNEP. 1983. Rain and stormwater harvesting in rural areas. Tycooly Inter. Publ. Ltd., Dublin, Ireland.

Wright, P. 1985. La conservation des eaux et des sols par les paysans: Le projet agroforestier au Yatenga, Burkina Faso. OXFAM Annual Report, Ouagadougou, Burkina Faso.

Role of U.S. Land-Grant Universities in Addressing Soil and Water Management Problems

J.L. Ozbun
Washington State University, Pullman, Washington, USA

ABSTRACT. To identify the role land-grant universities perform in addressing soil and water management or any specific problems, we need to look briefly at the origins and structure of land-grant universities.

General Role of U.S. Land-Grants

In 1862, the United States Congress created the first land-grant universities. The federal government provided each state with large grants of land to establish and maintain a land-grant university to teach agriculture and mechanic arts. Twenty-five years later, another federal act created a national agricultural experiment station system, individual units of which were to be part of each state's land-grant university. In 1914 still another federal act established Cooperative Extension, the outreach arm of the land-grant university. These last two acts also established the federal funding support which continues today.

The federal government thus created and provided funding for formal classroom instruction in agriculture and mechanic arts; it created a means to conduct research to resolve agricultural problems; and it created a way to take new and relevant information to farmers throughout each state. This, then is the role of U.S. land-grant universities in addressing problems such as soil and water management: to conduct research that addresses agricultural concerns; to educate and inform people about ways to use new and relevant information to resolve their problems.

After World War II, the government established the U.S. Agency for International Development (USAID) which, with various other federal acts, provided the means for and encouraged land-grant universities to work directly with other nations in formal education, research, and extension programs. And that added the fourth dimension to the land-grant university role.

A land-grant university includes subject matter areas in addition to agriculture. Increasingly these areas are being employed to address specific topics through interdisciplinary programs.

Climatic, social, and economic conditions influence the specific interests of the individual land-grant universities. They in turn influence the approaches and competencies available to address specific concerns. Some states are concerned with only three or four major agricultural commodities, and their research and education programs focus on them.

Land-grant universities have program as well as funding relationships with the U.S. Department of Agriculture (USDA). Both of these influence how land-grant universities approach specific problems. The USDA has its own research service. Many of these scientists are stationed on land grant university campuses. They receive some support from the university and work closely with research faculty at the university. Their research has a regional or national focus but it also addresses state concerns. This frees land-grant scientists to conduct other research more specific to the state.

USDA also has an Extension Service component which provides national program support for state extension efforts.

At first glance, resident instruction programs at land-grant universities may appear very similar. All students need a broad knowledge base on which to build their education. While there may be similarities at the undergraduate level, graduate programs differ considerably. A large number of faculty involved in research also teach. While the information in a basic soils course may be the same across the nation, the substance of graduate courses focuses on narrower and more specific areas within soils. These areas are determined by the instructors' research interests which are based on state need.

Washington State University as a Land-Grant University

Each year, the College of Agriculture and Home Economics of Washington State University (WSU) offers 42 courses which deal with soil and water conservation. WSU provides undergraduate and graduate education to students from a wide range of countries. Some of these students come to WSU in connection with technical assistance programs that WSU is conducting in their home nations. In 1981, 19 Jordanians were enrolled at WSU—10 in graduate school and 9 undergraduates. This year, two Jordanian graduate students are enrolled— one in soils and one in bacteriology. They join 794 other students from 103 countries studying on campus.

Washington has over 50 major commodities for which its producers seek research information. This means the College has a broad scope of research activity and expertise which it can bring to bear on specific problems in the state or in connection with an international development project. Of a total of 317 research projects being conducted by College scientists, 51 deal with some aspect of conservation, development and use of soils, water, and related resources (1984 CRIS data).

In the past, agricultural research focused on one specific subject matter area. A scientist looked for a specific way to stop rain water from running down the face of a hill and washing away topsoil. Today's research emphasizes a system or multidisciplinary approach. All physical and social aspects of soil erosion are being investigated at the same time and in a coordinated way to identify and predict occurrences beyond those which may be thought relevant initially.

Our STEEP (Solutions to Environmental and Economic Problems) erosion project with Idaho and Oregon is one example. Program objectives include: developing combinations of tillage machinery, cropping practices, residue management, and weed control to control erosion in dryland areas; developing wheats with characteristics that reduce erosion and maintain yields; integrating weed, disease, and insect control with tillage and plant management systems; determining the economic and social impacts of improved practices on farm organization and productivity.

This project exemplifies:

1) Our College's cooperative research programs with neighboring states.

2) A systems approach to resolving problems.

3) Our role in addressing soil and water management concerns.

Washington is a large state and has a wide variety of growing conditions. We have a Mediterranean climate similar to Jordan, although our winters are a little colder. We have large acreages under irrigation. Thus, some of our research activity focuses on managing and using irrigation water.

We also have large areas of rainfed agriculture where annual precipitation ranges from 250 to 500 mm. Wheat is Washington's major crop and most of it is grown on rainfed lands. It should be no surprise then that research and education concerning all aspects of limited rainfall wheat production are a major focus in the College. It follows that our research, instruction, and extension faculty have a high level of interest and expertise in the many aspects of efficient, high-yield cereal production.

In 1918, our wheat yields averaged 855 kg^{-1} ha (12.5 bu $acre^{-1}$); 1983 was our high average year with 4,391 kg^{-1} ha (64.2 bu $acre^{-1}$). When growing conditions are perfect, some land has yielded over 6,840 kg^{-1} ha (100 bu $acre^{-1}$). This indicates both the success and the potential of the varieties and cultural practices we have developed. And we have addressed milling, baking, and other processing concerns as well. Of perhaps greater importance, we have placed this information in the hands of farmers in ways they can readily understand and use.

In summary, the role of the U.S. land-grant university is to educate students, conduct research on the various problems which occur in its geographic area and for which it has the expertise, and to provide citizens with new and relevant information in a way they can understand and use. Initially, such activity focused on the state in which the land-grant was situated. The global economy in which we now live offers the opportunity to expand such activities beyond national boundaries.

SECTION V

Methods and Strategies for Improving Agricultural Efficiency of Conservation Systems

The Potential for the Production of Red Meat from Sheep in the Semiarid Regions of the Middle East from Pasture and Rangeland Flocks

I.G.H. Goddard
European Economic Community/Jordan Cooperative Organization, Amman, Jordan

ABSTRACT. The potential for improved regional production of rainfed forage crops and rangeland pastures can only be economically obtained if financial returns from livestock systems can be improved to pay for the required investment. Work carried out in Jordan has clearly demonstrated that it is possible to obtain significant economic returns from the local Awassi fat-tailed sheep. Improvement has been shown to be based on combining a number of factors. The major ones are: 1) improvement of nutrition throughout the breeding cycle; 2) adoption of disease prevention practices; 3) implementation of sound management practices; 4) following an improved lamb management program from birth to slaughter; and 5) to maintain progress by introduction of a sound breeding policy based on accurate recording and selection.

The data obtained from an ongoing program have shown the following levels of improvement: 1) 37.5 percent improvement in number of lambs weaned from extensively managed flocks; 2) 59.5 percent improvement from intensive lamb fattening in terms of red meat production; and 3) 219 percent improvement in total red meat production per 1,000 breeding ewes. The program has also obtained data which indicate that the Awassi breed has high genetic variability which provides a sound basis for breed improvement by intensive selection within the breed.

The potential for the development of improved stock from Awassi is of major importance as the breed is well adapted to the local environment. Variation has been identified in the following commercially important characteristics: multiple births, lamb growth rates, and milk production. The improved economic returns from the adoption of suitable technology for sheep breeding flocks can provide the economic base for the expansion of regional forage production by commercial farmers in rainfed agricultural zones.

Introduction

The semiarid regions of the Near East have a limited agricultural potential in terms of rainfed agriculture due in main to the limited and variable seasonal rainfall pattern. Traditional agriculture in the region has been based on a wide variety of related farming systems centered on the cultivation of winter cereals and legumes, such as lentils and chickpeas. Many of the systems had a livestock component based on seasonal grazing and the use of by-products. Development in the region over the past decades has been associated with a rapidly increasing population, urbanization, industrialization, and a demand for a higher standard of living. These changes have resulted in the region having an increasing dependence on imported feedstuffs from other regions to satisfy demands, with concomitant increasing expenditure of foreign exchange.

One of the results of these import levels has been the growing awareness of Governments in the region of the need to increase agricultural productivity to reduce import costs and to improve food security. Improvement of red meat production and milk production has been considered in many schemes for rainfed agricultural areas. Development of these projects has been influenced by two major limitations. These are:

1) Shortage of locally produced feedstuffs from either range or forage plants or from human food crops as by-products. Production is often limited due to current economic conditions.

2) Lack of available water supplies for maximum crop growth due to poor water harvesting management practices.

Table 1. Livestock Numbers in the Arab World, 1982 (AOAD, 1984).

	Cattle	Sheep	Goats	Camels	Buffaloes
Total (1000 head)	37,448	103,998	57,521	14,344	2,575
% of total	17.6	48.9	27.0	5.3	1.2
Jordan (1000 head)	35	990	590	15	0
Jordan %	2.1	60.7	36.2	1.0	
Syria (1000 head)	791	11,403	1,150	7	2
Syria %	5.9	85.4	8.6	0.05	0.01
Iraq (1000 head)	1,900	11,900	3,800	80	175
Iraq %	10.6	66.4	21.5	0.4	0.9

The majority of the papers at this Workshop are related to improvement of crop production. As all improvements have a financial cost which should be covered by increased yields if one expects farmers to adopt such measures, then increased forage production or by-product availability should be related to increased animal productivity for the development of an economic agricultural industry. In this semiarid region the most common grazing animals are sheep and goats, as shown in Table 1. The local breeds of sheep are well adapted to their environment and have a production pattern which is well adjusted to the seasonal pattern of feedstuff availability. On-going sheep programs in Jordan have shown that changes in the traditional management of sheep flocks in the Kingdom will result in a significant improvement in red meat and milk production from Awassi flocks.

This paper discusses the cumulative potential of various proven measures based on commercial farm results and attempts to assess the economic value of these gains. Only if farm income can be improved on a short-term basis will farmers invest in long-term development and improvement. The potential was discussed at the 1982 Sheep Workshop at the University of Jordan (Goddard, 1982).

Improvement of Ewe Productivity

As a policy of simple expansion of ewe numbers will increase the problem of feedstuff availability, the aim of the program has been to develop methods of improving ewe productivity in terms of number of lambs weaned, weaning age, and weight and milk production. The approach has been to measure existing productivity and to develop management systems rather than consider individual improvements. This review describes the methods recommended and considers the overall results.

Values obtained from local reports and studies on a range of local flocks showed that there was already a wide degree of variation within and among flocks (Goddard, 1984; Harb, 1983; Shiek, 1982). The following management-related practices have been found to increase productivity:

1) *Selective culling on age and productivity.* This is often difficult due to lack of any records, and advice has to be based on comparative physical condition and dentition related with the shepherd's memory as to past performance. In some flocks culling of

over 15 percent of the ewes can be considered on these terms. The major problem is to develop owner confidence in the economic value of this approach, and lack of replacements within the flock structure.

2) *Improvement of breeding flock nutrition.* The establishment of a flock feeding program based on stage of production is very difficult due to the normal management pattern of a widespread lambing and keeping the flock as a whole with no separation of sexes and age groups. The general approach has been to encourage owners to improve feeding at the mating period to flush the ewes, and to improve feeding in late pregnancy and during lactation. This is possible in many flocks due to the common use of supplementary feeds in winter and early spring. A number of possible ration formulations using locally available feedstuffs have been developed for on-farm use with initial recommendations for usage rates based on stage of production/breeding cycle and level of production. These programs emphasize the need to produce forage crops and to utilize them correctly to gain the maximum economic benefit in terms of improved production.

3) *Improvement of disease and parasite prevention.* Jordanian farmers are very aware of disease and parasite problems, however, they often are uncertain of the economic methods of control and prevention. At present there is a development program aimed at identifying economic solutions to problems as they are established as definite problems reducing productivity. To date recommendations have been based on individual solutions such as control of external parasites or clostridial diseases rather than as annual flock programs.

4) *Changes in management practices.* Practical changes to improve farm efficiency based on the use of improved basic equipment designs for feeders and drinkers are considered to be of value as they help make farmers aware of other problems such as feed wastage and water requirements. Demonstrations on handling methods to reduce stress have helped create interest in improved management. The potential value of ram separation as a management tool has been discussed with many farmers, however, the basic problem is that the common semi-intensive grazing program and physical facilities make this impractical for many commercial farmers.

5) *Improvement by selection.* There is a wide degree of genetic variation within the Awassi breed in Jordan (Goddard, 1984) and farmers often stress the importance of good selection. However there is only limited local progress at present. On many farms the lack of records makes it difficult to develop a systematic approach to selection and one has to rely on flock inspection and verbal reports from a shepherd.

The approach used to assess productivity has not been only to consider the number of lambs born but to assess ewe flocks on the number of ewe lambs weaned and on milk production. This is because weaned lambs are the major sellable product along with milk. This has meant that as well as looking at ewe flock management, the program has also stressed lamb management from birth to weaning to reduce mortality and increase growth rates. To date emphasis has been placed on the following factors:

1) Ewe nutrition from late pregnancy throughout lactation. The aim is to encourage strong healthy lambs at birth and an adequate milk supply for growth until weaning.

2) Reduction in early lamb mortality by improved management to
   (a) reduce chilling by good building design or windbreaks;
   (b) provide checks on early feed intake and mothering, especially with twin lambs; and
   (c) improve hygiene at birth. Initial results have shown that losses from twin births can be reduced by greater than 50 percent by adoption of simple management practices including adoption or fostering during this critical period.

Table 2. Improvement of Number of Lambs Weaned per 1,000 Ewes Mated.

Factor		Flock Type	
		Traditional	Improved
Number of ewes bred (mixed age flock)		1,000	1,000
Number of rams		30	25
Number of barren ewes (including maiden ewes)		150	100
% twinning		5	15
Number of lambs born		893	1,035
% Lamb mortality birth to weaning		8	4
Number of lambs weaned		822	994
Number ewe lambs required as replacements		300	280
Number ram lambs as replacements		10	10
Average age at weaning in days		70	55
Average body weight at weaning, kg liveweight		20	20
Number of lambs available for fattening			
	male	401	487
	female	111	217
	total	512	704
	% improvement	100	138

3) Improved feeding of the lamb by encouraging use of creep feeders and creep rations to increase growth rate and allow early weaning. Results from the University of Jordan have clearly shown that the average weaning age can be reduced to 45 days from 60 days at the same body weight. This allows for a longer milking period for sellable milk and higher yields per ewe of sellable milk.

The potential for increasing the number of lambs weaned per 1,000 breeding ewes is shown in Table 2. This result is based on values that have been recorded locally based on different combinations of the various factors discussed.

These results are based on improvements in semi-intensive flocks obtained from relatively low-cost improvement changes. The aim has been to try and produce one healthy lamb per ewe mated, as on currently available feed supplies a high twinning rate could cause high losses or expensive supplementary feeding. The program has also been based on one lambing per year; it is considered that any intensification will require a significant increase in costs and technical management skills which are not readily available.

Local fattening trials on commercial farms based on fattening of weaned ram lambs for 60 to 70 days on concentrate rations of whole grain barley and soybean meal mixtures have resulted in significant improvement in red meat yields (Table 3). The system is based on lamb selection and the adoption of a simple disease prevention program for clostridial vaccination and treatment against internal parasites associated with good management practices.

There have been a number of trials based on fattening lambs on cultivated pastures with successful results. However, the question remains as to whether the optimum use of such pastures is for lamb fattening or as a feed source for the breeding flocks which require good quality roughage to maximize production. The results of initial development programs organized by the Jordan Cooperative Organization have demonstrated that the local Awassi sheep flocks under commercial management have a very high potential for improving red meat production by introduction of low-cost changes in management practices. The overall potential is shown in Table 4 by the summarized values of current results.

Table 5 shows the economic costs of such a ewe flock program in Jordan and the potential returns based on use of imported feeds to gain improvement. Lamb fattening trials have shown that a profit of over J.D. 3,500 per lamb fattened can be achieved under good management. These results indicate that commercial farmers could generate funds to invest in increased crop production from well-managed sheep flocks. The need to demonstrate that farming system changes generate higher farm incomes is an important component of successful extension.

Summary

Results from commercial sheep flocks in the semiarid regions of Jordan under semi-intensive management systems have clearly demonstrated that there is a high potential to increase red meat production by over 200 percent from such flocks by adoption of improved management systems. Available data also show that this improvement is financially viable and in the long-term can be based on local resources if range areas and cultivated forage production improvements are adopted.

Table 3. Improvement in Red Meat Production by the Fattening of Weaned Lambs (Goddard, 1985).

Factor	Management System			
	Traditional	Improved		
		Low	Medium	High
% mortality + culls	10	7	5	3
No. sold/1000 weaned	900	930	950	970
Average carcasse weight, kg	12.5	15.0	16.5	18.5
Total weight sold, t	11.25	13.95	15.68	17.95
% improvement		24	3.9	60.0

Table 4. Improvement in Red Meat Production per 1,000 Ewes Mated by Management Changes.

Factor	Traditional Management	Improved Management
Number of lambs fattened	512	704
Number of lambs sold	461	683
Average carcasse weight, kg	12.5	18.5
Red meat sold, t	5.76	12.64
Improvement, %		219

Table 5. Estimated Economic Costs and Returns of Increased Lamb Production.

Extra Costs	J.D.
Increased concentrate feed per ewe, 100 kg × 1000 ewes × J.D. 68/t	6,800
Increased veterinary costs, J.D. 0.250/ewe	250
Total cost increase	7,050
Increased Income at Weaning	
86 Extra ram lambs, 20 kg L.Wt. @ J.D. 1.250/kg	2,150
106 Extra ewe lambs, 20 kg L.Wt. @ J.D. 1.200/kg	2,544
13,500 kg liquid milk @ J.D. 0.250/kg	3,375
Total increased income	8,069
Increased gross margin per ewe, based on sale of weaned lambs	1.02

References

AOAD. 1984. Yearbook of agricultural statistics. Vol. 4. AOAD, Khartoum, Sudan.

Goddard, I.G.H. 1982. Improvement of sheep production in Jordan. Sheep Production Workshop, University of Jordan.

Goddard, I.G.H. 1984. Performance of Awassi sheep in Jordan. Annual report JCO/EEC Sheep Project Delegation of EEC, Amman, Jordan.

Goddard, I.G.H. 1985. Red meat potential from Jordanian sheep. Annual report JCO/EEC Sheep Project Delegation of the EEC, Amman, Jordan.

Harb, M. 1982. Sheep production on natural pasture by roaming Bedouins in Jordan. Sheep Production Workshop. University of Jordan. Amman, Jordan.

Shiek, I. 1983. Report on sheep production in Jordan. Sheep Production Workshop, University of Jordan. Amman, Jordan.

Effect of Weed Control on Soil Water Conservation for Rainfed Agriculture in the Near East

C.R. Fenster
Panhandle Research and Extension Center, University of Nebraska, Scottsbluff, Nebraska, USA

ABSTRACT. Weeds and volunteer crop plants compete vigorously with crops for stored water. Weeds are strong competitors because of their vigorous growth habits and root systems which are often more extensive than those of crops.

Much of the cereal production in the world occurs in semiarid regions (annual precipitation less than 500 mm). Within these regions, traditional cultural practices to control weeds have relied on repeated hand weeding, cultivations, and livestock grazing. These traditional weed control practices often leave the soil bare and subject to wind or water erosion and high water evaporation. Weeds growing with the crop are often removed by hand when they are 15 to 20 cm high and fed to livestock. Weeds removed at this stage of growth have already reduced crop yields and removed valuable soil moisture and nutrients. After harvest, weeds and crop residues are frequently used for livestock feed, which is nutritionally a low quality forage. The weeds generally have high water requirements.

To increase the effectiveness of precipitation in the semiarid regions of crop production, consideration must be given to weed control to eliminate competition with the crop for moisture and nutrients. Cropping systems need to be developed that produce grain and forage, specifically, and emphasize technological practices that will conserve and utilize more of the available water supplies for crop production.

Dryfarming has been practiced in parts of North Africa and the Middle East for centuries. Much of this land is characterized by winter rainfall and hot, dry summers (Brengle, 1982). The period of the year during which precipitation is received is generally short, two to five months. Little, if any, precipitation is received during the remainder of the year (Figure 1) (Fenster, 1980). The precipitation is principally rainfall in the lower latitudes and elevations, but snow is common to some areas with high elevations.

Small areas are farmed by families which use animal power, wooden plows, hand broadcast seeding, and hand harvesting. Grazing of land is very intense on both grassland and weedy fallow. As soon as green vegetation appears, often the plants are grazed immediately. If plants do not have sufficient green growth, photosynthesis cannot take place to develop more plant material. The manufacturing system of the plant is its leaves, so it is necessary to maintain growth of plants to develop more plant material. If you continue to remove the shoot of a plant, you eventually kill the root, even in perennial plants. Not understanding the principle of dry matter production, farmers heavily graze their forage as soon as it begins to grow. Consequently, there is little total production of carbohydrate for forage. Using the rule of thumb "harvesting half and leaving half of a forage plant" would greatly increase forage production in the Middle East and North Africa.

Small grains are important dryland crops and are generally growing in what is called a wheat-fallow system. This is a forage-deficient region in which the land is grazed during the fallow period and no attempt is made to control weeds, for they are often the only forage plants available. Water conservation is nil in this system, and weed competition with the following crop often reduces yields by 20 percent or more (Ghosheh, 1975).

Lomas (1972) reported the average yields of wheat in Iran using traditional production methods were 300 to 400 kg ha^{-1} in areas receiving about 350 mm of precipitation annually, 700 kg ha^{-1} in areas receiving about 450 mm annually, and could be increased by improved weed control alone. Self-sufficiency in wheat production could be attained by

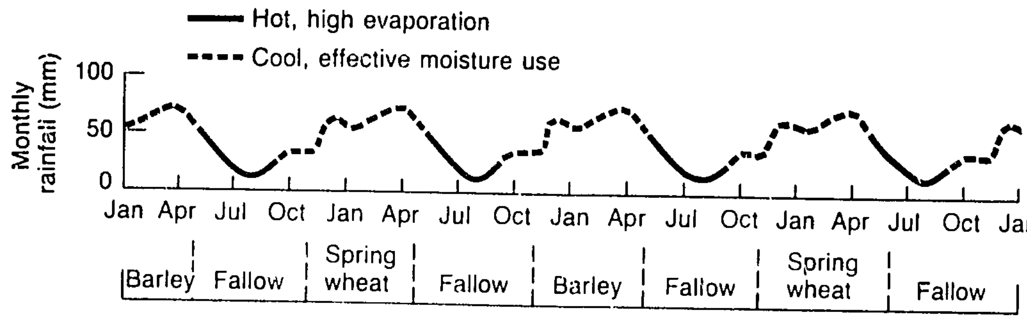


Figure 1. Annual Cropping for Semiarid Regions with Winter Rainfall but No Cold Season When Plants Are Dormant.

improved management and weed control. All livestock in the country, expressed as sheep units, is estimated to be about 80 million head. The capacity to produce feed is estimated to be adequate for 20 million sheep units (Shaidee, 1974). Improved management for crop production cannot be implemented without improved animal and range management. The natural forages that provide 70 percent of Iran's livestock feed are essentially crop residues and weeds. Livestock nutrition and range conditions are extremely poor, and crop residues are almost completely removed from the land.

According to Hepworth *et al.* (1975) the great majority of the wheat crop in Turkey suffers severely from weed competition. Research trials have demonstrated that weeds reduce wheat yields from 10 to 50 percent or more. Despite this great potential for increased yields, few farmers are obtaining maximum benefits from weed control.

In 1985 a Scientific Panel Review of Dryland Farming Applied Research in Morocco reported ruminant livestock are very important in the region. The main sources of forage appear to be, in approximate order of importance: cereal crop residues (June to September), weedy fallows (November to March), corn thinnings and weeds pulled from cereal crops (January to April), and, on occasion, dual-purpose barley crops. The forage program has identified improvement of the weedy fallow and or sown forage crops as its top research priorities.

Most weed control in Lebanon is still done by hand pulling, hand hoeing, or tillage by various implements (Cavin *et al.*, 1972). Often the weeds are not removed by hand until they are about 15 to 20 cm high because these weeds are fed to livestock. However, the most critical period in crop competition is during the first 1 to 2 months in the growth of the crop. Their method of weed control allows the weeds to grow at least 4 to 6 weeks, producing substantial crop yield losses.

In the United States, weeds are a serious problem to all wheat farmers (Reitz, 1976). Weeds compete with growing wheat for water, light, and mineral nutrients. They increase the cost of production, reduce the quantity and quality of the grain, and harbor insects and certain diseases. Weed seeds are a major part of the dockage found in marketed wheat. A large plant of common mustard may use twice as much nitrogen, twice as much phosphorus, four times as much potash, and four times as much water as a well-developed wheat plant.

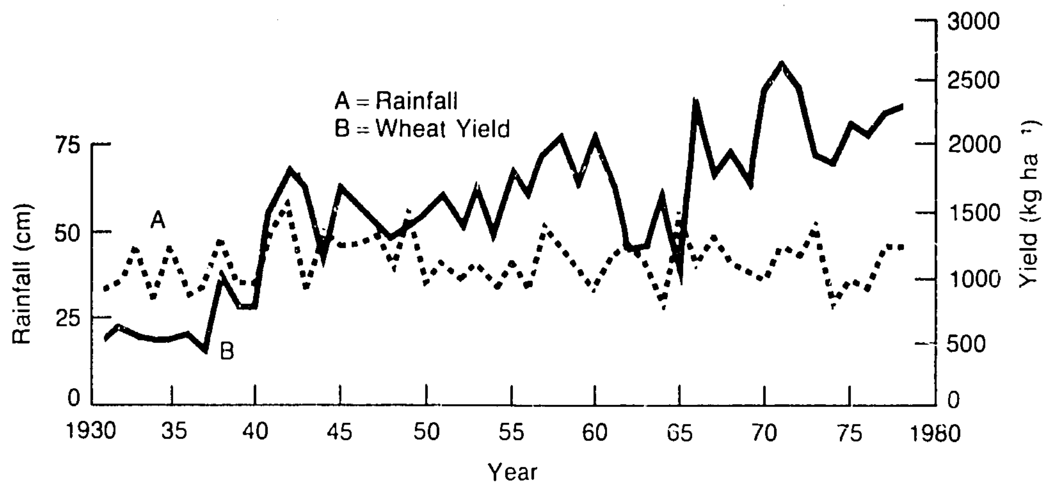


Figure 2. Nebraska Panhandle Averages for Rainfall and Wheat Yield from 1930 to 1980.

The potential yield of cereal grain is much higher in the semiarid regions than is currently realized with present production practices (Fenster, 1974; 1980). Technological methods have been and are being developed that conserve more precipitation for utilization in increasing cereal grain yields. Emphasis must be placed on water use efficiency. To increase the effectiveness of precipitation for crop production, consideration must be given to: 1) cropping systems that take advantage of the growing season precipitation; 2) cultural practices during the period between crop seasons which permit the accumulation of water in the soil profile; and 3) weed control as weeds are heavy users of soil nutrients and water in competition with the crop.

In the Panhandle of Nebraska, part of the United States Great Plains, yields of winter wheat were relatively low prior to 1940, averaging about 660 kg ha^{-1}. Following the adoption of the fallow system after 1940, the yields of winter wheat more than doubled on an every-other-year basis and became secure from drought as indicated in Figure 2. Prior to 1950, most of the winter wheat land was fenced and pastured during the fallow period. Frequently, fields were shallow-tilled after harvest to establish volunteer wheat for pasture. The volunteer wheat was pastured during the fall, winter, and into the spring. Tillage for summer fallow would begin around June 1 or later to control weeds. By this time, the weeds including the volunteer wheat had taken most or all of the soil water from the soil profile.

In the middle 1960s, pasturing of fallow land was discontinued and more emphasis was placed on weed control and residue retention during the fallow period. The storage of more water in the soil profile along with improved varieties of winter wheat tripled the yields of winter wheat in the fallow system during the late 1960s and 1970s. Yields of winter wheat will continue to increase with technology that improves water storage.

The increase can be largely attributed to development and implementation of technological practices for the total production system of wheat. Following is an estimate of the percent increase in yield of winter wheat due to new and improved technology.

Percentage Increase in Wheat Yield Due to Improved Technologies.

Improved varieties Genetic high yielding factor Disease resistance Insect resistance Shorter straw	30%
Improved storage of soil water Better weed control from harvest to planting of wheat. No livestock grazing on the fallow or in the growing wheat. Weed control in the growing wheat. Improved tillage techniques for optimum water infiltration and soil water storage. Maintenance of crop residues Runoff and erosion control	35%
Improved planting techniques Proper rate, dates, and methods of planting	20%
Improved harvesting techniques More timely and efficient Less handling of grain	10%
Fertilizer, especially on sandy soils Low fertility soils	5%

Crop yield losses from weeds usually are proportional to the amount of water, light, and nutrients used by the weeds at the expense of the crop (Burnside and Wicks, 1967). One needs to define fallow, weeds, and forage.

Fallow is the period of time from harvesting of one crop to the planting of the next crop. Successful fallow stores water, controls weeds, and prepares a seedbed.

A weed is any plant growing out of place.

A forage crop is grown primarily for animal feed.

If weeds in a crop are grown primarily for forage, then they should be treated as a forage crop and the soil water use should be charged to forage production. If not, the weeds should be considered competition to the production of the crop If weeds are used for forage, the quality of weeds for forage must be considered. In a study by Marten and Andersen (1975), weeds such as common lambsquarters (*Chenopodium album* L.) were as palatable to sheep as oats. However, weeds such as wild mustard [*Brassica kaber* (DC.) L.C. Wheeler var. pinnatifida (Stokes)] were unpalatable. A number of the thistles and many other weeds are very unpalatable to livestock, especially as they reach maturity.

Research workers have found that competition begins early from weeds that emerge with the crop and often persists through a major portion of the growing season (Burnside and Wicks, 1967). Weeds that emerge after the crop is established cause less competition. Knake and Slife (1966) found that if weeds in corn and soybeans were destroyed the first 3 weeks after planting, little yield loss resulted from subsequently emerging weeds. Burnside and Wicks (1969) showed that the most severe weed competition to dryland sorghum occurs during the first 30 days after planting, and weeds that germinate later have little effect on yield.

Weeds are the major economic pest of wheat (Reitz, 1976). Yield losses to weeds depend upon the weed species, density, time, and amount of weed growth. Wheat cultivar selection, management, climatic conditions, and edaphic factors also influence weed growth and resulting effects. Because of weed competition for moisture, nutrients, and light, there is an inverse relationship between weed growth and wheat yields. At Alliance and North Platte, Nebraska, Fenster and Wicks (1974) showed that a moderate infestation of downy brome (*Bromus tectorum* L.) (9 to 10 plants m^{-2}) reduced winter wheat yields 30 percent and a heavy infestation reduced yields 80 percent.

Weeds compete early in the life cycle of wheat and continue to compete as long as they are allowed to grow (Hurst and Feltner, 1966). Winter wheat starts growth in the fall, and unless stand reduction occurs due to winterkill, vigorous plant growth will utilize the soil moisture and produce sufficient foliage to densely shade the soil before summer annual weeds can become established. Winter annual weeds germinate at the same time as, or later than, winter wheat ... are able to grow unchecked.

Weeds infesting spring wheat are primarily early maturing summer annuals, while winter wheat is infested by winter annual weeds or broadleaf weeds that germinate in early spring. Perennial weed problems tend to increase as tillage decreases. Grassy weeds are a greater problem than broadleaf weeds since control methods which use reasonably priced herbicides are available for broadleaf weeds in wheat. Annual grasses have increased in the spring wheat growing areas because of semidwarf wheats and reduced tillage systems. The use of fertilizers has also increased weed problems.

Much of the research with fallow has been devoted to weed control systems. Measurements have shown that uncontrolled weeds may consume soil water at about 5 mm day^{-1} (Wicks and Smika, 1973). Certain broadleaf weeds, such as kochia (*Kochia scoparia* L. Roth) have a feeding depth and radius of root extension equal to or larger than that of most domestic crops. After harvest, growth of weeds in undisturbed wheat stubble in the central Great Plains of the United States has produced from 800 to 2700 kg ha^{-1} of dry matter (Greb, 1974). Dry matter production of 1000 kg ha^{-1} by weeds consumes 80 to 100 mm of water and about 30 kg ha^{-1} of available nitrogen. Good weed control resulted in increased wheat yields of grain and straw of about 60 and 120 kg ha^{-1}, respectively (Greb, 1974).

Mechanical implements control weeds with varying success. Tillage, however, causes 0.5 to 0.8 cm of evaporative water loss from each disturbance of moist soil (Good and Smika, 1978). Herbicidal weed control, on the other hand, does not disturb the soil. But to be effective, herbicides must rapidly and completely kill all unwanted vegetation. A stunted live weed continues to use water.

Uncontrolled weed growth decreases water storage, and weeds and volunteer crop plants compete strongly with planted crops for stored water. Weeds are strong competitors because of their vigorous growth habits and because their root systems are often more extensive than those of planted crops (Davis *et al.*, 1965; 1967). Weeds allowed to grow for several weeks after crop emergence reduce soil water and crop yields. After harvest, weeds and crop residues frequently used for livestock feed are nutritionally low quality forage. Weeds generally have a higher water requirement than most crops.

To increase the effectiveness of precipitation in the semiarid regions of crop production, consideration must be given to weed control to eliminate competition with the crop for moisture and nutrients. Cropping systems need to be developed that produce grain and forage specifically, and emphasis needs to be given to technological practices that will conserve and utilize more of the precipitation that falls on the land for crop and forage production.

References

Brengle, K.G. 1982. Principles and practices of dryland farming. Colorado Associated University Press.

Burnside, O.C., and G.A. Wicks. 1967. The effect of weed removal treatments on sorghum growth. Weeds 15:204-207.

Burnside, O.C., and G.A. Wicks. 1969. Weed composition with sorghum. Weed Sci. 17:332-334.

Cavin, G.E., D. Raski, R.G. Grogan, and O.C. Burnside. 1972. Crop protection in the Mediterranean Basin. USAID 77. Washington, D.C.

Davis, R.G., W.C. Johnson, and F.O. Wood. 1967. Weed root profiles. Agron. J. 59:555-556.

Dregne, H.E., and W.O. Willis (ed.). 1983. Dryland agriculture. ASA monograph 23, Madison, WI.

Fenster, C.R. 1974. Soil management research and farmer practices in the Great Plains of North America. 2nd Regional Wheat Workshop Proc., Ankara, Turkey.

Fenster, C.R. 1977. Conservation tillage in the Northern Plains. J. Soil Water Conserv. 32:37.

Fenster, C.R. 1980. Soil management for rainfed wheat production. p. 306-323. Proc. 3rd International Wheat Conf. Madrid, Spain, May 1980.

Fenster, C.R., H.I. Owens, and R.H. Follett. 1977. Conservation tillage for wheat in the Great Plains. USDA-ES. PA 1190. U.S. Gov. Print. Office, Washington, DC.

Fenster, C.R., and G.A. Wicks. 1974. Know and control downy brome. Nebr. Ext. Cir. 74-188.

Ghosheh, J. 1975. Durum wheat in Jordan. p. 345-349. Proc. Third Regional Wheat Workshop. FAO/Rockefeller Foundation, Tunis, Tunisia.

Good L.G., and D.E. Smika. 1978. Chemical fallow for soil and water conservation in the Great Plains. J. Soil Water Conserv. 33:89-90.

Greb, B.W. 1983. Water conservation: Central Great Plains. *In* H.E. Dregne and W.O. Willis (ed.) Dryland agriculture. Agronomy 23:57-73.

Greb, B.W., and C.R. Fenster. 1981. Water used by weeds in a wheat-fallow system. University of Nebraska, NebGuide G80-533. Lincoln, NE.

Greb, B.W., D.E. Smika, and A.L. Black. 1970. Water conservation with stubble mulch fallow. J. Soil Water Conserv. 15:281-284.

Greb, B.W., D.E. Smika, N.P. Woodruff, and C.J. Whitfield. 1974. Summer fallow in the Central Great Plains. p. 51-85. *In* Summer fallow in the western United States. USDA-ARS Conserv. Res. Report No. 17. U.S. Gov. Print. Office, Washington, DC.

Hepworth, H.M., W.L. Andersen, T.G. Zinn, and F.V. Pumphrey. 1975. More wheat from fallow farming. USAID Oregon State University, Ankara, Turkey.

Hurst, H.R., and K.C. Feltner. 1966. Grain sorghum—weed competition. Influence of weed density and time of removal on crop yield. Weed Sci. Assoc. Abstr. p. 57.

Knake, E.L., and F.W. Slife. 1966. Control those weeds early. Illinois Res. 8:8-9.

Lomas, J. 1972. Forecasting wheat yields from rainfall data in Iran. World Meteorol. Org. Bull. 21:9-14.

Marten, G.C., and R.N. Andersen. 1975. Forage nutritive value and palatability of 12 common annual weeds. Crop Sci. 15:821-827.

Reitz, L.P. 1976. Wheat in the United States. USDA-ARS. Agric. Information Bull. 386. U.S. Gov. Print. Office, Washington, DC.

Shaidee, G. 1974. Conservation, rehabilitation and improvement of rangelands in Iran. Iran Min. Agric. and Nat. Resources.

Unger, P.W. 1984. Tillage systems for soil and water conservation. FAO Soils Bull. 54. FAO, Rome, Italy.

Unger, P.W. 1983. Water conservation: Southern Great Plains. *In* H.E. Dregne and W.O. Willis (ed.) Dryland agriculture. Agronomy 23:35-57.

Wicks, G.A., and D.E. Smika. 1973. Chemical fallow in a winter wheat-fallow rotation. Weed Sci. 21:97-100.

Storage and Retention of Water During Fallow

R.I. Papendick
U.S. Department of Agriculture, Agricultural Research Service, Pullman, Washington, USA.

ABSTRACT. A major purpose of fallow in the dryland areas is to increase the supply of water for the subsequent crop. This is usually accomplished by storing precipitation during a rainy season for carryover to the next crop. One of the main limitations with many fallow systems is low storage efficiency. With some of the older systems, one-fifth or less of the precipitation is conserved in the Great Plains, United States, and about one-third is conserved in the Pacific Northwest. With newer systems of tillage and improved weed control, efficiencies can be doubled. Basically, two things must be accomplished to achieve high fallow efficiency: 1) the precipitation must infiltrate the soil; and 2) the soil water must be retained, often under high evaporative demand. Infiltration rates are generally maximum when the soil is left rough and covered with residue during the rainy season. Tillage for this purpose should be accomplished ahead of rains. Evaporation control is best achieved with surface residues during the rainy period and establishing a loose soil mulch just ahead of a dry season. Tillage during intermittent rains can increase evaporation and should be avoided except to kill weeds. Weed control should be accomplished with chemicals as much as possible during the time when maximum moisture storage is occurring.

Introduction

Water conservation is usually the most important practice in dryland soil management. The main approaches to conserving water usually involve 1) holding the precipitation where it falls or is collected from watershed areas, 2) infiltrating the water into the soil, and 3) minimizing evaporative losses of stored soil water. In some situations, an important objective of soil management is to conserve water in the seedzone for rapid crop establishment.

Seldom in dryfarming is precipitation sufficient or adequately distributed during the growing season for production of economical crop yields. Thus, it is usually necessary to have stored soil water available to supplement the limited amount of growing season rainfall.

Fallow

Fallowing is a common practice in dryland agriculture for storing water in the root zone for the subsequent crop. During fallow, the land is usually left in stubble with tillage used to control weeds, improve infiltration and retention of water, and prepare a seedbed. Alternatively, weeds may be controlled with herbicides, or combinations of tillage and herbicides. In some regions the fallow period serves additionally to provide stubble and weeds for livestock grazing, or to increase soil fertility through mineralization of organic matter. However, unless nutrients are recycled or supplied from outside sources such as fertilizer, manure, or nitrogen fixation, the fallow system becomes an exhaustive process, and the fertility will decline as nutrients are depleted through crop removal.

The length of the fallow period may vary widely in the different dryland regions. For example, it may be several crop years for each crop year in the semiarid tropics of Africa, half a year in the dry season of India, one to nearly two years in the continental regions, and one-half to one year in the Mediterranean regions. However, with increasing human populations and more pressure to produce food, the fallow periods are generally becoming shorter, which means in most cases less water to grow a given crop and a more rapid decline in soil fertility.

The basic types of cultivated fallow include clean or bare fallow, and stubble mulch fallow. Clean fallow is accomplished with tillage that buries most of the crop residue and weeds. With this practice the soil is often highly vulnerable to serious wind and water erosion. Stubble mulch fallow is accomplished with undercutting implements for maximum retention of surface residues while controlling weed growth at the same time. Chemical or reduced tillage fallows are newer practices that rely on herbicides to replace several or all tillage operations during the fallow period. With some of the newer herbicides, weeds can often be controlled more effectively with chemicals than tillage, and the fuel energy used in weed control with herbicides is less than that used with tillage.

The greatest problem with fallow systems for water conservation is to control weeds without causing serious soil erosion. Both wind and water erosion are generally increased by intensive tillage practices used for weed control. Frequent tillage and tillage of wet soils may also increase soil compaction.

Fallow Efficiency

There is often much controversy over the moisture-conserving value of fallow. It is well known that with many soil management systems fallow efficiencies are very low. Fallow efficiency is defined as the percentage or fraction of the total precipitation received during the fallow period that is stored in the soil for the subsequent crop. Studies in the dryland areas of the Great Plains, United States, show that over a range of practices only 16 to 20 percent of the precipitation during the fallow period is stored in the soil. Results with cultivated fallow in Canada and Australia show even lower efficiencies, often less than 10 percent. With intensive grazing and weedy fallow the efficiency may approach zero. Nevertheless, where water is saved, though inefficiently, there is more dependable crop establishment and stable yields.

Fallow efficiencies up to 50 percent or more are possible with new technology including effective weed control and improved tillage practices that maintain adequate soil cloddiness and surface stubble to maximize infiltration and minimize evaporation. Table 1 presents soil water storage efficiencies for several different fallow systems in the central Great Plains. With the older systems of soil management (primarily moldboard plow based agriculture) using 7 to 10 tillage operations, one-fifth or less of the precipitation is conserved during the fallow period. Fallow efficiencies are increased as the number of tillage operations is reduced and more stubble is retained on the soil surface. It is highest with no-till and full weed control with herbicides.

Winter wheat yields in the central Great Plains dryland areas have more than tripled over the past several decades. Improved water conservation techniques account for about 45 percent of this increase (Greb, 1979).

Factors Affecting Fallow Efficiency

A number of factors affect the water storage efficiency during fallow. These include precipitation and temperature patterns, weed control, soil characteristics, length of the fallow period, crop residues, and tillage and crop residue management. Precipitation, temperature, and soil characteristics are not directly subject to man's influence but the effects of these factors on soil water storage can be strongly influenced by management methods.

Precipitation and Temperature Patterns

Form of precipitation (snow or rain), rainfall intensity, and time of year during which the rainfall occurs are often just as important to conservation as the amount that falls. Snow precipitation is generally stored much more efficiently than rain except possibly when the soil is deeply frozen. High intensity and/or widely spaced rains may provide little available water for the crop because of high runoff and/or high evaporation compared with the same amount of water falling in one slow rain. Winter rains, such as those which occur in the

Table 1. Effect of Different Tillage Systems on Fallow Efficiency at Akron, Colorado, United States (Greb, 1979).

Tillage System	Years in Use	Number of Tillage Operations	Efficiency†
Maximum tillage plow and harrow	1915-30	7 to 10	16 to 22
Conventional bare shallow disk, rodweed or harrow	1931-45	5 to 7	20 to 24
Modified conventional disk (once) chisel, rodweed	1946-56	4 to 6	24 to 27
Stubble mulch sweep, rodweed	1957-70	4 to 6	27 to 33
Minimum tillage herbicide to replace one or more tillages	1968-77	2 to 3	33 to 38
No-till herbicides only	1975-77	0	45 to 55

† Defined as the percentage of precipitation stored in the soil.

Mediterranean climate of the Near East region, are potentially more efficient for water storage than summer rainfall. For example, in the Sahelian countries south of the Sahara, water losses are increased due to higher temperature and evaporation during the rainy period. Moreover, in the winter rainfall climate, rains tend to be more reliable and less intense than summer rainfall and, hence, more effective for recharging the root zone.

Weed Control

The importance of weed control to water conservation in dryland agriculture cannot be overemphasized. Before modern herbicides, weed infestations accounted for nearly 50 percent of the crop losses from pests in the United States (Crofts, 1975). The effect of weed control on crop yields is clearly illustrated by changes in farming practices in western Nebraska. Prior to 1940, weeds were not controlled during the overwinter and spring of the fallow period, and stubble and weed growth were intensively grazed by cattle and sheep. After the grazing period in late spring, several spring-summer tillage operations were carried out to kill remaining weeds and to prepare a seedbed for fall planting. Winter wheat yields nearly tripled and became more secure from drought during the 1940s after

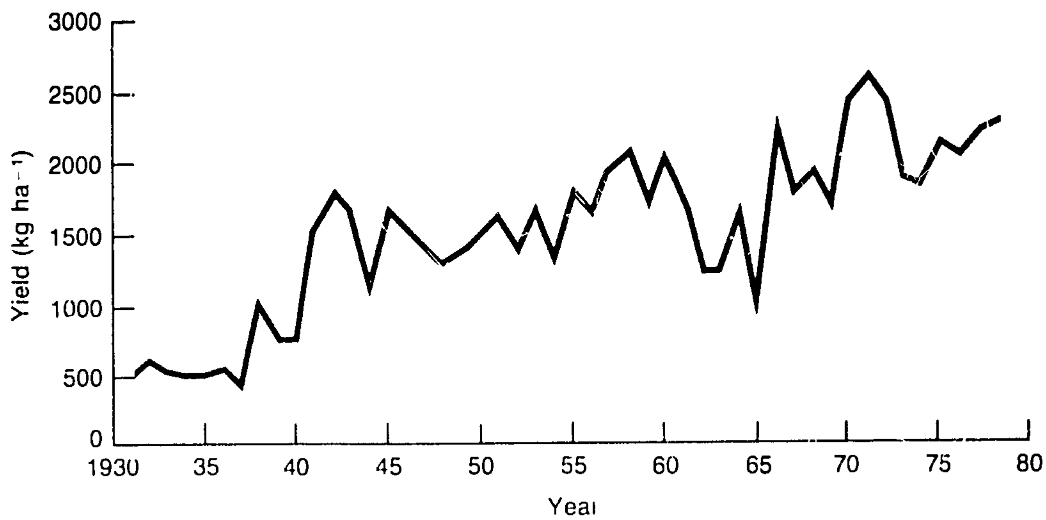


Figure 1. Average Winter Wheat Yields in Western Nebraska over Time. The Sharp Increase in Yields during the Early 1940s Occurred when the Practice of Stubble Grazing was Decreased and Weeds were Controlled over the Whole Fallow Season.

farmers adopted a fallow system that eliminated grazing and controlled all plant growth between crops with cultivation and or herbicides (Figure 1). The marked increase in wheat yields was due mainly to increased available water and increased fertilizer use to take advantage of the additional water. Although retention of surface stubble was important in increasing stored water, there was obviously a large loss of water in the pre-1940 system from weed transpiration. Greb *et al.* (1979) cited research showing that growth of volunteer wheat and arable land weeds in the central Great Plains, produced from 900 to 2700 kg of dry matter in undisturbed stubble following wheat harvest and during certain times heavy infestations consumed 5 mm of water per day. Production of 1120 kg of weed dry matter requires about 76 mm of water that could otherwise produce 700 to 1300 kg of wheat grain per ha.

For effective water conservation, weeds must be controlled at an early growth stage. With cultivation, weeds are easiest to kill on the first tillage pass. Poor weed control early in the fallow period results in weeds developing a dense root system near the soil surface. Not only is much water lost but the large weeds are then very difficult to kill with tillage or herbicides.

Tillage has long been the traditional method for controlling weeds during fallow. During the recent decades, the development of new herbicides and application methods has made it more practical for many dryland farmers to use chemicals in lieu of tillage for weed control, and thereby conserve surface residues more effectively for water conservation and erosion control. Moreover, cost benefits have made it advantageous to substitute herbicides for tillage under some dryland farming conditions.

Length of Fallow

Generally the efficiency of fallow decreases with increase in length of the fallow period; however, to be effective the fallow period must be long enough for sufficient precipitation to recharge the root zone. In the Pacific Northwest, which has a Mediterranean type climate, storage efficiencies during the first winter of fallow range from 50 to 70 percent of the precipitation received. Efficiencies the second winter, where either winter wheat has been fall planted or the fallow is carried over for a spring crop (planted 21 months after harvest of the previous crop), are about one-half of this amount. First winter storage is high because the soil is initially dry, and hence very receptive to water intake, and there is a full complement of surface stubble (Leggett *et al.*, 1974). There is less soil water storage the second winter because most of the crop residues have either decomposed or been buried by tillage. In addition, the infiltration rate continually decreases as the soil profile recharges. Surface aggregation is also not as good the second as the first winter because of breakdown by cultivation. These effects result in increased runoff and greater evaporation losses. Soils also freeze in the Pacific Northwest and wet soils (the second winter) tend to remain frozen longer and are less permeable to water than dry soils, which also increases runoff.

Figure 2 shows a relationship between antecedent soil moisture and subsequent recharge for the Pacific Northwest. The figure shows that as the amount of water stored during the first winter of fallow increases (horizontal axis) there is a linear decrease in the amount of water stored the second year (vertical axis). In other words, the fallow efficiency generally decreases as the length of the fallow period is increased.

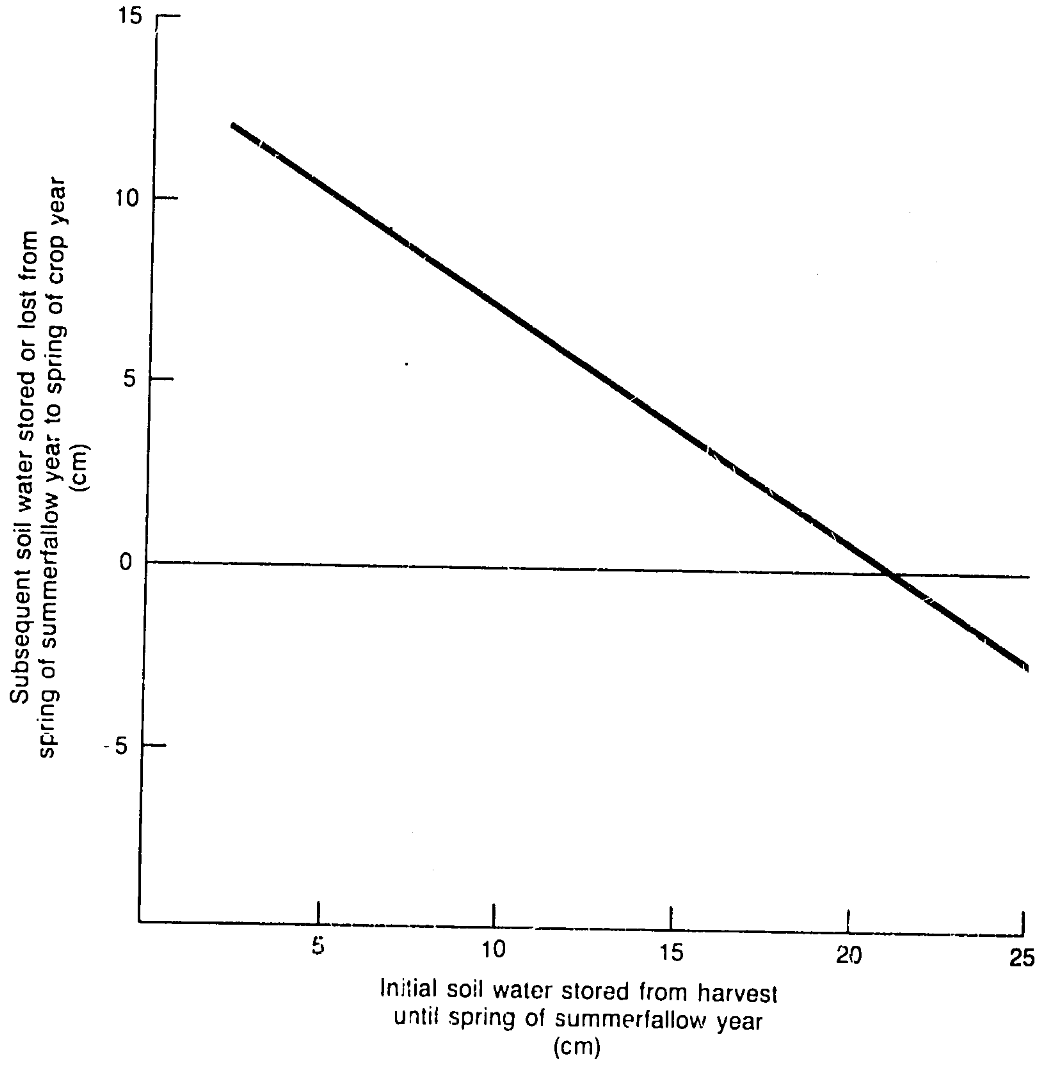


Figure 2. Water Stored or Lost after the First Winter of Fallow as Related to the Amount of Water Stored during the First Winter Period in the Pacific Northwest, United States (Leggett *et al.*, 1974).

Table 2. Final Infiltration Rates on a Silt Loam Soil. A Total of 16.25 cm of Water Applied Over Four Runs at an Intensity of 5 cm h^{-1}. (Mannering and Meyer, 1963)

Mulch Rate	Runoff	Total Infiltration
t ha⁻¹	*cm*	*cm*
0	7.1	8.7
0.6	6.3	9.5
1.1	3.8	11.9
2.2	0.8	15.1
4.5	0.2	15.6
9.0	0	15.9

Crop Residues

Mulches of crop residues can enhance water conservation in two ways: 1) by increasing infiltration of water into unsaturated soil when rainfall intensity exceeds the intake rate on bare soil; and 2) by slowing evaporative loss when the soils are wet, hence allowing more time for infiltration. The effectiveness of crop residues for conserving water is limited in many areas because of the meager amounts generally produced by dryland crops. Even with stubble mulch, tillage, or chemical fallow, water gains are sometimes small because the residue amounts are too low to effectively enhance infiltration and decrease evaporation.

Nevertheless, relatively small quantities of surface residues, if properly managed, can increase infiltration, especially during moderately intense and intense rains. Table 2 shows that with simulated rainfall, 0.6 t ha^{-1} of mulch increased infiltration compared with bare soil and that 2.2 t ha^{-1} of mulch was as effective as greater amounts of residues (Mannering and Meyer, 1963). With low amounts of residues, placement (flat vs. standing stubble) may be an important factor in determining effectiveness for infiltration.

Surface residues are most effective in suppressing evaporation during the rainy season. As drying proceeds, the effect of the straw mulch diminishes and becomes greatly reduced once the upper soil layers have dried. Greb (1966) showed in laboratory studies that surface applications of wheat straw at rates of 1.1, 2.2, and 3.4 t ha^{-1} (equivalent to 30, 60, and 90 percent surface coverage) reduced water losses from an initially wet soil by 16, 33, and 49 percent, respectively, over a 20-day period as compared with loss from bare soil. These types of experiments also show that the effectiveness of the mulch in suppressing evaporation diminishes with time after drying. Black (1979) conducted field studies with straw mulch rates up to 6.7 t ha^{-1} and found that available water at the end of the fallow period was increased by 5 mm t^{-1} of straw mulch. Similarly, Unger (1978) in the southern Great Plains, and Greb *et al.* (1970) in the central Great Plains, showed in field studies that average available stored water after the fallow period increased significantly and was positively correlated with increasing residue levels. The Greb *et al.* (1970) study showed that most of the benefits from residues accrued during the winter and when the interval between rains was short. Their studies also showed that snow catch by stubble was also an important source of stored water.

Tillage Practices

Tillage during fallow should be designed to facilitate water absorption during precipitation and water retention during periods between precipitation events. Moreover, the number of tillage operations should be kept to a minimum for the purpose of erosion control and reducing farming costs. Where runoff is a problem, tillage may be necessary to increase the infiltration rate and enhance water penetration into the deeper layers. Water intake rates and retention in the surface layers can be increased by tillage which leaves the surface residue covered and rough with large depressions on the surface for ponding water. Concentrating water temporarily in pockets promotes deeper penetration.

Tillage for the purpose of increasing infiltration should be accomplished ahead of the rainy season with best results when the soil is relatively dry. Chisel plows or blade-type implements will create depressions and leave residues on the surface. A new type of implement that shows promise for reducing runoff is the Paraplow manufactured by the Howard Company in the United Kingdom.† The machine is designed with an undercutting action to break traffic or compaction zones while creating very little disturbance to the soil surface and to crop residues on the surface. It especially appears to have potential for improving water infiltration in areas with sloping soils, low amounts of surface residues, and low water intake rates.

When rainfall becomes less frequent or ceases for the season, some tillage may be necessary to slow evaporation and prevent losses from the deeper soil layers. Cultivation breaks capillary continuity with the subsoil layers and hastens formation of a surface dry layer. Tillage for this purpose should be carried out before high summer temperatures occur. The loose soil mulch slows evaporation from the seedzone layer and kills any weeds that have escaped previous tillage or herbicide application. Tillage may have to be repeated to reestablish the soil mulch if rains reestablish liquid continuity through the previous tillage layer.

Soil Type

Soil type can influence water storage and retention during fallow through both water-holding characteristics and conductivity properties. Sands have much less capacity to hold water than silts or clays, but sands generally have much higher infiltration rates than finer textured soils. Moreover, during extended dry periods and high potential evaporation, sands will lose much less water than silts or clays because of their low water-holding capacity and rapid decrease in conductivity upon drying.

Figure 3 shows a computer simulation of change in water content starting with field capacity for a sand, silt, and clay soil during a 20-day period of high evaporative demand. Note that water loss occurs progressively at deeper depths with shift from sand to the finer textured soils. This occurs because the silt and clay soils are at higher water contents initially and maintain higher unsaturated conductivities over a wider range of water contents than the sand and therefore maintain higher rates of liquid flow over deeper depths. The net effect is that sandy soils generally retain water more efficiently than silts or clay soils during extended drying. One reason that fallow efficiencies are relatively high in the Pacific Northwest is that most of the dryland soils are coarse-textured (fine sandy loams that border or grade into silt loams) and lose liquid continuity rather rapidly upon drying. Water conservation is much more difficult on clay soils because upward movement of water from deep layers to the surface can continue at relatively high rates for a long time.

---

†Trade names and company names are included for the benefit of the reader and do not imply endorsement or preferential treatment of the product by the U.S. Department of Agriculture

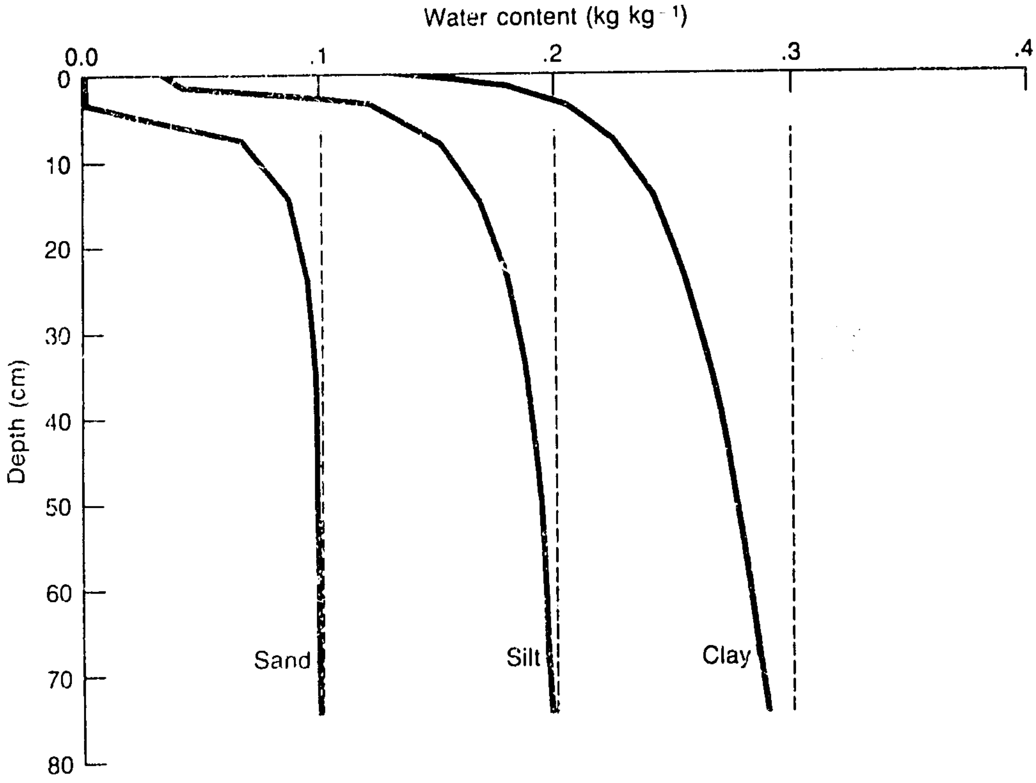


Figure 3. Computer Simulation of Water Content Profiles for Sand, Silt, and Clay after Being Subjected to a Period of High Evaporative Demand. The Vertical Dash Lines Represent the Field Capacity Water Content at the Start of the Drying Simulation.

Because of differences in capacity and conductivity relationships, water conservation measures for different soils may require different tillage managements. For example, a tillage mulch is much more important for conserving water for a clay soil during extended hot, dry weather than for a sandy soil. The same is true for infiltration during rainy weather because sands are more porous and have higher infiltration rates than clay soils.

Retention of Seedzone Water

An important goal in some dryfarming systems is to maintain adequate water in the seedzone during fallow for rapid establishment of the crop after planting. This is particularly so where the planting season follows a dry summer and it is desirable for agronomic reasons to establish the crop ahead of fall or winter rains. Such is the case in the dryland wheat region of the Pacific Northwest where the rainy season does not begin until late fall or early winter after temperatures have cooled considerably. Establishment of crops in late summer (August or early September) with deep furrow seeding can increase winter wheat yields by 50 percent or more compared with late planting because of improved water use efficiency. Successful early establishment relies on carryover of seedzone moisture from the previous winter through the hot, dry, summer fallow period.

Research conducted in the Pacific Northwest wheat region shows that a fine tillage mulch is highly effective for conserving seedzone water over summer for early establishment of winter wheat (Hammel *et al.*, 1981; Lindstrom *et al.*, 1974; Papendick *et al.*, 1973). The mulch must be established after the soil begins to dry in the spring and well before the onset of hot, dry weather. Initial tillage is carried out with a sweep plow or heavy tandem disk to a depth of 20 cm. Subsequent operations are with a rodweeder, which firms the soil at a depth of 13 to 15 cm and leaves loose soil above. Firming the soil below the depth of tillage establishes liquid continuity between the seedzone and the moist subsoil layers. The tilled layer breaks capillary continuity between the surface layer and the seedzone and, in addition, thermally insulates the seedzone. The insulation effect of a fine tillage mulch is sufficient to slow evaporation from the seedzone so that losses of water by diffusion through the dry layer are replenished by upward liquid flow from the subsoil. This keeps the seedzone from drying out and the water content fairly constant and adequate for germination for a long time even under high evaporative demand.

The tillage mulch is less important on sandy soils that have a tendency to self mulch upon drying. It is especially effective in conserving seedzone water in soils of high silt or clay content which form cracks as they dry out.

Experiments with early fall establishment on chemical fallow (no-till) have often been unsuccessful because the untilled soils tend to dry out too deeply by seeding time (Lindstrom *et al.*, 1974). Exceptions occur if timely rains occur just ahead of planting to sufficiently wet the seedzone. Research has also shown that a cloddy mulch is less effective for conserving seedzone water during dry conditions than a fine mulch (Papendick *et al.*, 1973). This is probably a result of greater convective transfer of heat and water vapor in rough-tilled soil where there is a preponderance of large voids interconnecting the seedzone with surface.

Conservation Tillage Systems

Conservation tillage is a concept of farming designed to reduce energy requirements, to protect the soil from erosion, and increase water infiltration into soil without reducing crop yields. It is not a new concept and was first advocated for semiarid regions many years ago for economic reasons. The U.S. Department of Agriculture definition of conservation tillage is "methods of farming that maintain adequate plant cover or residue on the land to conserve soil and water while reducing labor, energy, and capital." The main approach to conservation tillage is to reduce tillage operations and use practices that conserve surface residues.

With today's agriculture, modern herbicides have made it possible to eliminate some or all of the tillage operations in the fallow system. In many cases this results in more effective weed control, reduced erosion, and improved water conservation. Limitations with conservation tillage systems are herbicide costs, broad-spectrum control of weeds with herbicides, and inadequate equipment for seeding through crop residues or in hard, or rough-tilled seedbeds. Studies in the Pacific Northwest also show that there is greater water loss in the upper 30 cm of soil with chemical fallow (no-till) than with conventional stubble mulch fallow. Because of the importance of breaking capillary continuity in the surface layers during dry weather, chemicals will probably not replace tillage completely for fallow for all soil types. However, some minimizing of tillage should be possible and desirable for both erosion control and water conservation benefits.

Research Needs

There are a number of areas in dryland soil management in need of research to improve fallow efficiency. These include the following:

1) Determine tillage-residue management systems to maximize water conservation under different soil and climatic conditions.

2) Determine the water-conserving benefits of low amounts of crop residues typical of dryland production, and management methods that optimize their value for water conservation.

3) Determine how the value of crop residues for water conservation varies according to rainfall distribution during the fallow season and in relation to amounts of residues present and management methods used.

4) Determine the effect of weed growth (density, species, time of growth during the fallow period) on water loss during fallow.

5) Evaluate tillage-herbicide combinations on water conservation during fallow.

6) Determine the disappearance rate of surface residues for different crop, soil, and climatic conditions and how these rates can be altered by management methods to maximize water conservation.

References

Black, A.L. 1979. Crop residue, soil water, and soil fertility related to spring wheat production and quality after fallow. Soil Sci. Soc. Am. Proc. 37:754-758.

Crofts, A.S. 1975. Modern weed control. University of California Press, Berkeley, CA.

Greb, B.W. 1966. Effect of surface-applied wheat straw on soil water losses by solar distillation. Soil Sci. Soc. Am. Proc. 30:786-788.

Greb, B.W. 1979. Technology and wheat yields in the central Great Plains: Commercial advances. J. Soil Water Conserv. 34:269-273.

Greb, B.W., D.E. Smika, and A.L. Black. 1970. Water conservation with stubble mulch fallow. J. Soil Water Conserv. 25:58-62.

Greb, B.W., D.E. Smika, and J.R. Welsh. 1979. Technology and wheat yields in the central Great Plains: Experiment station advances. J. Soil Water Conserv. 34:264-268.

Hammel, J.E., R.I. Papendick, G.S. Campbell. 1981. Fallow tillage effects on evaporation and seedzone water content in a dry summer climate. Soil Sci. Soc. Am. J. 45:1016-1022.

Leggett, G.E., R.E. Ramig, L.C. Johnson, and T.W. Massee. 1974. Summer fallow in the Northwest. p. 110-135. *In* Summer fallow in the western United States. USDA-ARS Conserv. Res. Report No. 17. U.S. Gov. Print. Office, Washington, DC.

Lindstrom, M.J., F.E. Koehler, and R.I. Papendick. 1974. Tillage effects on fallow water storage in the eastern Washington dryland region. Agron. J. 66:312-316.

Mannering, J.V. and L.D. Meyer. 1963. The effects of various rates of surface mulch on infiltration and erosion. Soil Sci. Soc. Am. Proc. 27:84-86.

Papendick, R.I., M.J. Lindstrom, and V.L. Cochran. 1973. Soil mulch effects on seedbed temperature and water during fallow in eastern Washington. Soil Sci. Soc Am. Proc. 37:307-314.

Unger, P.W. 1978. Straw-mulch rate effect on soil water storage and sorghum yield. Soil Sci. Soc. Am. J. 42:486-491.

Utilization of Crop Residues in Semiarid Regions for Effective Soil and Water Conservation

C.S. Ofori
Food and Agriculture Organization of the United Nations, Rome, Italy

ABSTRACT. The technology for efficient utilization of crop residue for soil and water conservation in semiarid areas has been well-developed in highly mechanized, large-scale agriculture. Research is further needed on various aspects of residue decomposition rate, development of appropriate tillage implements for various soil types and conditions, and the development and testing of new herbicides.

Under small- and medium-scale farm conditions with limited adoption of mechanization, options for the use of crop residues often exist. In such cases the integration of livestock with crop production should be given high priority as an initial step. Planted pastures using grass-legume mixtures should form a vital part of the farming system. Development of tillage implements should be given high priority. Research should be planned to find solutions to local problems, while cautiously attempting to transfer technology from similar agroecological situations. Greater emphasis needs to be directed at the initial stages in optimizing what the farmer can do by himself to ensure success and sustain production.

Introduction

The role of organic matter in the maintenance of soil productivity is well-documented. It contributes to soil physical, chemical, and biological properties and activities, the sum total of which influences to a large extent the productivity of the soil. Soil aggregation, aeration, infiltration rate, cation exchange capacity, availability of plant nutrients, and buffer and microbial activities are very much dependent on the level of organic matter present in the soil.

The main sources of organic matter in cultivated soils are root remains of harvested crops and remains of aerial parts of crops. The latter is, however, not always left on the soil to recycle nutrients that have been taken up by the crops. Depending on the agroecological zone, socioeconomic setting, and the farming systems practiced, these surface residues may find various uses and are often lost completely to the farms.

The development of cropping systems in the various agroecological zones has brought with it problems of resource management, in particular, the conservation of soils for optimum production on a sustained basis. Such problems are more acute in semiarid zones where farming under rainfed conditions has a high risk element because of the variable weather conditions. Soil conservation and, in particular, conservation of adequate moisture, are essential in order to obtain reasonable crop yields.

Crop yields under small farm management in semiarid zones are generally low. Soil and water conservation problems on these farms limit productivity, and consequently, yields of crop residues are low. Resources for developing effective conservation programs are usually meager or nonexistent. The use of crop residues could offer an opportunity to improve soil productivity but the farmer is faced with the choice of alternate uses of the residues produced. Possible strategies for optimizing the use of crop residues for soil and water conservation by medium- and small-scale farmers in semiarid zones of the Near East region are discussed in this paper.

Amount of Residue Produced

The two important grain crops produced in the Near East region are wheat and barley. Wheat grain yields have improved and average 1500 kg ha^{-1} and that of barley 1300 kg ha^{-1} (FAO, 1984). These two grain crops are produced in areas with rainfall of 300 mm or more following two-year or three-year rotations (Tamimi, 1981).†

† In the two-year rotation, wheat is rotated with food legumes such as lentil and chickpeas, while in the three-year rotations wheat, food legumes and summer vegetable crops are rotated in areas with high and reliable rainfall. Fallowing is a common practice in areas with rainfall of 250 mm or less (Tamini, 1981).

Grain yields in semiarid agriculture are influenced by climate, soil, genotype, cropping systems, and soil management. Particularly crucial in determining crop yield is the amount of water available in the soil during the cropping season. Wheat and barley yields in semiarid agriculture could be much higher given adequate water conservation, tillage practices, management systems, and the appropriate and requisite inputs such as fertilizers, pesticides, and herbicides for weed control.

The amount of crop residue produced by a crop bears a relationship to grain yield. In the United States, residue:grain ratios of 1.7 for wheat (Fenster and McCalla, 1970) and 1.5 for barley (USDA, 1975) have been used to estimate crop residue produced. Using these ratios, the amount of crop residue available from wheat and barley yields in the Near East region are 2560 kg ha^{-1} and 1970 kg ha^{-1}, respectively. These quantities appear adequate to contribute partially to soil erosion control under good management and appropriate tillage practices. However, the main problem arises when other options for the use of crop residues in the region are considered.

Crop residue is the main source of animal feed in the Near East region and almost all residue from a winter wheat crop is removed for livestock feeding (Rauzi, 1963). The remaining stubble is grazed by large numbers of sheep let into the fields after harvesting. The overstocking by itself is a potential cause of soil erosion and consequent degradation.

In many areas under rainfed small-scale agriculture in semiarid zones, the use of residues for soil and water conservation is very limited. In addition to livestock feed, alternative uses such as fuel, building, and roofing materials are attractive options which the small farmers rate much higher than the use of the residues for soil and water conservation. In some cases the cash returns from residues may even be higher than from the grains.

The options mentioned above necessarily involve exportation of plant nutrients from the farm lands. Nutrients are often lost to crop production since there is little or no recycling of the nutrients in this type of agricultural system. This situation is further aggravated by the low level of inorganic fertilizer application in semiarid rainfed agriculture. Estimates of nutrients in wheat and barley crop residues produced in the Near East region are given in Table 1.

Crop Residues in Soil and Water Conservation

Crop residue management is intrinsically associated with soil and water conservation practices particularly in large-scale mechanized agriculture in semiarid zones. The various management systems such as leaving the residues on the soil surface, or shallow or deep incorporation into the soil result in different effects on erosion control and conservation of moisture.

Table 1. Estimates of Crop Residue Production, Wheat and Barley, and Nutrient Removal in the Near East Region.

Crop	Grain Yield†	Straw Yield‡	Nutrient Uptake§ N	P	K	Total Area Harvested†	Total Yield of Crop Residue
	kg ha⁻¹					*ha* × 10^3	t × 10^3
Wheat	1,500	2,560	17.2	1.8	24.8	21,500	55,000
Barley	1,310	1,970	14.8	2.2	24.6	7,610	5,000

† FAO (1984), includes irrigated areas.
‡ Straw/grain ratios are: 1.7 for wheat and 1.5 for barley.
§ Average N: P: K concentrations in crop residues are 0.75, 0.11 and 1.25%, for barley and 0.67, 0.07 and 0.97% for wheat, respectively (National Plant and Food Institute, 1962, USA).

Intensive research work on tillage systems coupled with the development of planting and tillage implements has contributed greatly to the effective utilization of crop residues in dryland farming. Another major contribution is the remarkable progress made in recent times in the development of herbicides.

The effect of crop residues on runoff has been well-covered by Onstad and Otterby (1979). Residues left on the soil surface contribute in various ways to water conservation and crop production by intercepting the impact of rain drops and thereby reducing soil surface deterioration, increasing rainfall infiltration, decreasing evaporation from the soil surface, and reducing excessive temperatures during hot periods. Other advantages include provision of organic carbon for soil microorganisms, soil organic matter, and nutrients. Surface-applied crop residues check wind and water erosion depending on the amount of residue applied.

Residues left on the soil surface show disadvantages such as their effect on the nitrogen status of the soil (Smika *et al.*, 1967) and lowering of surface temperatures below the optimum for germination in cold climates (Greb *et al.*, 1970). Release of toxic substances upon decomposition could also be a major problem to germinating seeds (Norstadt and McCalla, 1968).

Van Doren and Allmaras (1978) pointed out that the potential benefits of residues on crop yield depend upon initial soil physical conditions, soil drainage, precipitation quantities and distribution, amount, kind and disposition of crop residues, and ability to establish a desirable crop and maintain satisfactory weed control. This underscores the cautious approach essential in transferring the results obtained under one set of conditions to other situations without careful evaluation.

Considering the relatively scarce quantities of residue available in semiarid regions, the crucial question of quantity of residue required to achieve the desired soil conservation effect becomes important. Woodruff *et al.*, (1977) point out that different crops vary in the effectiveness of their residue to provide sufficient cover to prevent wind erosion as shown in Table 2. It is evident from the data that wheat residue is more effective in preventing wind erosion than sorghum residue.

Table 2. Kilograms of Residue Required per Ha to Hold Wind Erosion to a Tolerable Level of 11 Mg Ha^{-1} Yr^{-1}

Soil Texture†	Wheat Residue		Sorghum Residue		Growing Wheat	
	Standing	Flattened	Standing	Flattened	In Furrow	On Smooth Ground
	kg ha^{-1}					
Silts	500	1040	2020	2910	560	480
Clay and silty clay	900	1790	3700	5320	1090	920
Loamy fine sands	1180	2380	4700	6940	1340	1120

† Silts with 50% nonerodible fraction greater than 0.84 mm in diameter, clay and silty clay with 25% nonerodible fractions, loamy fine sand with 10% nonerodible fractions.

The quantity of straw adequate for effective moisture conservation is important. Unger (1978) found one ton of straw per ha in sorghum fields conserves soil moisture without decreasing soil temperature to a level where germination is affected. Black (1970) obtained the best results with wheat yields using 1680 kg ha^{-1}. Equations developed by Singer and Blackard (1977) provide an efficient method of estimating amounts of crop residues required for different management situations.

The method of residue placement, the control of weeds, and the type and number of tillage operations influence the effective residue coverage of the soil. Management systems, therefore, play a decisive role in the effectiveness of the limited straw available. Under Near East conditions, it would appear that if all the crop residue were to be used as surface soil application (Table 1) under good management and similar climatic and soil conditions, some degree of soil moisture conservation and erosion control could be achieved as practiced in the United States.

Various factors affect the quantity of residue remaining on the soil surface after its application. Among these are climate, tillage operations, soil type, loading rate, and the microbial biomass associated with residue decomposition. The rate of decomposition of crop residues affects the effective coverage of the soil surface by the residue for erosion control. Residue on the surface will not decompose as rapidly as that which is buried in or incorporated into the soil. Chemical composition and those factors that affect the soil environment influence the decomposition rate. Other factors that have the greatest potential for altering the rate of decomposition in the soil are those that affect microbial growth and activity (Parr and Papendick, 1978). Knowledge of decomposition rates is essential so that residue management systems can be devised to control the rate of decomposition minimizing wind and water erosion and nutrient runoff losses (Elliott, 1986; Parr and Papendick, 1978).

In some areas of the semiarid zones, termites play an important role in residue decomposition, especially in warmer climates. Termites travelling below the soil surface utilize crop residue for food. Much of the residue left on the soil surface for erosion control is consumed before the next cropping season. The soil with no cover is thus left unprotected at the start of the rains and is more vulnerable to water erosion. Termite damage to growing crops could also be serious in some areas. Work carried out in East Africa showed that the humus content of the soil could have much effect on the severity of termite attack on crops. (Harris, 1954).

Crop residue management by either incorporation or burying it in the soil is largely dependent on the availability of appropriate farm machinery and draught power. These residue management systems are less effective as soil erosion control measures. However, residue recycling increases soil productivity through increased organic matter, improved soil structure and water infiltration, and enhanced microbial activity and supply of plant nutrients upon decomposition. Results of long-term experiments conducted in semiarid areas in the United States, with annual rainfall of 280 mm for a period of 18 years, showed a net gain of organic matter under conditions of returned residues (Smith *et al.*, 1946).

Strategies for Maximum Utilization of Crop Residues

Mechanized Farms

Much research on the utilization of crop residue for erosion control and moisture conservation in semiarid agriculture has been carried out in the last three decades in the United States (Oschwald, 1978; Dregne and Willis, 1983). The development of special tillage and planting equipment coupled with progressive adoption of no-tillage or minimum tillage practices has contributed to the efficient use of crop residue in soil and water conservation. Furthermore, specialization of farm enterprises in either crop or animal production has resulted in noncompetitive uses of crop residue on farm lands. In some of those farms excess residues are often burned causing air pollution and other environmental problems resulting from lack of soil protection (Parr and Papendick, 1978).

Although a large volume of research data is available under highly developed and mechanized agricultural practices, more research on crop residue management under semiarid conditions is advocated to promote its wider application. Possible lines of approach have been summarized by Parr and Papendick (1978). These include:

1) Evaluation of the quantity of residue actually needed to protect the soil from erosion and to maintain its tilth and productivity.

2) A thorough understanding of the factors affecting the decomposition of the residues by microorganisms.

3) Determination of the nature of phytotoxic constituents resulting from the decomposition of crop residue and possible breeding and selecting crop varieties specifically for conservation-tillage systems.

4) Monitoring of plant diseases and insect and rodent infestation.

5) Development of tillage and harvesting machinery to achieve desired residue management objectives.

Small- and Medium-Size Farms

In large parts of the world, food production is mainly on small- and medium-size farms. The use of farm machinery is very much limited on these farms, and in some cases, nonexistent. Crop residues generated from these farms are hardly utilized for soil erosion control. Such residues have high values as feedstock or sometimes domestic fuel. In the Near East, for example, winter wheat residue is mainly fed to sheep. There is at the same time the urgent need for conservation practices to control some of the serious erosion problems in the region.

One of the possible strategies of developing efficient utilization of crop residue to maintain soil productivity in semiarid areas is through the integration of livestock into the farming system. Planted pastures could form a part of the crop rotation and the residue could be fed to the livestock. The manure produced could be applied to the land for maintenance of soil fertility.

Effect of Fallows

Fallowing is practiced in large parts of semiarid zones as a means of conserving soil moisture. The water storage efficiency of various fallows may differ greatly depending on the management system, i.e., weed control, straw mulch management, and the number of tillage operations. Smika and Whitfield (1966) and Smika and Wicks (1968) gave water storage efficiencies for the Central and Northern Great Plains of the United States as 25 to 45 percent. Figures quoted by Evans and Lemmon (1957) and Leggett *et al.* (1974) for the Great Plains range from 15 to 33 percent.

Large areas of rainfed agricultural lands are fallowed in the Near East region. Smith (1979) estimated that 55 percent of the rainfed lands are left in fallow each year. Loizides (1979) pointed out that the fallow estimates for the Near East region are inflated and that these might include land cropped at irregular intervals in the 200 to 250 mm rainfall zone as well as nonagricultural marginal lands devoted to rough grazing in the higher rainfall areas.

Improved methods of fallowing significantly increase the yields of succeeding crops. Greb (1980) reported that the yield of wheat from a wheat/fallow rotation in the Central Great Plains (United States) was doubled in the last forty years. Similar increases in wheat yield resulting from fallows were obtained in Australia. Loizides (1979), however, reported that under a Mediterranean climate fallow does not result in any significant increase in the amount of water available to the next crop. The reasons underlying this are not clear and the subject merits greater attention. Some of the fallows in the region could be profitably replaced by planted forage legumes such as medics and clover in rotation with winter cereals.

The introduction of the ley farming system of Australia in some of the countries in the region holds much promise for more effective utilization of the fallows. Such farming systems, if well-managed, enhance organic recycling in the agricultural system and increase soil productivity.

Tillage and Weed Control

Tillage implements have a major influence on the utilization of crop residues for soil and water conservation. Tillage provides means by which crop residues are managed, that is, left on the surface, mixed in the shallow layers or buried beneath the soil surface. In agricultural systems where simple implements are in use without even animal draught power, crop residues, if available, are usually burnt to enable the farmer to reduce his labor input into seedbed preparation. The development of tillage implements and the adoption of appropriate tillage methods are closely linked. Strategies for efficient use of crop residue for soil and water conservation must therefore, first and foremost, be worked out to solve tillage problems in the specific agroecological zones. The increasing rate of adoption of conservation tillage or no-tillage systems in the semiarid areas of the United States, the great advances made in the development of appropriate tillage implements, and more effective herbicides have contributed to greater and more efficient management of crop residues for soil erosion control and conservation.

Weed control is a major problem facing the small farmer, particularly in semiarid zones with severe crop weed competition for the limited amount of moisture available. Research into suitable, less expensive herbicides needs to be carried out as a part of conservation tillage development.

The need for training cannot be over-emphasized in the overall development of conservation tillage and efficient utilization of crop residues. Tamimi (1981) pointed out the substantial contribution that the misuse of farming machinery and lack of training of operators has made to the problem of soil degradation in the Near East region.

A direct transfer of technology unfortunately does not always provide the appropriate solutions to the problems in other semiarid areas. The approach should be to develop suitable, well-coordinated research programs taking into consideration socioeconomic conditions, and particularly farmers' practices. Krishnamoorthy (1980) pointed out that for technology transfer to be useful to a small farmer, the first approach would be to optimize what the farmer can do by himself.

A research program based on the team approach is necessary to test some of the solutions to crop residue management problems already obtained under well-developed, highly mechanized agricultural systems in other semiarid zones. At the same time new programs should be developed based essentially on problems specific to the local conditions.

References

Black, A.L. 1970. Soil water and soil temperature influence on dryland winter wheat. Agron. J. 62:797-801.

Dregne, H.E., and W.O. Willis. (ed.) 1983. Dryland agriculture. ASA, CSSA, SSSA, Madison, WI, USA.

Elliott, L.F. 1986. Influence of tillage on organic matter dynamics and plant nutrient availability. *In*: FAO Tillage Bull. FAO, Rome, Italy.

Evans, C.E., and E.R. Lemon. 1957. Conserving soil moisture in soil. p. 340-359, *In* Yearbook of agriculture. USDA, U.S. Gov. Print. Office, Washington, DC.

FAO. 1980. Rainfed agriculture in the Near East and North Africa. FAO, Rome, Italy.

FAO. 1984. 1983 Production yearbook. FAO, Rome. Italy.

Fenster, C.R., and T.M. McCalla 1970. Tillage practices in Western Nebraska with a wheat fallow rotation. Nebraska Agric. Exp. Stn. Bull. 507.

Greb, B.W. 1980. Technology and dryland winter wheat yields in the semiarid Central Great Plains of USA. p. 144-147. *In* Int. Congress on Dryland Farming. Vol. 1. Adelaide, S. Australia (Working paper).

Greb, B.W., D.E. Smika, and A.L. Black. 1970. Water conservation with stubble mulch fallow. J. Soil Water Conserv. 25:58-62.

Harris, W.V. 1954. Termites and tropical agriculture. Trop. Agric. Trinidad 31.

Krishnamoorthy, C. 1980. Cropping systems for optimum utilization of resources under semiarid conditions. p. 126-138. *In* Rainfed agriculture in the Near East and North Africa. FAO, Rome, Italy.

Leggett, G.E., R.E. Ramig, L.C. Johnson, and T.W. Massee. 1974. Summer fallow in the Northwest. p. 110-135. bIn Summer fallow in the western states, USDA-ARS Conserv. Res. Report No. 17. U.S. Gov. Print. Office, Washington, DC.

Loizides, P. 1980. Crop rotations under rainfed conditions in a Mediterranean climate in relation to soil moisture and fertilizer requirements. p. 23. *In* Rainfed agriculture in the Near East and North Africa. FAO, Rome, Italy.

Norstadt, F.A., and T.M. McCalla. 1968. Microbially induced phytotoxicity in stubble mulched soils. Soil Sci. Soc. Am. Proc. 32:241-245.

Onstad, C.A., and M.A. Otterby. 1979. Crop residue effects on runoff. J. Soil Water Conserv. 34:94-96.

Oschwald, W.R. (ed.) 1978. Crop residue management systems. ASA, CSSA, SSSA, Madison, WI.

Parr, J.F., and R.I. Papendick. 1978. Factors affecting decomposition of crop residues by micro-organisms. *In* Crop residue management systems ASA, CSSA, SSSA, Madison, WI.

Rauzi, F. 1963. Water intake and plant composition as affected by differential grazing on rangelands. J. Soil Water Conserv. 18:114-116.

Singer, M.J., and Blackard. 1977. Evaluation of wild oats straw as a soil erosion retardant using simulated rainfall. Agron. J. 69:811.

Smika, D.E., and G.O. Wicks. 1968. Soil water storage during fallow in the 1968 Central Great Plains as influenced by tillage and herbicide treatments. Soil Sci. Soc. Am. Proc. 32:591-595.

Smika, D.E., A.L. Black, and B.W. Greb. 1967. Soil nitrate, soil water and grain yield in a wheat/fallow rotation in the Great Plains as influenced by straw mulch. Agron. J. 59:785-787.

Smika, D.E., and C.J. Whitfield. 1966. Effect of standing wheat stubble on storage of winter precipitation. J. Soil Water Conserv. 21:138-141.

Smith, A.J. 1980. The integration of livestock into rainfed agricultural system. p. 139-152. *In* Rainfed agriculture in Near East and North Africa. FAO, Rome, Italy.

Smith, V., T. Lawrence, C. Wheeting, and Vandecaveye. 1946. Effects of organic residues and nitrogen fertilizers on a semiarid soil. Soil Sci. 61:393-410.

Tamimi, S.A. 1981. A brief review of research on rainfed agriculture. Regional Project on Land and Water Use, FAO/TM/REM 508 (MUL). FAO, Rome, Italy.

Unger, P.N. 1978. Straw mulch effects on soils temperature and sorghum germination and growth. Agron. J 70:858-864.

USDA. 1975. Agricultural statistics. U.S. Gov. Print. Office, Washington, DC.

Van Doren, D.M., and R.R. Allmaras. 1978. Residue management practices on the soil physical environment, microclimate and plant growth. *In*: Crop residue management systems. ASA, CSSA, SSSA, Madison, WI.

Woodruff, N.P., L. Lyles, F.H. Siddoway, and D.W. Fryrear. 1977. How to control wind erosion. USDA Agric. Inform. Bull. No. 354. U.S. Gov. Print. Office, Washington, DC.

Rehabilitation of Degraded Agricultural Soils with Organic Wastes

J.F. Parr and S.B. Hornick
U.S. Department of Agriculture, Agricultural Research Service, Beltsville, Maryland, USA

ABSTRACT. Soil erosion by wind and water and consequent land degradation and loss of soil productivity are serious environmental and economic problems in the United States. The key to controlling soil erosion and nutrient losses through excessive runoff is the proper use of on-farm agricultural wastes including animal manures and crop residues. Off-farm municipal wastes such as sewage sludge and refuse are potentially valuable organic resources that could be used as soil conditioners and biofertilizers. Low-cost composting technologies can essentially eliminate the environmental hazards and health risks associated with these materials. Strategies are discussed that would provide a more reliable approach for using organic wastes to improve the productivity of degraded agricultural soils and crop quality in both developed and developing countries.

Introduction

Soil erosion of agricultural croplands in the United States, by both wind and water, remains our most serious environmental problem (Brink *et al.*, 1977; Carter, 1977). The principal reason for this is that many farmers have shifted to highly intensive and exploitive farming systems which mainly involve continuous row crops which no longer include sod based rotations, cover crops, green manure crops, conservation tillage, strip cropping, and contouring. Many farmers have gone to continuous wheat or corn or corn-soybean rotations which fail to provide the soil with adequate protection against wind and water erosion. They have done so in order to maximize short-term crop yields and profits, which have taken precedence over the longer-term advantages of soil and water conservation (Carter, 1977).

According to Berg (1979) the current average annual soil loss from erosion in the United States Corn Belt, which contains much of the country's prime farmland, exceeds 8 tons $acre^{-1}$ (18 Mg ha^{-1}). This is about double the maximum tolerable rate or T-value that will sustain a reasonably high level of crop production.

There is growing concern about the effect of soil erosion on the decline of long-term soil productivity (Follett and Stewart, 1985).† According to a 1984 Worldwatch Institute estimate, the loss of soil from cropland worldwide is some 26 billion tons per year (Brown and Wolf, 1984). If one assumes an average topsoil depth of seven inches and an average weight of 160 tons per inch per acre, this is equal to the loss of 23 million acres of cropland per year (Brown and Wolf, 1984). This crisis is likely to worsen in the near future because rapidly expanding populations throughout the Third World have necessitated the farming of marginal lands that are often steeply sloping, coarse-textured, lacking in topsoil, and, thus, highly erodible by wind and water. Already, in some regions of the world, e.g. Sub-Saharan Africa, food grain production per capita has decreased dramatically in the past few years. Much of this can be attributed to improper or inadequate soil and water management practices and continued degradation of the natural resource base.

Proper management of organic wastes such as crop residues, animal manures, and sewage sludges on land is essential for protecting agricultural soils from wind and water erosion, and for preventing nutrient losses through runoff. Efficient and effective use of these materials as soil amendments also provides one of the best means we have for maintaining soil productivity by recycling plant nutrients and by improving soil physical properties.

† Soil productivity as defined in *Soil*, the 1957 USDA Yearbook of Agriculture, is, "the capability of a soil for producing a specified plant or sequence of plants under a defined set of management practices. It is measured in terms of the outputs or harvests in relation to the inputs of production factors for a specific kind of soil under a physically defined system of management."

The beneficial effects of organic wastes on soil physical properties are widely known (Allison, 1973; USDA, 1957) as evidenced by increased water infiltration, water-holding capacity, water content, aeration, permeability, soil aggregation and rooting depth, and by decreased soil crusting, runoff, and bulk density.

The purpose of this paper is to present some new perspectives and strategies that may help to insure the efficient and effective use of organic wastes to reduce soil erosion and to improve soil productivity and tilth in both developed and developing countries.

Traditional Use of Organic Wastes in Agriculture

Developing countries have traditionally used organic materials such as animal manures, crop residues, green manures, and composts to maintain or improve the productivity, tilth, and fertility of their agricultural soils. Such materials also were the principal sources of plant nutrients in United States agriculture until the late 1940s and early 1950s when farmers began to replace them with chemical fertilizers. With the beginning of the Green Revolution in the early 1960s, most developing countries began to replace organic recycling practices with chemical fertilizers applied to high-yielding cereal varieties, which required irrigation and frequent use of pesticides. Consequently, the importance of recycling organic materials in maintaining soil productivity and controlling soil erosion was neglected. As a result the agricultural soils in both developed and developing countries have undergone serious degradation with resulting loss of productivity because of excessive soil erosion and nutrient runoff losses. Moreover, as soil productivity declines there is usually a concomitant decrease in the crop use efficiency of applied chemical fertilizers.

In the early 1970s there was renewed interest in recycling organic materials in developing countries for soil improvement and plant growth because of steadily rising energy costs and the uncertain availability of chemical fertilizers. Subsequently, the Food and Agriculture Organization (FAO) of the United Nations convened a series of regional workshops to emphasize the value and importance of organic wastes as soil amendments and fertilizers, and to reintroduce both established techniques as well as new methods and practices for their utilization on agricultural lands. One such workshop was held in the Near East region (FAO, 1978).

The proper management of organic wastes and residues (from both agricultural and municipal sources) on land provides the best means we have for protecting agricultural soils from wind and water erosion, preventing nutrient losses through runoff and leaching, and for maintaining and restoring the productivity of degraded soils. Hauck (1981) estimated that recycling of organic materials on agricultural lands in developing countries could contribute more than 50 percent of the increased food production that will be needed worldwide in the years ahead.

An important concept that is often overlooked and illustrated in Figure 1 is that for most agricultural soils, degradative processes such as soil erosion, nutrient runoff losses, and organic matter depletion are going on simultaneously with conservation practices such as residue management, crop rotations, and conservation tillage (Hornick and Parr, 1987). The potential productivity of particular soil then depends on the interaction of degradative processes and conservation practices. On our best agricultural soils, e.g., gently sloping, medium-textured, well structured, and with a deep topsoil, a high level of productivity can be maintained by a relatively few, but essential, conservation practices that can readily offset most degradative processes. However, on marginal soils, e.g., steeply sloping, coarse-textured, poorly structured, with shallow depth, and low fertility, soil conservation practices must be maximized to offset further degradation. The vital component in this dynamic equilibrium is soil organic matter which is maintained and replenished through periodic applications of organic wastes and residues.

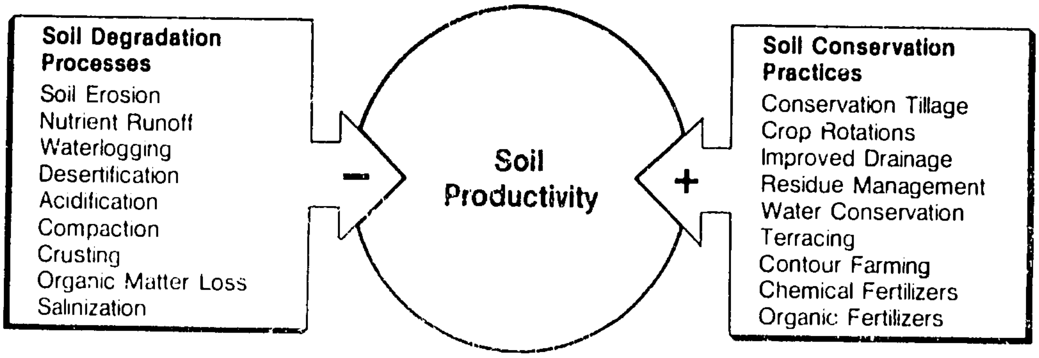


Figure 1. Relationship of Soil Productivity to Soil Degradative Processes and Soil Conservation Practices (Hornick and Parr, 1987).

Surveys of Organic Wastes and Residues

Most developing countries have never conducted inventories on the types, amounts, and availability of organic materials that could be utilized as fertilizers and soil amendments on agricultural lands. Such information should be an essential part of national planning documents for the development, conservation, and management of the natural resource base (FAO, 1975).

This information is not readily available in developed countries either. For example, the Food and Agriculture Act of 1977 (PL 95-113) mandated the U.S. Department of Agriculture to prepare a report for the U.S. Congress on the "practicability, desirability, and feasibility of collecting, transporting, and placing of organic wastes on land to improve soil tilth and fertility." A task force was immediately assigned to compile the necessary, but then nonexistent, information on the kinds, amounts, and availability of organic materials that could be used as alternative fertilizer sources. This information was urgently needed because of the growing concern for the effect of excessive soil erosion on the loss of soil productivity, and the potential impact of agricultural chemicals, both fertilizers and pesticides, on environmental quality (USDA, 1978).

A summary of the USDA report (Table 1) shows that approximately 730 million dry Mg of organic wastes, comprising seven major categories, were produced by the United States in 1978. When one calculates only the fertilizer value of the materials in terms of their content of macronutrients, i.e., nitrogen, phosphorus, and potassium, it represents a national resource of significant economic value. More than 50 percent of the total is comprised of crop residues, and about 22 percent consists of animal manures. Thus, agricultural wastes, i.e., crop residues and animal manures, represent about three-quarters of the total annual production of organic wastes in the United States. The USDA report shows that considerable amounts of these two wastes are already being recycled on land, and the probability of increased use on land is low. Sewage sludge and septage make up only 0.5 percent of the total production. However, since these data were compiled, the amount of sewage sludge currently applied to land has increased from 23 to more than 40 percent.

The other four waste categories listed in Table 1 have not been used extensively on agricultural lands because of certain competitive uses; high cost of collection, processing, transportation, and application; and constraints on usage due to certain undesirable chemical and physical properties. For example, industrial wastes may contain highly toxic organic chemicals; logging and wood manufacturing wastes may have ready markets as fuel and specialized construction materials; and municipal refuse, even though shredded, may detract aesthetically when applied to land because of fragments of glass, plastic, and metal.

Table 1. Annual Production of Organic Wastes in the United States, Current Use on Land, and Probability of Increased Use (USDA, 1978).

Organic Wastes	Total Production	Current Use on Land†		Probability of Increased Use on Land‡
	dry Mg x 1000	*% of total*	%	
Animal manure	158,730	21.8	90	Low
Crop residues	391,009	53.7	68	Low
Sewage sludge and septage	3,963	0.5	23	Medium
Food processing	2,902	0.4	(13)	Low
Industrial organic	7,452	1.0	3	Low
Logging and wood manufacturing	32,394	4.5	(5)	Very low
Municipal refuse	131,519	18.1	(1)	Low
Total	727,969	100.0	—	—

† Values in parentheses are estimates because of insufficient data.
‡ Medium indicates a likely increase of 20 to 30%, low indicates a 5 to 20% increase, and very low indicates less than a 5% increase.

Value of Organic Materials as Fertilizers and Soil Conditioners

The actual value of organic materials as fertilizers and soil conditioners is often not properly accounted for. The simplest and most common method of estimating the value of organic materials is to consider them as substitutes for chemical fertilizer that the farmer would otherwise need to purchase. This is done by using the current market value of the plant nutrients they contain, and is usually limited to their macronutrient content, i.e., nitrogen, phosphorus, and potassium. This method was used to establish the value of beef manure, crop residues, sewage sludge, and municipal refuse reported in Table 2. Of these materials, sewage sludge has the highest nutrient content and is worth about \$43 ton^{-1}. Beef manure has a somewhat similar nutrient content and is valued at \$40 ton^{-1}. Most crop residues and municipal refuse have considerably lower contents of the three macronutrients and are worth only \$13.40 and \$6.70 ton^{-1}, respectively.

Table 2. Content and Value of Nutrients Per Dry Mg of Organic Waste (USDA, 1978).

Organic Material	Nutrients N	P_2O_5	K_2O	Value†
	....	%	....	*\$ Mg^{-1}*
Beef manure	4.4	2.5	2.9	40.0
Crop residues	1.1	0.5	2.4	13.4
Sewage sludge	4.0	4.6	0.5	43.0
Municipal refuse	0.70	0.5	0.4	6.7

† Value per kg of N, P_2O_5, and K_2O was set at \$0.46, 0.51, and 0.24, respectively.

However, many organic materials contain other components in addition to organic matter and macronutrients (N, P, K) that can contribute significantly to higher crop yields. These include secondary nutrients (S, Mg), micronutrients (Cu, B, Zn, Mn, Fe, Mo), and sometimes lime. When these constituents can substitute for plant nutrients that the farmer would have to purchase, the value of the organic material increases accordingly. On the other hand, some organic materials may contain such constituents as soluble salts, heavy metals, and hazardous organic chemicals that could adversely affect soils, plants, animals, and the human food chain. Some organic materials such as crop residues may have very high C:N ratios which would reflect a low N content and a slow rate of mineralization and release of inorganic N. Other materials such as food processing wastes may have unusually high levels of acidity or alkalinity. Such properties would likely reduce the value of these materials as fertilizers and soil conditioners.

In some cases, the organic components of a particular material may have a higher monetary value than that of its total nutrient content because of the beneficial effect of organic matter on soil physical properties and improvement of soil productivity. This is especially true when certain organic materials such as composted sewage sludge are used to restore the productivity of severely eroded agricultural soils, or to reclaim marginal soils (Hornick, 1982).

The rate at which organic materials decompose or mineralize in soil is highly variable depending on their chemical and physical properties, and soil environmental conditions including temperature, moisture, aeration, pH, and mode/method of application to soil (Parr and Papendick, 1978). Nevertheless, organic materials have a greater residual effect on soil fertility than most chemical fertilizers because of the slow-release character of the nitrogen and phosphorus components. Thus, a significant portion of the value of organic materials as fertilizers is their capacity to elicit yield responses from succeeding crops. This response must be accounted for to assess the true value of the material. Barbarika *et al* (1980) estimated that the cumulative economic value of some organic materials applied to agricultural soil could be as much as five times greater in succeeding years than the value realized during the application year.

Special Management Practices for Utilization of Organic Materials on Land

There are many problems involved in handling and applying organic wastes to land because their physical characteristics are so variable. Such wastes are almost always bulky, and can range from liquid on one extreme to dry solid material on the other. Existing application technologies are often ineffective and fail to achieve the desired level of erosion control or increased crop production. Thus, special management practices may be needed to obtain the full value of organic materials as fertilizers and soil amendments. Such methods must be simple, cost effective, energy conserving, and effective for nutrient cycling and erosion control.

An example of a particularly effective soil erosion control measure for sloping land is that of vertical mulching, a procedure which incorporates organic materials such as crop residues into a vertical channel 30 to 40 cm deep and some 10 to 12 cm wide at the soil surface (Parr, 1959). The operation is usually conducted on the contour at intervals ranging from 5 to 10 m. A recent modification of this procedure is referred to as slot mulch and has been demonstrated as an effective means of controlling erosion on steeply sloping lands in the winter wheat area of eastern Washington State (Saxton *et al.*, 1981). Both techniques are highly effective in intercepting runoff, enhancing root penetration and development, and providing for effective water conservation and storage for crop use. Although several types of machines have been designed for these operations, similar results could be achieved using hand labor.

This concept of residue management may have application in developing countries for restoring the productivity of sloping lands that have suffered from severe soil erosion. Besides crop residues, other types of organic materials, including composts, could also be utilized in the vertical mulch or slot mulch procedures.

Another concept that may have considerable merit for increasing the cost-effectiveness of composted organic wastes is that of localized placement in contoured bands on sloping lands, or in conjunction with broad bed-furrow systems. Composts are more expensive than raw wastes, but provide an essential stable form of carbon that imparts a greater residual effect on soil properties. Thus, rather than attempting to treat an entire tract of cropland, it may be much more effective to follow a localized placement approach with seed sowing or transplanting of seedlings directly into the treated zone.

Composting to Enhance the Usefulness and Acceptability of Certain Organic Materials

Some of the problems associated with the utilization of various organic wastes (e.g. odors, human pathogens, and storage and handling constraints) can be resolved by composting. Composting is an ancient practice whereby farmers have converted organic wastes into useful materials that provide nutrients for crops and improve the tilth, fertility, and productivity of soils. Through composting, organic wastes are decomposed, nutrients are made available to plants, pathogens are destroyed, and malodors are abated. The historical aspects of composting have been thoroughly discussed in reviews by Gotaas (1956) and Golueke (1972).

The U.S. Department of Agriculture at Beltsville, Maryland has developed the highly successful Beltsville Aerated Rapid Composting (BARC) Method for composting sewage sludge, animal manures, municipal refuse, and pit latrine wastes (Parr *et al.*, 1978; Willson *et al.*, 1980). This method has been widely adopted by both large and small municipalities throughout the United States for composting sewage sludge and solid waste. A number of developing countries have also adopted this technology for composting. The method is simple and relatively inexpensive, yet effective, and allows considerable tradeoff between labor and capital.

In the BARC Method (Figure 2) sewage sludges ranging from 15 to 25 percent solids are mixed with woodchips as a bulking material and then composted in a stationary aerated pile for 3 to 4 weeks. Sludges in this high moisture range will not readily compost aerobically because sufficient air cannot penetrate the biomass, either naturally or through forced aeration. Thus, it is essential to mix the sludge with bulking material to provide the necessary structure and porosity to facilitate forced aeration. The bulking material also

Composting with Forced Aeration

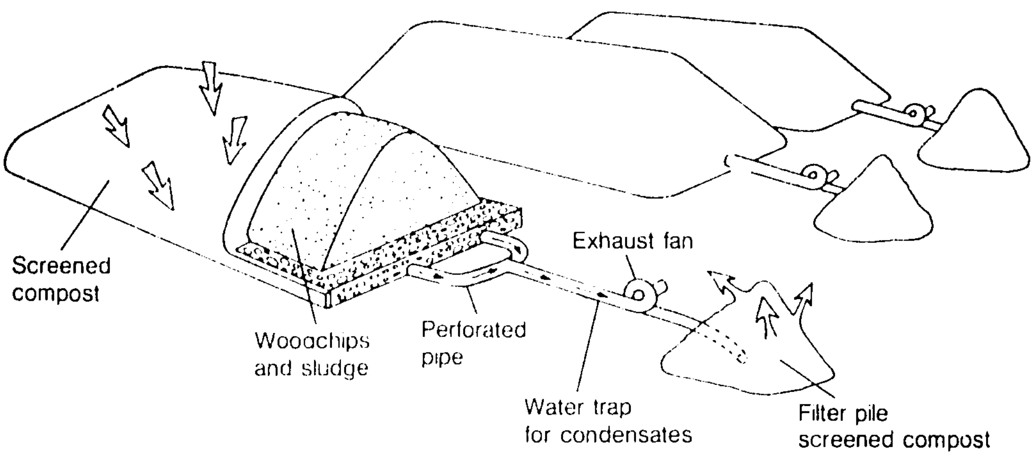


Figure 2. A Schematic Diagram of the Beltsille Aerated Rapid Composting Method for Composting Sewage Sludge and Other Organic Wastes.

lowers the moisture content of the sludge thereby ensuring rapid aerobic/thermophilic composting. Aerobic conditions are maintained by drawing air through the pile with a blower connected to a loop of perforated pipe in the pile base. Other bulking materials that could be used include leaves, refuse, paper, peanut hulls, straw, corn cobs, and wood bark.

As shown in Figure 2, air is drawn into and through the composting biomass and finally exhausted into a small pile of screened, cured compost where odorous gases are effectively absorbed. The pile is blanketed with a 30 to 40 cm layer of screened compost for insulation and odor control. Uniform temperatures are maintained throughout the pile with a timer programmed to operate the exhaust fan on a predetermined intermittent cycle. Within three days after composting begins, temperatures are well into the thermophilic range (60 to 70°C) and remain there for several weeks. This ensures complete destruction of enteric pathogens. There are now more than 50 BARC-type composting facilities operating in United States cities and municipalities with 25 other in various stages of construction and development (Goldstein, 1985).

Composts provide a more stabilized form of organic matter than raw wastes and can vastly improve the physical properties of soils. For example, addition of sludge compost to sandy soils will increase their ability to retain water and render them less droughty. In heavy-textured clay soils, the added organic matter will increase permeability to air, and increase water infiltration thereby minimizing surface runoff and increasing water storage. Addition of sludge compost to clay soils has been shown to reduce soil compaction, lower the bulk density, and increase the rooting depth.

Hornick *et al.* (1984) discussed the uses of sewage sludge compost for soil improvement and plant growth including 1) establishment, maintenance, and production of turfgrass and sod, 2) use in vegetable gardens, 3) production of field crops and forage grasses, 4) use on nursery crops and ornamentals, 5) use in potting mixes, and 6) reclamation and revegetation of disturbed lands. This paper provides recommendations as to time, methods, and rates of compost application for different soils, and management practices.

Some organic wastes may have chemical, physical, and/or microbiological properties that would greatly limit the extent to which they could be composted alone. For example, some wastes may have an extremely acidic or alkaline pH, others may have unusually high or low C:N ratios, and still others may vary widely in their solids content. In such cases, selective co-composting of these wastes with sewage sludge, pit latrine waste or night soil, municipal solid waste (i.e., garbage or refuse), crop residues, animal manure, food processing wastes, and certain industrial wastes, may alleviate these limitations and provide a readily compostable mixture and a higher quality product (Obeng and Wright, 1987).

Crop Quality and Bioavailability of Nutrients

There are a number of factors that can affect crop quality in the rehabilitation of degraded agricultural lands with organic wastes. These include the chemical properties of the organic fertilizer, the soil characteristics or soil environment, and the crop cultivar.

As mentioned earlier, organic wastes can differ widely in their physical and chemical properties. Some wastes such as cereal straws and composted animal manure and sewage sludges are more resistant to microbial attack. This higher level of organic stability provides a distinct advantage in the initial reclamation of marginal soil because it imparts a beneficial and long-term improvement of soil physical properties and in turn increases the plant use efficiency of nutrients. It has been shown that the addition of lime and chemical fertilizers alone is not adequate to restore acidic, eroded, infertile sand and gravel spoils to an acceptable level of productivity and stability over the short-term (Hornick, 1988).

Generally, differences in mineral composition of the organic wastes are largely responsible for differences in the macro- and micronutrient contents of crops grown on reclaimed lands (Hornick, 1988). Differences in nitrogen mineralization rates, however, affect not only yield but the ascorbic acid (i.e., vitamin C) content of leafy vegetables. Hornick and Lloyd (1986) showed that increasing rates of inorganic nitrogen fertilizer decreased the ascorbic acid content of kale. Earlier experiments with increasing rates of composted sewage sludge and beef feedlot manure also showed an inverse effect on ascorbic acid contents. The different levels of ascorbic acid in crops grown on soils with the two wastes, were attributed to different rates of nitrogen mineralization.

Often the effect of cultural and management practices on the nutritional quality of crops has been discounted while the crop cultivar has been considered as the most important factor. Traditionally, plant breeders have selected crop cultivars and new varieties for their high yields and resistance to insects and diseases. However, there is a growing concern that selection criteria should also include resistance to environmental stresses, i.e., drought and high temperatures, as well as nutritional quality, and even the bioavailability of nutrients consumed.

Summary and Conclusions

There is a growing worldwide shortage of good quality organic wastes for use in maintaining and restoring the tilth, fertility, and productivity of agricultural soils. Indeed, most of our traditional agricultural wastes in the United States, i.e., animal manures and crop residues, are currently being recycled on agricultural land. These wastes are often of limited availability in developing countries because of such competitive use as fodder, fuel, and fiber.

Both developed and developing countries need to conduct periodic inventories on the kinds, amounts, and availability of organic materials that could be utilized as fertilizers and soil amendments, and especially municipal wastes such as garbage (refuse), sewage, and nightsoil. Composting techniques are available to minimize environmental hazards and health risks, and to overcome certain chemical and physical constraints that would limit their use on agricultural lands. Because these materials represent a potential source of considerable agronomic and economic value, their proper and efficient use as fertilizers should be emphasized by national governments in promoting the development of environmentally sound, economically viable, and resource-efficient farming systems.

Most organic wastes and residues are low in their content of macro- and micronutrients compared with chemical fertilizers. However, research has shown that crop yields are consistently higher when organic materials are applied in combination with chemical fertilizers than when either one is applied alone. This would suggest that organic materials can increase the efficiency of chemical fertilizers and, if so, farmers might be able to reduce their fertilizer and energy inputs accordingly. Research is needed to evaluate crop yield response to various combinations of organic and chemical fertilizers and to determine what agronomic, nutritive, energy, and economic trade-offs are possible.

Research is also needed to improve the efficient and effective use of organic materials in cropping systems. Studies should be conducted to establish the best mode/method of application to soil (i.e., surface mulched, plowed down, disked in, or sidedressed), proper rate and time of application, best sequence of crops to be grown, and the rate of release of nutrients. A better understanding of the interaction of these factors would provide a more reliable basis for using organic wastes to restore the productivity of degraded agricultural soils.

References

Allison, F.E. 1973. Soil organic matter and its role in crop production. Elsevier Scientific Publ. Co., New York, Amsterdam.

Barbarika, A.D., D. Colacicco, and W.J. Bellows. 1980. The value and use of organic wastes. Maryland Agri-Economics, May 1980. Coop. Ext. Serv., Univ. Maryland, College Park, MD.

Berg, M.A. 1979. Soil conservation: The physical resource setting. p. 8-17. *In* Soil conservation policies: An assessment. Soil Cons. Soc. Am., Ankeny, IA.

Brink, R.A., J.W. Densmore, and G.A. Hill. 1977. Soil deterioration and the growing demand for food. Science 197:625-630.

Brown, L.R. and E.C. Wolf. 1984. Soil erosion: Quiet crisis in the world economy. Worldwatch Paper No. 60. Worldwatch Inst., Washington, DC.

Carter, L.J. 1977. Soil erosion: The problem persists despite the billions spent on it. Science 196:409-411.

Follett, R.F. and B.A. Stewart (ed.). 1985. Soil erosion and crop productivity. Am. Soc. Agron., Madison, WI.

FAO. 1975. Organic materials as fertilizers. FAO Soils Bull. No. 27. FAO, Rome, Italy.

FAO. 1978. FAO/SIDA Workshop on Organic Materials and Soil Productivity in the Near East. FAO Soils Bull. No. 45. FAO, Rome, Italy.

Goldstein, N. 1985. Sewage sludge composting facilities on the rise. BioCycle 26:19-24.

Golueke, C.G. 1972. Composting: A study of the process and its principles. Rodale Press, Emmaus, PA.

Gotaas, H.B. 1956. Composting, sanitary disposal and reclamation of organic wastes. World Health Organization Monograph 31. Geneva, Switzerland.

Hauck, F.W. 1981. The importance of organic recycling in the agricultural programmes of developing countries. p. 17-28. *In* Organic recycling in Asia. FAO/UNDP Regional Project RAS/75/004. Project Field Document No. 20. FAO, Rome, Italy.

Hornick, S.B. 1982. Crop production on waste amended gravel spoils. p. 207-218. *In* W.E. Sopper, E.M. Seaker, and R.K. Bastian (ed.) Land reclamation and biomass production with municipal wastewater and sludge. Penn. State Univ. Press, University Park, PA.

Hornick, S.B. 1988. Use of organic amendments to increase the productivity of sand and gravel spoils: Effect on yield and composition of sweet corn. Am. J. Alternative Agric. (In press).

Hornick, S.B. and C.A. Lloyd. 1986. Fertilizer effects on crop fiber and nutrient content. p. 202. *In* Agron. Abstracts. ASA, Madison, WI.

Hornick, S.B., L.J. Sikora, S.B. Sterrett, J.J. Murray, P.D. Millner, W.D. Burge, D. Colacicco, J.F. Parr, R.L. Chaney, and G.B. Willson. 1984. Utilization of sewage sludge compost as a soil conditioner and fertilizer for plant growth. USDA, Agric. Inform. Bull. No. 464. U.S. Gov. Print. Office, Washington, DC.

Hornick, S.B. and J.F. Parr. 1987. Restoring the productivity of marginal soils with organic amendments. Am. J. Alternative Agri. 2:64-68.

Obeng, L.A. and F.W. Wright. 1987. The co-composting of domestic solid and human wastes. World Bank Tech. Paper No. 57. Washington, DC.

Parr, J.F. 1959. Effects of vertical mulching and subsoiling on soil physical properties. Agron. J. 51:412-414.

Parr, J.F., E. Epstein, and G.B. Willson. 1978. Composting Sewage Sludge for Land Application. Agriculture and Environment 4:123-137.

Parr, J.F. and R.I. Papendick. 1978. Factors affecting the decomposition of crop residues by microorganisms. p. 101- 129. *In* Crop residue management systems. ASA, Madison, WI.

Parr, J.F. and D. Colacicco. 1987. Organic materials as alternative nutrient sources. p. 81-99. *In* Z.R. Helsel (ed.), Energy in plant nutrition and pest control. Elsevier Science Publishers, Amsterdam, The Netherlands.

Saxton, K.E., D.K. McCool, and R.I. Papendick. 1981. Slot mulch for runoff and erosion control. J. Soil Water Conserv. 36:44-47.

U.S. Department of Agriculture. 1957. Soil—Yearbook of agriculture. USDA, U.S. Gov. Print. Office, Washington, DC.

U.S. Department of Agriculture. 1978. Improving soils with organic wastes. Report to the Congress in response to Section 1461 of the Food and Agriculture Act of 1977 (PL 95-113). U.S. Gov. Print. Office, Washington, DC.

Willson, G.B., J.F. Parr, E. Epstein, P.B. Marsh, R.L. Chaney D. Colacicco, W.D. Burge, L.J. Sikora, C.F. Tester and S.B. Hornick. 1980. Manual for composting sewage sludge by the Beltsville aerated pile method. Joint publication by USDA-USEPA, EPA-600/8-80-022. U.S. Gov. Print. Office, Washington, DC.

Response Farming for Improvement of Rainfed Crop Production in Jordan

J.I. Stewart
World Hunger Alleviation through Response Farming, Davis, California, USA

ABSTRACT. Rainfed wheat production in Jordan is limited by low and variable rainfall. Farmers traditionally delay planting until the onset of the rains and adjust their wheat hectarage based on the amount of early rainfall relative to normal. Variable rainfall also limits farmers' incentives for investing in costly inputs which would raise crop yields. Long-term rainfall records show that total wheat season rainfall is directly related to the date on onset of the rainy season, that is, the earlier the onset, the higher the rainfall expectations, and the higher the wheat yields. Improved local rainfall forecasts early in the growing season, and yield predictions based on water production functions and rainfall forecasts can strengthen farm level decision-making in this environment.

Response farming is a flexible farming system based on a rainfall forecast followed by an appropriate agronomic response. The date of rainfall onset is used to predict seasonal rainfall. Recommendations for crop selection, planting practices, and inputs then are adjusted to that expectation through the use of water production functions. Response farming combines the best bet recommendations for wheat production developed by the Jordan Cooperative Cereals Improvement Project with farmers traditional practices to improve wheat yields in years with high or medium rainfall and to reduce losses in years with low rainfall. It is hoped that this approach may be adopted with more confidence by the growers since it is based on their traditional knowledge and beliefs.

Introduction

Crop yields and economic returns in the rainfed sector of Jordan are, generally speaking, limited by water. However, extreme rainfall variability from one year to the next, rather than rainfall amount per se, is the greater part of the problem. The practical meaning of the variability is that any single fixed farming system which one might devise will be poorly suited to the actual water supply in a majority of cropping seasons. What is needed is a flexible farming system which each season emphasizes those crop types (within the overall system) and utilizes those levels of inputs such as seed rates and fertilizer application rates, herbicides, pesticides, etc., which will maximize yields or economic returns per unit of available water supply.

A companion paper titled "Mediterranean-Type Climate, Wheat Production, and Response Farming" shows there is sufficient predictability in Mediterranean rainfall, including rainfall in Jordan, to make the needed flexible farming system a reality. The indicator of rainfall amount and duration through the approaching rainy period is the date of onset.

Mediterranean rainfall records show clearly, with probability ≤ 0.01, that total annual rainfall and rainfall during the wheat growing period decline in actual rainfall amount and duration with delayed onset of the rainy period. In practical terms this means a farmer faces a markedly different set of rainfall probabilities if the rain begins in November than if it begins in December or later. The record shows that each period when onset might occur carries with it a range of possible rainfall occurrences, but the range for each period is greatly narrowed over that one sees when considering the entire rainfall record. A narrowed range of possible rainfall amounts and durations means easier and more accurate decision-making by the farmer.

Response farming is a term used to describe a flexible farming system based on a rainfall forecast followed by an appropriate agronomic response. The rainfall forecast is that described above. The response lies in the decisions the farmer then makes about how he will operate in the upcoming season to make the best use of the expected water supply. It should be noted that the response farming method has as much applicability in animal production systems as in cropping, and in irrigated as well as rainfed agriculture. However, the focus of this paper is rainfed crop production.

The response a farmer makes to a given rainfall forecast may affect many aspects of his operation, for example, preplant tillage. Pending wet conditions may require sloping cultivation to facilitate runoff of excess water to avoid waterlogging the crop or soil erosion. On the other hand, a forecast of dry or moderately moist conditions would call for flat tillage to assure retention of all rainfall.

Early onset, indicative of a long rainy season with relatively high total rainfall, would require emphasis on long season crops/varieties with higher water requirements and greater value in the market place. In this instance, production for the market, in addition to subsistence, would be anticipated. Higher production levels should be supported by higher input levels, including (frequently) higher seed rates for increased plant populations; higher nitrogen fertilizer applications plus associated nutrients as needed; herbicide and pesticide use as required to protect the enhanced production; arrangement for augmented harvesting; storing and marketing assistance; and other factors as applicable.

Late onset, indicating a short rainy period with relatively low total rainfall, would require much different decisions, often the opposite of those above. In many cases in Jordan, late onset may dictate switching crops altogether. It will also be shown that Jordanian farmers, particularly those in cropping areas with 250 to 400 mm mean annual rainfall, are already aware of the implications of late onset of the rains, and respond to it by reducing planted acreage, changing crop types, and other measures. They may be less aware of the good implications of early onset of the rains and how they might profit from increased input levels, etc. in those years.

This paper concerns both the rainfall forecasting and response aspects of response farming. Published meteorological and crop yield data from Jordan are used to illustrate how this approach might work for farmers in the low rainfall zones of the Amman and Irbid Governorates.

The data have been used to develop water production functions which show historical relationships between crop yields and rainfall in the study areas of Jordan. Seven crops, wheat, barley, chickpea, lentil, vetch, tobacco, and olive, were considered. As might be imagined, these relationships, drawn from crude and limited data, are only presented as illustrative. The purpose is twofold: 1) to suggest the nature of the benefits to be gained from the response farming approach and 2) to urge the establishment of a research program to develop water production functions and related transferable equations in Jordan. The usefulness of the latter is also illustrated in this paper by introducing transferable information on wheat-water relationships developed in research at the University of California at Davis.

Jordanian Rainfall Characteristics and Predictability in Relation to Wheat Production

The study area covered in this paper is the northern Jordanian Highlands from Balqa Governorate in the north through Irbid Governorate into the portion of Amman Governorate around and just south of the city of Amman. Mean annual rainfall is high in Balqa (560 mm) and in Ajlun District (543-599 mm) in the northwest of Irbid Governorate. Rainfall is moderately high in Kura (402-490 mm), Irbid (455-481 mm), and Jerash (442 mm) Districts of Irbid Governorate, then fairly low in the Ramtha/Rihab areas (219-263 mm) of southeast Irbid and in Amman (278 mm). Some of the discussion will cover all of these areas but most will focus on rainfall up to 400 mm.

The companion paper mentioned earlier presents scatter diagrams which relate total annual rainfall to the actual dates the rains effectively began for wheat production (date of onset) in each of 31 years of common record at sites in Morocco, Cyprus, and Jordan. This west-east transect across the Mediterranean indicates that onset may occur anytime in a period of several months, and that each day that onset is delayed reduces the amount of rainfall to be expected in the season, as well as the duration of the rainy period. Details of the history of this phenomenon, as it relates to rainfall in the wheat production season in Jordan, may be seen in Figure 1.

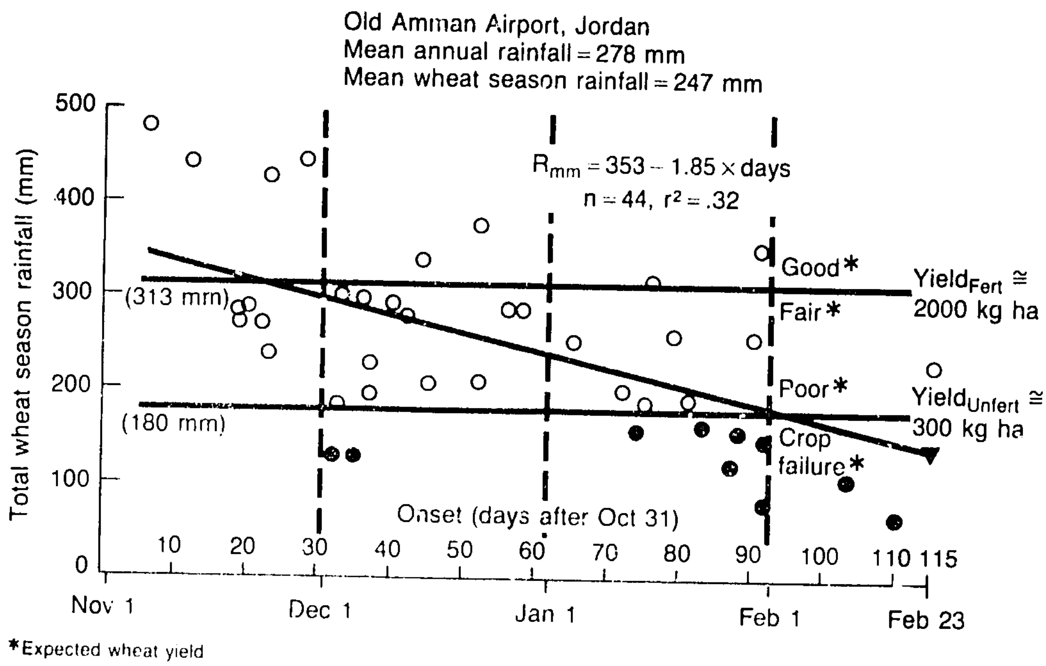


Figure 1. Decline of Wheat Season Painfall Amount with Later Onset of the Rains in Amman, Jordan, 47-Year Rainfall Record from 1937/38 to 1983/84 Inclusive. Data Points Represent Years and Expected Wheat Yield Levels Are Indicated.

Figure 1, like Figure 3 in the companion paper, shows how the amount of rainfall at Old Amman Airport varies with the date of onset of the rainy season. But Figure 1 differs from the information in the companion paper in two ways. The rainfall record examined is lengthened from 31 to 47 years, and the measure of rainfall is changed from total annual to total wheat season rainfall. The latter excludes ineffectual rains prior to onset and any rainfall after May 31 when the wheat is presumed mature.

Mean annual rainfall at Amman over the period of record was 278 mm while mean wheat season rainfall was 247 mm, or 89 percent of the former. Therefore, it is not surprising to see that the phenomenon of declining seasonal rainfall with delayed onset is similar in both representations. The regression equation quantifying this effect (Figure 1) is based on 44 of the 47 years of data, because effective onset for wheat production never occurred in the other three seasons. They are represented by the large inverted triangle at the lower right side of the figure. In statistical terms the regression is significant at the 1 percent level.

Figure 1 shows that onset for wheat production at Amman (defined as 30+ mm of rainfall accumulated in the seedbed) may occur anytime from November to February inclusive, with December 22 as the median date in the study period. Vertical lines divide the onset period by months to make it easier to see the changes in rainfall amounts associated with onset in each of the four months.

Figure 1 also includes two horizontal lines which indicate (roughly) wheat yields expected with the amounts of seasonal rainfall represented by the lines. For example, the lower line at 180 mm represents the least amount of rainfall which should produce a subsistence level wheat yield of 300 kg ha^{-1}, using traditional farming methods and levels of technology. In Figure 1 rainfall levels less than 180 mm are presumed to result in total crop failure, denoted by blackened data points.

The upper horizontal line at 313 mm rainfall indicates the lower level for good wheat yield, with the amount of rainfall required to produce 2000 kg ha^{-1} of grain utilizing advanced technologies, in particular commercial fertilizers. Between the two lines crop yields expected range from fair to poor.

A single exception to the above occurs in the far right data point (February 23 onset, 232 mm) which would in fact have been a totally failed crop because rainfall in that particular season only persisted for 38 days beyond onset. Thus, all February onsets in this record would have produced crop failures. This raises the question of how rainfall duration is related to date of onset. The median date of rainfall cessation in this record was April 21, with March 21 the earliest and May 28 the latest, a much shorter time period than the possible onset period. Roughly speaking, a one-day delay in onset may be expected to shorten the rainy period by one day. This means that rainfall onset in February will always be very detrimental to wheat production.

The main lesson to be drawn from Figure 1 is that the amount of rainfall expected in any given wheat season is not a totally random feature. It is linked to the actual date of onset, at which time we may, if history is any guide, quantify a narrowed range of possible occurrences, narrowed with respect to the overall range of possibilities represented in the record ignoring the date of onset.

The linkage between seasonal rainfall and date of onset means that the potential for crop failure rapidly increases with delayed onset. Accordingly, the probability of a good crop steadily decreases.

Jordanian Wheat Farmer Responses to Late Onset of the Rains and Implications for Food Security

The actions of the wheat farmers of Jordan demonstrate that they are well aware of the implications of late onset for lowered yields or even complete failure. They respond to late onset by reducing the hectarage they plant to wheat and also to barley. And in each season, if rains are considerably below normal during the prolonged planting period following onset, they reduce the planted area still further. Figure 2 shows the result of these actions in the nine-year period from 1968/69 to 1976/77, averaged for Balqa, Irbid, and Amman (south) Governorates.

Figure 2 shows considerable year to year variation in rainfall over the study area during the nine-year period, and a corresponding adjustment in the area planted to wheat and barley each year which conforms closely to the rainfall amount. Note that Figure 2 includes all of the study areas from the wettest to the driest.

In a report by FAO (1982), it is stated that in Jordan:

> ...It is interesting to note that wheat farmers delay seeding till a good part of the rainy season is gone. If sufficient rain is received, they go ahead with their planting, if not then they do not plant. It is not unusual, therefore, to see farmers planting wheat as late as mid or even late February. This practice is very common in the arid and marginal zones of the country. Accordingly, the area planted with wheat in these two zones depends on the rainy season. Data on areas planted and production and yield of wheat in each zone when the rainy season is good, medium or poor are presented in Table 26 [seen in referenced publication]. It is interesting to note in this table that fluctuation of area according to rainfall does not apply to the semi-arid or the semi-humid zones....

Although some details of the FAO (1982) explanation differ from the writer's data and observations, the essence remains true: Jordanian cereal farmers are now practicing, and have historically practiced, what this paper labels response farming. They are judging the coming rainfall season in two ways: first by the date of onset, and second by winter rainfall accumulation by January when final decisions are made about how much area to

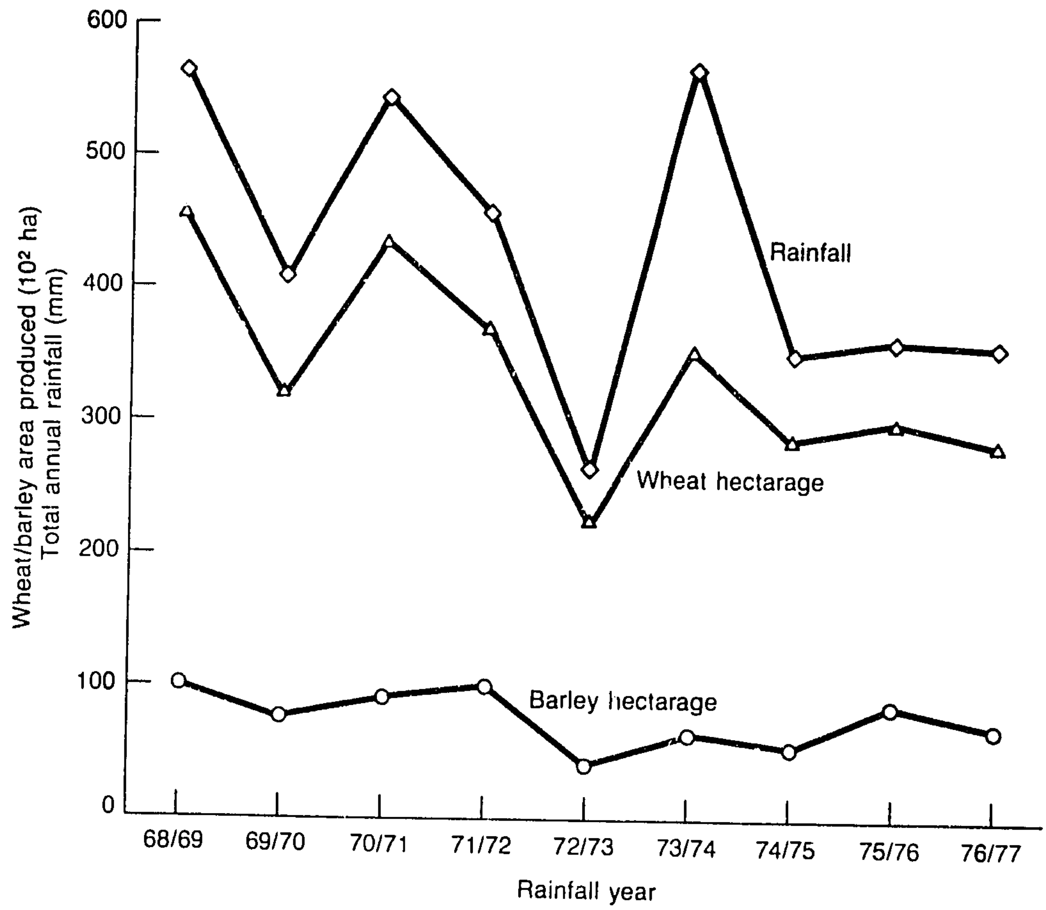


Figure 2. Close Correspondence between Areas Planted by Farmers to Wheat and Barley, and Rainfall over the Period 1969 to 1977 in Irbid, Balqa, and Parts of Amman Governorates, Jordan (AOAD, 1977a, 1978; Water Authority of Jordan, 1985).

plant. Note that planting begins whenever adequate rains begin and a minimum area for subsistence is planted every year. It is the additional area planted for market which is decided upon at the last moment.

The final report of a major research effort carried out by ICARDA, the University of Jordan, and the Ministry of Agriculture Jordan, has recently been published (ICARDA, 1984). Their best bet recommendations are for all wheat farmers to plant before the rains, with the implication that the entire area available will be planted each year. For rainfall areas greater than 250 mm (their zones A and B), a blanket application of nitrogen at 30 kg ha^{-1} is recommended at seeding time. In all rainfall zones including the 200 to 250 mm zone, an additional 30 kg ha^{-1} N is recommended at tillering (February), provided the season is good. Summarizing then, planting practice recommendations suggest that the date of onset and early season rainfall are of no consequence, but the latter should be considered when the decision is made about the final nitrogen fertilizer rate.

The ICARDA report clearly alludes to the problems associated with fixed recommendations for farming in highly variable rainfall zones. In an earlier report, Arabiat (1983) concluded that future research must be devised to deal with the actual rainfall variability faced by farmers.

The writer agrees with Arabiat's thesis and believes that the variability should be managed in two steps. First, the rainfall season at hand should be categorized, at least roughly, based on the date of onset (see Figure 1). Decisions such as planting wheat versus alternative crops, wheat area and varieties to be planted, and seeding rates and initial fertilizer rates, should be based on this categorization. A revised rainfall season categorization should be made at tillering based on the actual early season rainfall characteristics and final decisions may be made about nitrogen rates and levels of other costly inputs such as herbicides to be employed. More detailed discussion will follow in the section on development of recommendations.

Water Production Functions to Guide Farm Decisions According to Rainfall Expectations

Farm level decision-making in variable rainfall conditions can be greatly strengthened by two types of research. The first has already been addressed: the study of rainfall history to sharpen our ability to predict actual rainfall expectations in the approaching season, early enough to modify our actions in ways calculated to maximize output with the expected water supply.

The second type of research needed involves careful study of relationships between crop yields and water supply, that is to say water production function studies. Three types of water production function studies are needed. The types of studies and sequencing are: 1) present relationships existing in traditional agriculture; 2) studies of potential crop yields with the available (variable) water supply, assuming improved management can overcome other limitations such as low soil fertility; and 3) the actual effects of management decisions and practices on yield/water relationships in the local environment.

It is the combination of water production functions with water supply forecasting which is needed for developing farm level recommendations. This paper presents examples of water production functions for seven crops as they exist today in traditional agriculture in Jordan. A suggested relationship showing potential wheat yields with different rainfall amounts is also presented, based on transferable equations developed at UC Davis. The above water production functions and information on rainfall expectations at Amman are combined to illustrate the approach the writer suggests for development of improved farm level recommendations.

Figures 3 and 4 show present day relationships between wheat yields and rainfall, as they exist in traditional agriculture in three distinct rainfall zones in the northern highlands of Jordan. Figure 3 shows how wheat yield varies with total annual rainfall in the moderately high rainfall areas of Irbid, Kura, and Jerash Districts of Irbid Governorate. The yield data derive from a 9-year study by the Arab Organization for Agricultural Development over the period 1969 to 1977 inclusive (AOAD, 1978). Corresponding rainfall data are published by the Water Authority of Jordan (1985).

There are a number of interesting points to be made about the information in Figure 3:

1) The yield vs. rainfall relationship is fairly good considering that it represents only surveyed district averages and rainfall data from six locations. This type of relationship could be useful to food planners and those engaged in early warning activities.

2) Although average annual rainfall is similar in the three districts, there are important differences in both rainfall behavior and associated wheat yields. Irbid District produced the overall highest yield, better then the highest yields in Jerash three of the nine years, and those in Kura four of the nine years. Jerash wheat yields appear to be most unstable, falling below the subsistence threshold (300 kg ha^{-1}) two of nine years, and below a suggested economic threshold of 400 kg ha^{-1} three of nine years. Kura was next lowest with one subsistence failure and two economic failures. Irbid showed no failures over the study period.

3) Despite rainfall above 500 mm in more than a third of all cases, yield never exceeded 1150 kg ha^{-1}. This will be discussed later.

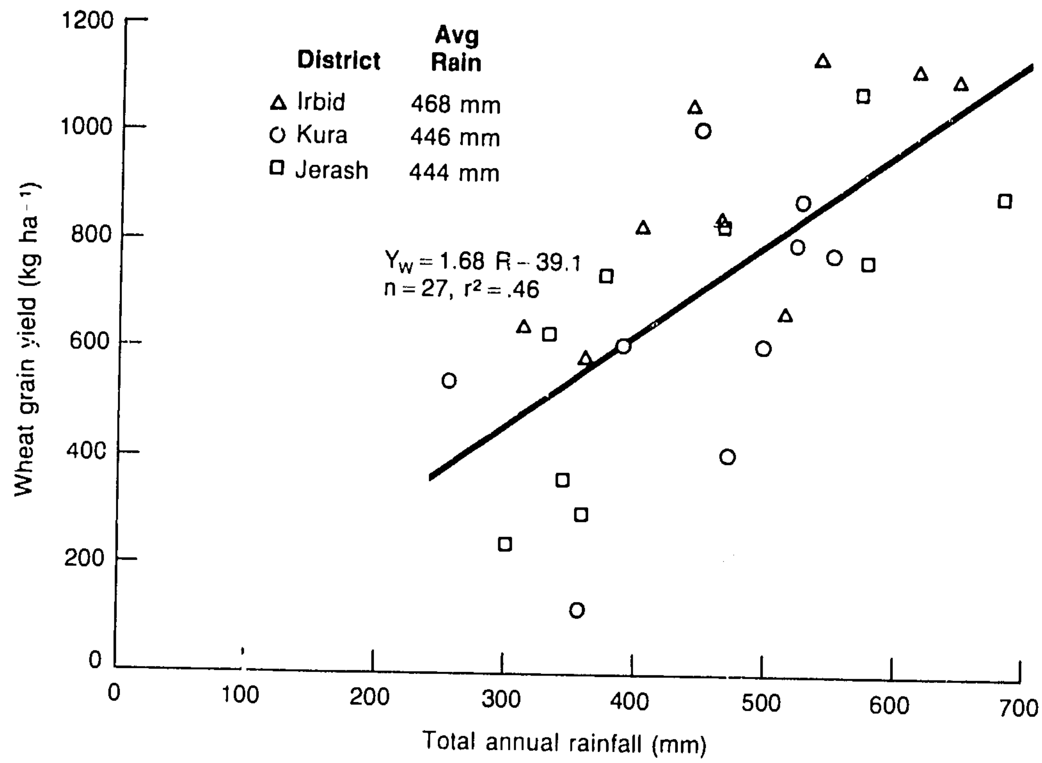


Figure 3. Relations between Wheat Grain Yields and Rainfall over the 1969 to 1977 Period in Irbid, Kura, and Jerash Districts, Irbid Governorates, Jordan (AOAD, 1978; Water Authority of Jordan, 1985).

Figure 4 is similar to Figure 3, but covers both higher and lower rainfall areas. Yield data for the Amman South area may be seen in AOAD (1978). As in Figure 3, the relationship between yield and annual rainfall is quite good in the higher rainfall zones of Ajlun District and Balqa Governorate, and still better in the drier zones of Irbid East and Amman South. The findings are very similar to those of a 3-year research effort in Syria by scientists of the Arab Center for Studies in the Arid Zones and Drylands (ACSAD, 1984). This study reveals many variables responsible for the scatter in the relationship, including weed competition, soil stoniness, slope, depth and calcium content, soil fertility (especially phosphorus and nitrogen levels), and others. As noted above, the closest relationship is found when rainfall is below 400 mm.

As in Figure 3, Figure 4 shows no yields exceeding 1200 kg ha^{-1}. On the lower end of the scale in the drier areas there are a number of subsistence and economic failures. This will be discussed more when considering recommendations. In the wet zones only one failure was seen in Balqa when rainfall fell to 350 mm. However, the highest yields are below those in the dry zones, and overall water use efficiency is very low by comparison.

Figure 5 is a compilation of the information in Figures 3 and 4, with the data points removed for clarity. Also, the 9-year mean rainfall levels and wheat grain yields are shown for each rainfall zone. On the left side of the figure is a suggested relationship for potential wheat yield which assumes that water is the only factor limiting yield, and that 74 percent of rainfall is used in evapotranspiration. The maximum water use in this case is estimated at 807 mm, with a maximum yield of 6400 kg ha^{-1}.

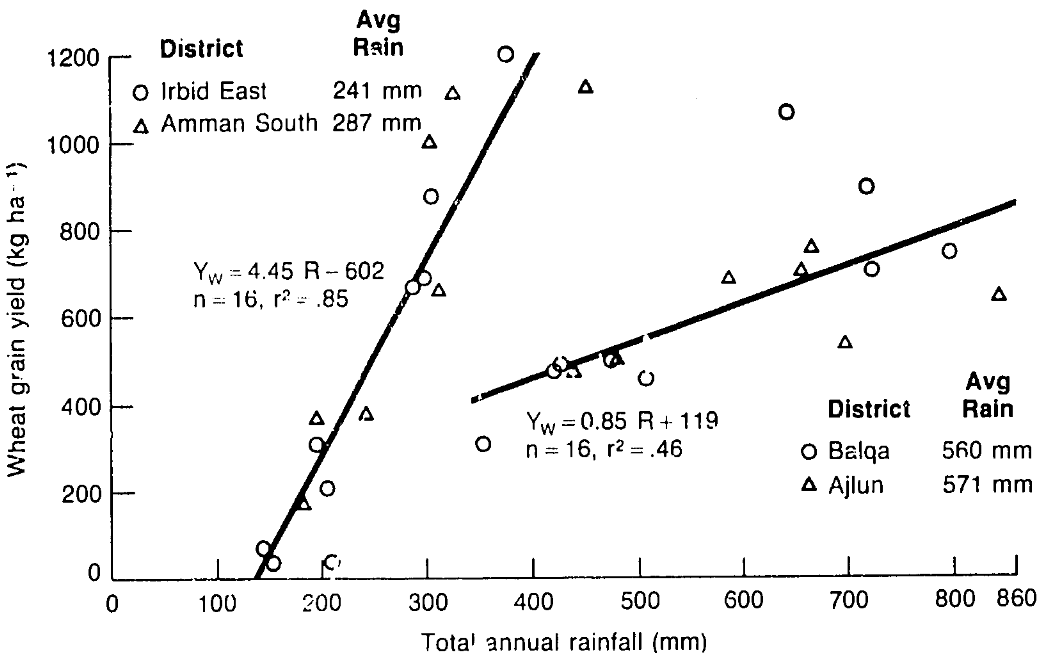


Figure 4. Relations between Wheat Grain Yields and Rainfall over the 1969 to 1977 Period in the Low Rainfall Areas of Irbid East and Amman South Governorates, and the High Rainfall Areas of Balqa and Irbid Governorates (AOAD, 1977a, 1978; Water Authority of Jordan, 1985).

The characteristics of the potential wheat yield function are derived from water production function research by the writer, by colleagues at UC Davis, by other researchers elsewhere, and by observations in Jordan. The linearity of the function and maximum yield are derived from research as above; the 74 percent efficiency of water use is suggested by the dry zone function in Figure 4 which reaches zero yield at 135 mm rainfall. Other research shows yield beginning with 100 mm of actual evapotranspiration; thus, 100/135 = 74 percent efficiency. The maximum water use of 807 mm is equal to the wheat water requirement estimated for Irbid, 597 mm, divided by the efficiency, 0.74. The curve used to estimate the wheat water requirement for Irbid may be seen in Figure 6.

Figure 6 contains two curves showing crop coefficients for estimating water requirements of wheat. These curves were developed by the writer using data gathered by W.O. Pruitt and J.L. Hatfield in four years of lysimeter studies with wheat and barley. Daily measurements of evapotranspiration from the cropped (adequately watered) lysimeter were related both to evapotranspiration from a grass lysimeter (upper curve) and to standard Class A pan evaporation (lower curve). The estimated wheat water requirement, 597 mm at Irbid, is based on Figure 6 pan coefficients and adjusted pan evaporation data from the Irbid meteorological stations averaged over a number of years. The adjustment to the data consists of multiplying the original data by 0.94 to account for two nonstandard features of the Irbid pan. These features are that it is located in a bare soil rather than a green grass compound, and it is screened against the depredations of birds and animals. The screen reduces the rate of evaporation but the bare soil condition more than compensates and the net rate is greater than from a standard pan.

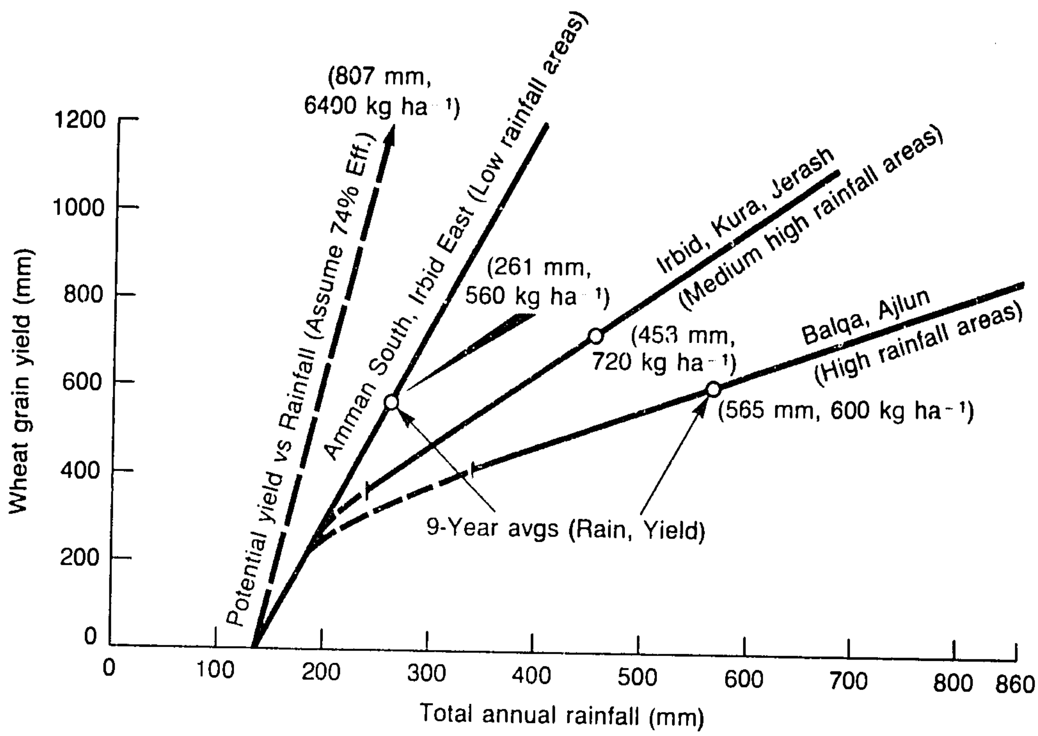


Figure 5. Relations between Wheat Grain Yields and Rainfall over the 1969 to 1977 Period in Three Rainfall Zones of Amman, Irbid, and Balqa Governorates, Jordan, Plus a Simulated Wheat Production Function for High Technology Rainfed Conditions (AOAD, 1977a, 1978; Water Authority of Jordan, 1985).

Figure 7, like Figures 3 and 4, shows water production functions based on recent data from traditional agriculture in Jordan, but for olives rather than wheat. The relationships between olive yields and annual rainfall in the medium-high and high rainfall areas, are still better than those for wheat, probably because olives use a larger and more constant fraction of the yearly total rainfall. This would include rainfall occurring before and after the wheat season, and much of that which percolates below the wheat root zone, especially into the interstices between rocks in shallow soils as are commonly found in the higher rainfall zone of Balqa Governorate.

Note that both olives and wheat in Balqa have lower water use efficiency than in the medium-high or low rainfall zones. The main reasons for this are the greater losses of water to both runoff and deep percolation, respectively, in the steeper and shallower soils of the high rainfall area, plus greater losses of nitrogen and other nutrients through leaching.

Still another point of interest in the olive production functions is their often cited propensity for alternate bearing, i.e., yielding relatively high in one year and low in the next. In both the Irbid and Balqa functions in Figure 7, the years in which yields are relatively high with respect to rainfall are the even-numbered years. Only the Irbid function will be considered in the remainder of this paper, which focuses on the performance of crops when rainfall does not exceed 400 mm.

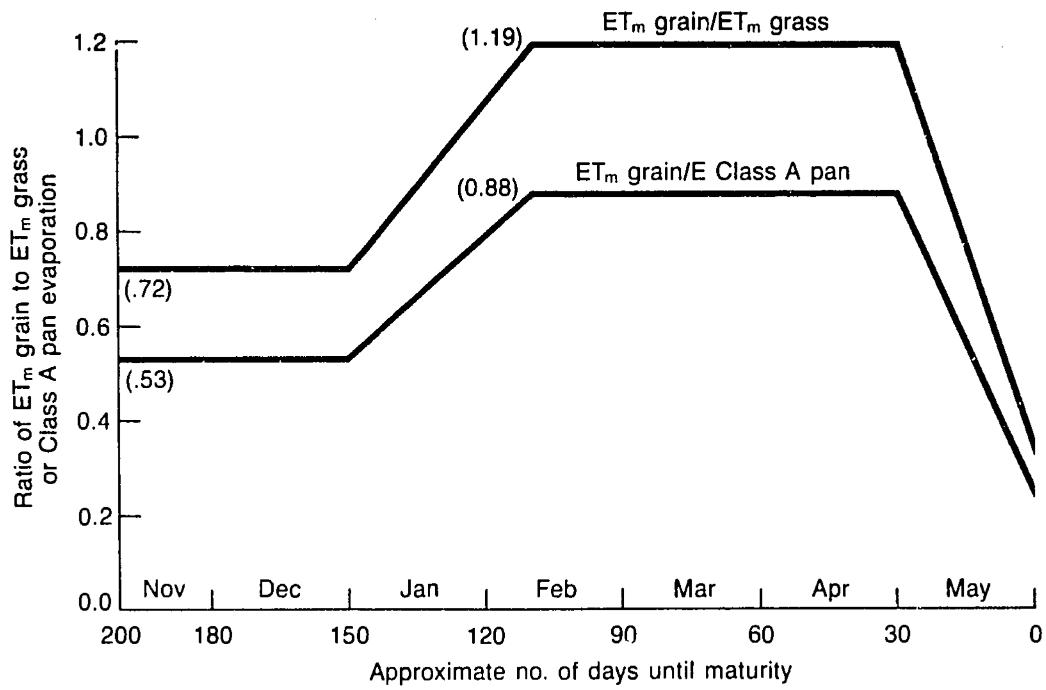


Figure 6. Curves for Use in Estimation of Water Requirements (ET_m) of Wheat and Barley in Mediterranean Zones. Based on Unpublished Lysimeter Studies by W.O. Pruitt and J.L. Hatfield on Barley (1969/70 and 1977/78) and Wheat (1976/77 and 1977/78) at University of California at Davis.

In addition to the wheat and olive water production functions seen in Figures 3, 4, 5, and 7, the yield data developed in the previously cited ACAD studies were utilized to quantify functions for barley, vetch, lentils, chickpea, and tobacco. These are for the rainfall zones of less than 400 mm per annum. They are based on area-wide yield samples over the seven years 1969 to 1975 (Amman South) or the nine years from 1969 to 1977 (all other areas). In all cases rainfall is represented by the published annual totals for the study areas in the indicated years. The functions for all seven crops are presented in Table 1.

Information Requirements for Generation of Response Farming Recommendations

Response farming recommendations are generated by combining improved information about rainfall expectations with research findings on crop responses to water. Figure 8 is an example of this kind of combination, incorporating the water production functions in Table 1 and averaged rainfall data from the Amman-Ramtha-Rihab meteorological stations.

The four vertical lines in Figure 8 show the historical rainfall means for years with onset in each month from November to February inclusive. Thus, while the overall mean is 261 mm, the means for years decline from a high of 318 mm (November onset) to a low of 174 mm (February onset).

The slopes are the crop water production functions. Each is labeled with the name of the crop and shows the yield expected at 400 mm rainfall and the rapidity with which it declines with decreased rainfall expectation. Wheat, for example, has a mean yield expectation of 813 kg ha^{-1} if onset is in November, 600 kg ha^{-1} with December onset, 386 kg ha^{-1} with January onset, and 172 kg ha^{-1} with February onset.

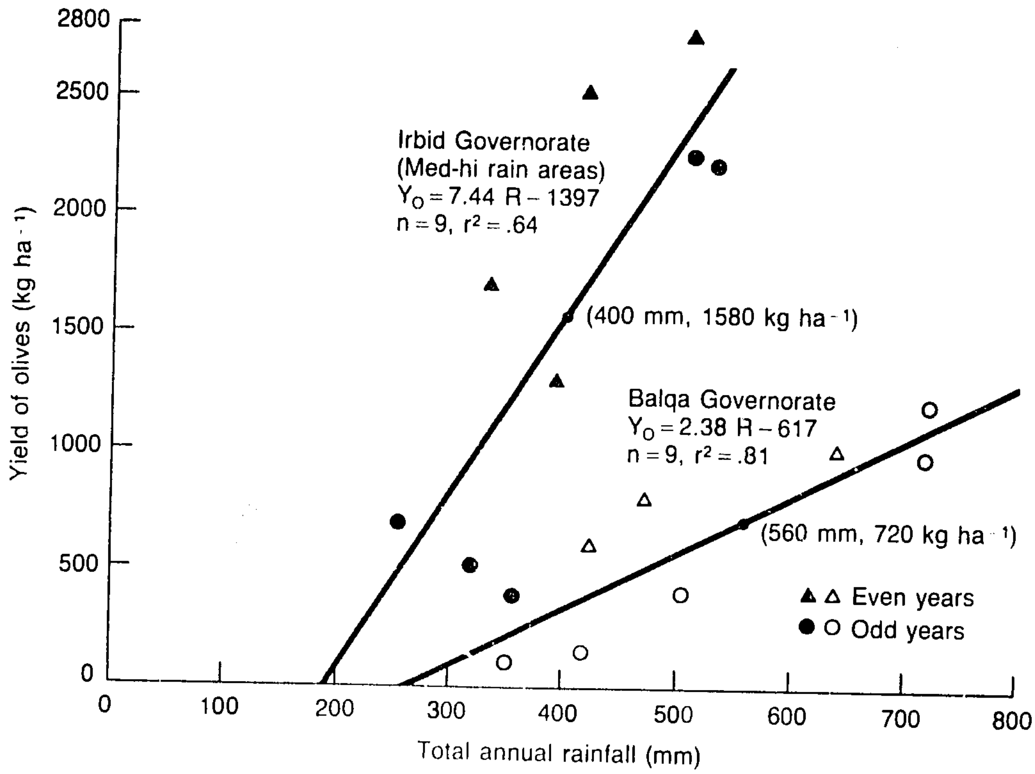


Figure 7. Relations between Yields of Olives and Rainfall in the Medium-High Rainfall Areas of Irbid and the High Rainfall Areas of Balqa Governorates, Jordan, over the Period 1969 to 1977 (AOAD, 1978; Water Authority of Jordan, 1985).

Table 1. Water Production Functions Relating Yield (Y, kg ha^{-1}) to Total Annual Rainfall (R, mm) for Seven Crops Grown in the Low to Medium (to 400 mm) Rainfall Areas of Irbid and Amman Governorates.

Crop	Water Production Function	Number of Samples, n	Coefficient of Determination, r^2
Wheat	Y = 4.45 R- 602	16	.85
Barley	Y = 4.54 R- 598	16	.61
Lentil	Y = 4.21 R- 553	16	.75
Chickpea	Y = 1.83 R + 33	16	.25
Vetch	Y = 4.43 R- 643	16	.91
Tobacco	Y = 1.41 R- 16	16	.39
Olive	Y = 7.44 R-1397	9	.64

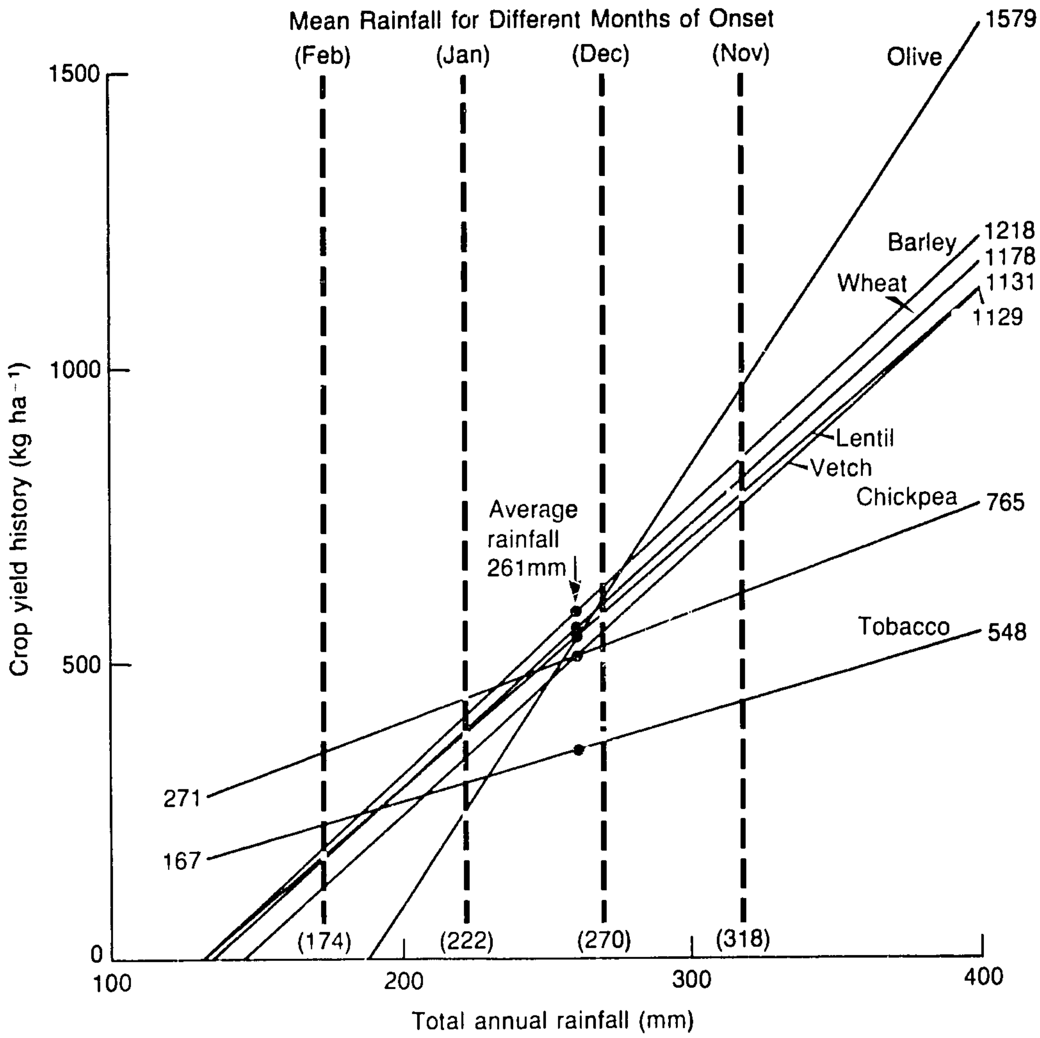


Figure 8. Comparison of Water Production Functions for Seven Crops Grown over the Period 1969 to 1977 Using Traditional Technology in the Low to Medium-High Rainfall Areas of Amman and Irbid Governorates, Jordan (AOAD, 1977a, 1977b, 1978; Water Authority of Jordan, 1985).

In contrast, chickpea yields are less than wheat with higher rainfall, but greater with lower rainfall. Mean yields for years with onset in each month from November to February are 615, 527, 439, and 351 kg ha^{-1}, respectively. This suggests that the anticipated wheat crop failures with January and February onsets (subsistence failure is 300 kg ha^{-1} or less, economic failure is 400 kg ha^{-1} or less), might be avoided by planting chickpea.

Additionally, if one were dissatisfied with the overall long term wheat yield of 560 kg ha^{-1}, one might opt for a total change to a perennial crop like olive, with a long term mean yield of 545 kg ha^{-1}. Table 2 will enable the reader to make more rapid comparisons of yield expectations of different crops with different onset dates of the rainy season. Note that these yields derive from traditional agriculture with few if any cash inputs.

Table 2. Yield Expectations† as Related to Date of Onset of the Rains, for Traditionally Managed Rainfed Crops in the Transition Zone between Relatively Well Watered Highlands and Arid Desert in Irbid and Amman Governorates, Jordan.

Crop Category	Crop Type	Mean Yield Expectations				
		Long Term Mean (261 mm)	Month of Onset			
			Nov (318 mm)	Dec (270 mm)	Jan (222 mm)	Feb (174 mm)
		.... *kg ha⁻¹*				
Cereal grains	Wheat	559	813	600	386	172
	Barley	587	846	628	410	192
Grain legumes	Lentils	546	786	584	382	180
	Chickpea	511	615	527	439	351
Forages	Vetch	513	766	553	340	128
Annual, cash	Tobacco	352	432	365	297	229
Perennial, fruit	Olives‡	545	969	612	255	0

† See Figure 8 and text for details of derivation.

‡ Figures shown are averages of all years. Due to strong alternate bearing characteristics of olives, average yields will be relatively higher than shown in even years and lower in odd years.

Final decisions about matters such as changing crops generally require knowledge of economic as well as yield expectations. Water production functions lend themselves readily to economic interpretation. Figure 9 shows how this applies in very simplified form to the information in Figure 8. The only difference is that prices have been applied to each of the seven commodities, forming water return functions rather than production functions. The prices used are farm gate prices as of November 1985.

Figure 9 bears some resemblance to Figure 8, but also has some interesting new information. As with yields, gross returns are highest with high rainfall and decline with less. Tobacco, with its high support price, is clearly the most valuable crop at rainfall levels below 360 mm. At rainfall above 360 mm, olives become still more valuable than tobacco.

If rainfall onset is in November or December, lentils are the most valuable of the grains or grain legumes, but chickpeas are more valuable with late onset and low water expectations. Table 3 summarizes the information in Figure 9.

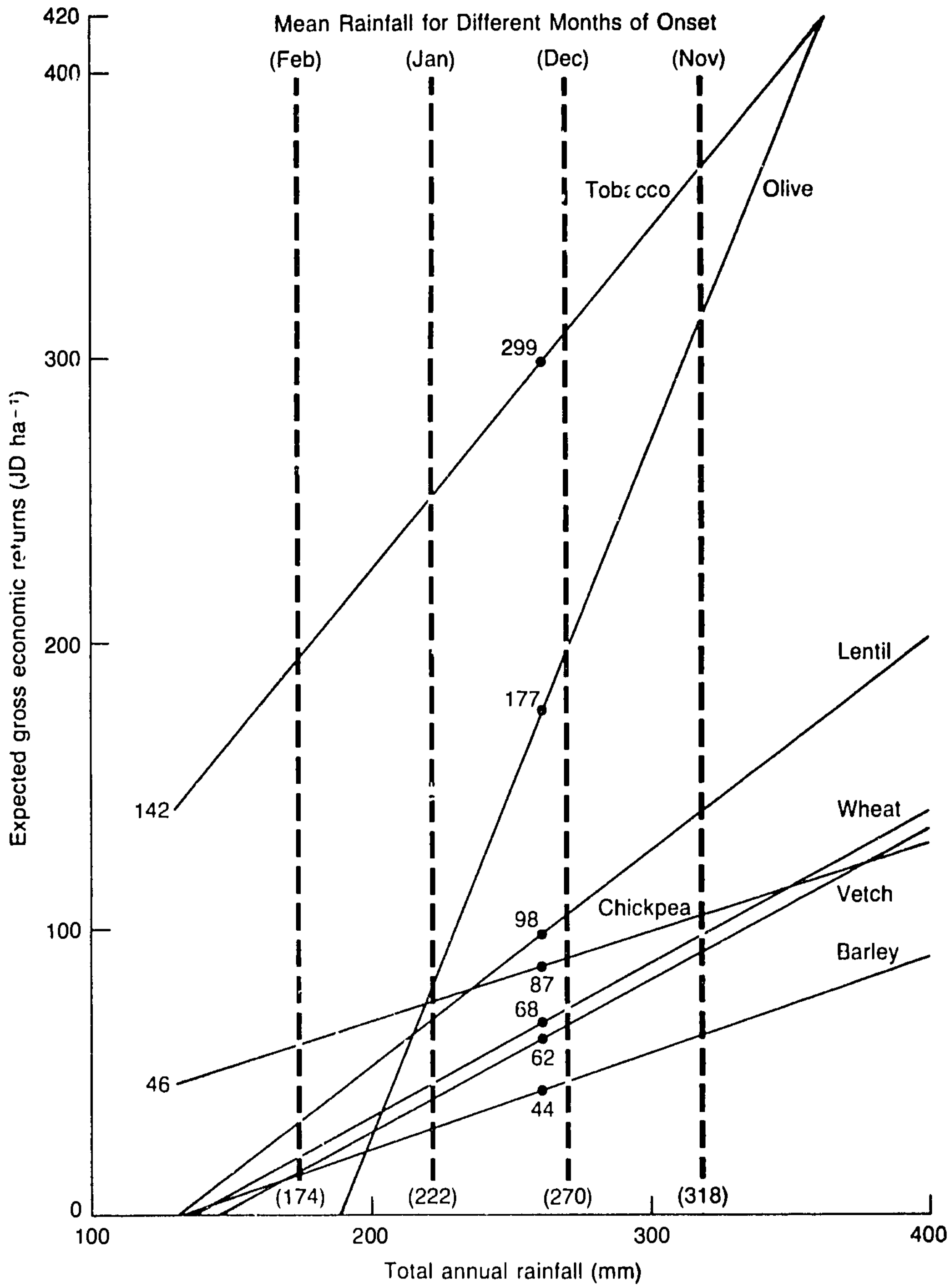


Figure 9. Gross Returns from Seven Crops Expected at Different Rainfall Levels as They Relate to Rainy Period Onset in Different Months. Units Are Jordanian Dinars with Commodity Prices as of November, 1985.

Table 3. How Expected Gross Returns† from Rainfed Crops Differ with Differing Dates of Onset of the Rainy Season under Traditional Management in the Transition Zones of Irbid and Amman Governorates, Jordan, and Long-Term Mean Rainfall of 261 mm.

Crop Category	Crop Type	Mean Gross Returns Expected				
		Long Term Mean (261 mm)	Month of Onset			
			Nov (318 mm)	Dec (270 mm)	Jan (222 mm)	Feb (174 mm)
		......	......	*JD ha^{-1}*	......	......
Cereal grains	Wheat	67	98	72	46	21
	Barley	44	63	47	31	14
Grain legumes	Lentils	98	141	105	69	32
	Chickpea	87	105	90	75	60
Forages	Vetch	62	92	66	41	15
Annual, cash	Tobacco‡	299	367	310	252	195
Perennial, fruit	Olives	177	315	199	83	0

† Commodity prices as of November, 1985. (Vetch price estimated.)
‡ Tobacco production is licensed and subsidized by the Government, with the overall payment totalling in the range of 700-1000 fils kg^{-1}. Figures are based on 850 fils kg^{-1}.

Hypothetical Example of Response Farming Guidance Development for Wheat Production in the Amman Area

The following example is based on the rainfall record displayed in Figure 1, and on these considerations and assumptions:

1) Rainfall for wheat production occurs at three levels which, with two exceptions in the 47 years, are those shown in Figure 1. The upper level is rainfall above 320 mm, or 10 of the 47 years. The medium level is from 180 to 320 mm which represents 23 of the 47 years. The exceptions are: inclusion of the year with 316 mm in mid-January, and exclusion of the year with 232 mm and onset February 23. The latter is placed in the lower level of 180 mm or less, representing 14 of the 47 years.

2) It is not possible to break even economically on wheat production at the lower rainfall level, and not likely that even a subsistence crop can be obtained. In terms of national food security, the loss to the nation by not planting in the lowest rainfall years is insignificant. Therefore, the only reason a farmer plants in these years is to reap a subsistence crop, because he greatly prefers durum wheat to the soft wheats imported by the government. Our example assumes that the rightful aim of the farmer is to plant all of his wheat land to wheat whenever rainfall is high or medium and to plant half of the area to wheat (as a gamble) in low rainfall years, with the other half devoted to alternative crops (or fallow) of choice.

3) Rainfall onset on or before January 15 will be termed early, and from January 16 onward, late. Early onset occurred 32 of the 47 years, with late (or no) onset in 15 years.

4) Nitrogen fertilizer is assumed to increase wheat yields by 20 kg ha^{-1} for each kg ha^{-1} of N applied, provided water is available to support the implied yield.

5) Water production functions describing the relationships between wheat yields (both unfertilized and fertilized) and wheat season rainfall (R) at Amman are a) Y_{Unfert} = 3.84 R season - 392, and b) Y_{Fert} = 9.5 R season - 969.

6) The aim of fertilizer application is to enable maximum yields with the expected water supply, bridging the gap between unfertilized yields and fertilized ones. Nitrogen rates shown in the example are calculated to accomplish this.

Table 4 shows the hypothetical response farming recommendations which would emerge from a study of Figure 1 and the considerations/assumptions listed. The table also shows the traditional agricultural practices and the best bet recommendations developed in the major research effort recently concluded in Jordan (ICARDA *et al.*, 1984). All of the above are compared in the upper part of Table 4, then evaluated below.

Traditional wheat production practices have the great virtue of adapting the planting area almost perfectly in accordance with wheat season rainfall. This is one of the aims of response farming also. However, to accomplish this as well as the farmers do requires planting very late, well into February in many years. This creates a number of problems, but chief among these is that the potential for high yields is lost. Accordingly, the farmers do not fertilize with nitrogen or other fertilizers, which would, together with earlier planting, better weed control, etc., enable them to realize their yield potentials.

The best bet recommendations from the Jordan Cooperative Cereals Improvement Project (ICARDA, 1984) provide the bulk of the needed inputs for higher yields, but go to the other extreme by recommending planting before the rains every year in November. The obvious problem with this approach is that all of the wheat area is both planted and fertilized every year, despite the fact that total failure can be expected in 14 of 47 years, or 3 years in 10. These failures are costly in terms of labor and capital, and may not be evident in time to turn to alternative crops.

The response farming approach takes advantage of the fact that rainfall is related to onset date to combine the better features of both the traditional and conventional research-based systems. The time scale for onset is divided on January 15 into two subsets. Early onset implies that either high or medium rainfall is expected and recommended planting practices reflect that expectation. The date of planting, based on actual time of onset, is early enough to assure high yields provided that the long range forecast is realized. Six out of ten high rainfall seasons have onset in November, with two more in December and only one more before January 15. As seen in Figure 1, the tenth high rainfall season had a late onset, and thus constitutes an exception.

Other exceptions include the three low rainfall seasons with early onset. In these years, the land would receive the initial nitrogen fertilization and all of the land would be planted, rather than the 50 percent desired. This is the major problem of the best bet recommendations, but this problem would occur in all 14 low rainfall years rather than just in 3 of them.

When January 16 arrives without rainfall onset, planting reduced hectarage (50 percent) should proceed without the use of nitrogen because either low or medium rainfall is expected, not high rainfall. Waiting for onset beyond this date should have no real effect on practices because the farmers have demonstrated that even in the worst of conditions they still wish to plant a minimum hectarage. The response farming approach causes them to move their planting date forward in low rainfall years and lets them plan ahead.

Table 4. Comparison of Wheat Farmer Traditional Practices with Recommended Practices Based on Conventional Research and Response Farming Research. Also, Evaluation of Expected Achievements from Each Approach. (Hypothetical Example for the Amman, Jordan Area with Mean Rainfall of 278 mm.)

Wheat Production Practice	Actual Practices & Recommendations from 3 Approaches			
	Traditional Farming	ICARDA Research Findings	Response Farming	
			Early Onset	Late Onset
Sowing date	Onset to tillering	Nov	Onset	Jan 16
Sowing method	Broadcast	Drill	Drill	Broadcast
Sown area	Variable, 50-100%	100%	100%	50%
Alternative crops	Various on unplanted wheat area	None	None	As selected for unplanted wheat area
Nitrogen, kg ha^{-1}	None	30 at sowing + 30 at tiller if good season	40 at sowing + 40 at tiller if good season	None at sowing, 40 at tiller if good season
Weed control	None	2,4-D ester	2,4-D ester	None
Comparative Evaluation of Matching Practices to Rainfall Yields, and Other Aims				
Planted area, % of years correct	100	70	85	
N rate, % of years correct	30	70	91	
Avg N rate, kg ha^{-1}	0	36	38	
Avg wheat yield, kg ha^{-1}	530	1150	1200	
Avg land area for alternative crops	15	0	15	

Both the best bet and response farming systems provide for the adjustment of input levels in accordance with actual amounts of rainfall received by tillering time, usually in February. If, at that time, rainfall has been above normal, additional nitrogen can be profitably added. This is in keeping with the writer's early determinations about the value of the response farming approach, and how it can be used to match farm practices with variable water supplies (Stewart, 1980; Stewart and Hash, 1982).

The evaluation at the bottom of Table 4 indicates that the response farming approach is more capable of matching agronomic practices to rainfall than either the traditional methodology or the best bet approach. In terms of nitrogen fertilizer costs, the response farming and best bet are nearly the same, but the former provides higher levels of N when needed, and none when not required. The result should be an overall average yield increase on the order of 50 kg ha^{-1}. At the same time, the response farming method reduces the basic planting effort and costs by 15 percent in seasons when the effort and time would have been wasted.

It is well-documented that Jordanian farmers have been reluctant to adopt the best bet recommendations and similar approaches from earlier studies, even though the potential benefits have been clearly established. The reasons for the low adoption rate are not entirely clear. However, a modified approach which incorporates the farmers' traditions of planting with the rains and adjusts the planting area accordingly, may find favor with them. When they see that the recommended system is based on their own traditional beliefs about rainfall, it may give them the confidence required to purchase and apply needed inputs in years of early onset.

Conclusions

The long-term record shows that Jordanian rainfall totals for the wheat growing season are strongly linked to the time of onset, the earlier the onset the higher the rainfall expectations.

Jordanian wheat farmers traditionally have demonstrated their awareness of the sensitivity to this phenomenon by delaying the start of planting until onset is clearly manifest, and the finish of planting until January or even February when it is fairly clear how much rainfall is expected. In this way they have adjusted the area planted to wheat in nearly perfect accordance with actual rainfall, planting the maximum area when high rainfall is experienced and the minimum area when lower rainfall amounts are experienced. The reductions in planted area are in all areas, wet to dry, and are based on early rainfall relative to normal for the particular area. The greatest reduction is to approximately 50 percent of maximum possible area, leaving the farmer the hope of at least a subsistence level of production even in the poorest years. Available data show these reductions have little impact on the national food supply because wheat yields in low rainfall years are so low.

The best bet recommendations for wheat production developed in the recent Jordan Cooperative Cereals Improvement Project have the major strength of introducing realistic quantities of key inputs such as fertilizers and herbicides, essential for attaining the higher yield levels indicated by actual rainfall. A weakness in these recommendations is that they require planting the maximum wheat area together with costly inputs every year, prior to the onset of the rains. The farmers' traditional behaviors are not considered. The low rate of adoption of these recommendations indicates the farmers are unwilling to commit their resources when they, in fact, have a better grasp of the situation operating in their traditional fashion.

Response farming offers the advantages of both systems by 1) institutionalizing and quantifying the farmers' lore, and by actually following it in practice, and 2) incorporating needed inputs at times and in amounts adjusted to the date of onset and early season rainfall amounts. Thus costly inputs are not called for when indications for the season are poor. This approach may be adopted with more confidence by the growers since it is based on their traditional knowledge and beliefs.

References

ACSAD. 1984. Wheat productivity under rainfed agriculture as related to soil, precipitation and management variables in Syria. ACSAD, Damascus, Syria.

AOAD. 1977a. Technical and economic feasibility study for the development of rainfed agriculture in the Amman Governorate of the Hashemite Kingdom of Jordan. Khartoum, Sudan.

AOAD. 1977b. Agroclimatological study in the Arab countries - Jordan. Khartoum, Sudan.

AOAD. 1978. Technical and economic feasibility study for the development of rainfed agriculture in the Irbid and Balqa Governorates of the Hashemite Kingdom of Jordan. Khartoum, Sudan.

Arabiat, S., D. Nygaard, and K. Somel. 1983. Factors affecting wheat production in Jordan. Jordan Collaborative Project Report. ICARDA, Aleppo, Syria.

FAO. 1982. Regional study on rainfed agriculture and agro- climatic inventory of eleven countries in the Near East region. FAO/UN Near East Regional Office, Land and Water Development Division, Rome, Italy.

ICARDA. 1984. A report on the Jordan Cooperative Cereals Improvement Project. University of Jordan, Ministry of Agriculture, Hashemite Kingdom of Jordan, and ICARDA. Aleppo, Syria.

Pruitt, W.O., and J.L. Hatfield. 1986. Provision of data from four years of lysimetry studies with wheat and barley. Unpublished. University of California, Davis. CA.

Stewart, J.I. 1980. Effective rainfall analysis to guide farm practices and predict yields. Proc. 4th Annual General Meeting of the Soil Science Society of East Africa. Arusha, Tanzania. October 1980.

Stewart, J.I., and C.T. Hash. 1982. Impact of weather analysis on agricultural production and planning decisions for the semiarid areas of Kenya. J. Appl. Meteorol. 21:477-494.

Stewart, J.I. 1986. Mediterranean-type climate, wheat production and response farming. Companion presentation, this Workshop.

Water Authority of Jordan. 1985. Rainfall in Jordan, daily at all stations, 1976-80; Annual records, all years, all stations. Amman, Jordan.

Water Authority of Jordan. 1986. Provision of long term daily rainfall record for Old Amman Airport and other stations.

SECTION VI
Working Groups

Concepts of Systematic Commodity/Resource Analysis and Development Process as Applied to Rainfed Agricultural Development Projects and Regional Soil-Water Management Programs

T. Izumi
University of Hawaii and Jordan Highland Agricultural Development Proj. Amman, Jordan

ABSTRACT. The College of Tropical Agriculture and Human Resources at the University of Hawaii has developed a planning and management system to ensure that its instruction, research, and extension programs meet the needs of the agricultural industries and other concerned sectors in Hawaii. It is believed that with appropriate modification, this system can serve as a practical model for agricultural development in less developed countries. The Systematic Commodity/Resource Analysis and Development (SCRAD) Process has been used in Jordan to plan the Highland Agricultural Development Project. During this Workshop the SCRAD Process was used to: 1) identify the components of an effective soil-water management program; 2) identify constraints that prevent the realization of those components; and 3) identify some actions that could be used to overcome the constraints. Results of this exercise are presented. It is concluded that 1) the SCRAD Process is simple; 2) it assists people in thinking systematically about components of the agricultural sector within the larger socioeconomic system; and 3) the major limitations to the adoption of sound soil-water management practices are largely socioeconomic.

The Agricultural Planning and Management System Developed at the University of Hawaii

Like all other American land-grant agricultural colleges, the basic mission of the College of Tropical Agriculture and Human Resources (CTAHR), University of Hawaii, is to carry out instruction, research, and extension programs that meet the needs of the agricultural industries and related businesses in the State of Hawaii. However, the manner in which the College has organized itself and how it plans and manages its programs is somewhat unique. It is believed that with appropriate modifications, the system developed by the CTAHR can serve as a practical model for agricultural research, extension, and development in developing countries.

Organization and Management System

In the mid-1970s, the CTAHR undertook a major reorganization to improve the coordination of research and extension so that the latter functioned as a continuum/feedback source of the former, and to set program priorities that concentrated on the needs of the agricultural sector and communities in the state as well as those of the academic disciplines. Thus, the Hawaii Institute of Tropical Agriculture and Human Resources (HITAHR), which amalgamated research and extension into a single administrative unit, was established (Prior to this, Hawaii had the traditional structure of separate units for the Hawaii Agricultural Experiment Station and the Cooperative Extension Service). Perhaps more crucial than the organizational structure has been the planning and management systems that CTAHR has adopted to ensure that programs focus on the current and future priority needs of the state's agricultural sector, communities, families, and consumers as well as the needs of the disciplines.

Planning for discipline-oriented programs is undertaken by multidisciplinary faculty groups as well as by individual departments. Some of the programs that were planned in this manner are integrated pest management, biotechnology, biological nitrogen fixation, benchmark soils and agrotechnology transfer, agricultural production systems, crop modeling, computer applications and education, aquaculture, pesticides, and human resources. In addition, all of our departments are required to undertake program reviews in conjunction with annual budget allocations and departmental/college staffing plans.

The College has developed a commodity and resource subsector analysis process which draws upon representatives (farmers, cooperatives, agribusinesses) from the subsector and pertinent county, state, and federal agencies, and a multidisciplinary team of research and extension faculty to conduct a comprehensive analysis of that commodity/subsector. The analysis determines the bottlenecks preventing that subsector from achieving its full potential and sets priorities for actions to be taken by each applicable agency and the farmers themselves to overcome each of the bottlenecks. This includes the estimated cost, time required, and probability for success of the actions. When accepted by representatives from the subsector, the subsector analysis/action plan is presented to the Governor's Agriculture Coordinating Committee (GACC). If accepted by the GACC, it becomes an official part of the State of Hawaii's functional plan for agricultural development. The GACC provides grant funds to the College to support research and extension projects determined by the commodity/resource analyses to be of high priority. Such commodity/resource analyses have been conducted or are in process for all major crops and are updated periodically.

1) Since the commodity/resource analysis process was initiated, 58 analyses involving 25 major commodities have been completed: three for the fourth time, seven for the third time, eight for the second time, and the remaining seven for the first time.

2) These commodities represented 94 percent of the total 1984 farmgate value of commercial crops grown in the state. Thus, the coverage of major agricultural crops by the commodity/resource analysis system is nearly complete.

3) Approximately 60 percent of the agricultural research projects in the College are directed at eliminating bottlenecks identified through commodity/resource analyses.

The commodity/resource analysis process, as modified for the Jordan Highlands Agricultural Development Project (JHADP), will be described later in greater detail.

Factors Essential to Success

There are several factors that have been essential to the success of the University of Hawaii's system. These are:

1) The establishment by law of a high level coordinating body to ensure that all relevant agencies as well as growers participate in the planning, approval, and implementation of agricultural development projects.

2) The amalgamation by the CTAHR of research and extension functions into a single unit so that the organizational structure will facilitate, rather than hinder, the planning and management of programs/projects.

3) The adoption of a systematic agricultural industry (commodity/resource) analysis process to identify problems and set priorities for actions designed to overcome such bottlenecks. The process not only has wide participation but has gained the acceptance and commitment of farmers and other affected individuals who themselves set the priorities.

4) The availability of funds, appropriated by the state legislature, which enables the GACC to make grants to the University and private sector organizations to initiate follow-up actions.

These features have been retained in the planning of the JHADP.

The Jordan Highland Agricultural Development Project

Similar to other countries in the region, formal responsibility for agricultural research and extension in Jordan has been vested in the Ministry of Agriculture (MOA), Directorate of Research and Extension (DRE). In practice, however, agricultural research and extension have also been carried out by the University of Jordan, Faculty of Agriculture (UOJFA), the Jordan Cooperative Organization (JCO), private sector companies, and by various projects past and present. Due to problems of resource and administrative constraints, DRE has experienced problems in carrying out its responsibilities.

One of the immediate purposes of the JHADP is to strengthen and institutionalize Jordanian (both public and private sector) agricultural technology development and transfer capability in support of highland development. This is to be accomplished by establishing an organization that will amalgamate research and extension in recognition of the fact that functionally they constitute a continuum of knowledge development, transmission, application, and feedback; provide for systematic planning and management of programs and projects; and serve as a mechanism for utilizing available public and private sector resources and channeling and coordinating their efforts toward agricultural development of the highlands.

Organization and Management Principles

The basic principles that guided the organization and programs of the JHADP were as follows:

1) The JHADP will provide for the establishment of technology development and transfer capability predominantly for rainfed highland agriculture. A National Center for Agricultural Research and Technology Transfer (NCARTT) and a high level agricultural development council to give direction to the planning and implementation of government and donor-sponsored projects should be established.

2) The NCARTT should have the flexibility to address high priority needs as they are identified through continuous analysis of the agricultural development requirements of the highlands and compatible regional and international needs through networks for exchange of information and technology.

3) The NCARTT should take advantage of available research capabilities and focus on the adaptation or improvement of imported or locally available technology instead of conducting research from scratch.

4) The development and delivery of technology and services should be based on multidisciplinary team approaches comprised of both research and extension components and involve farmers, cooperatives, and other private sector interests that will be affected by the project.

5) In addition to providing field research support, district agricultural service centers should be established to serve as a focal point for demonstration, workshops, information dissemination, and responding to individual requests for assistance or service.

6) The NCARTT should provide technical, analytical, and diagnostic services in support of research projects, farmers and other clientele groups and selected private sector industries serving the highlands.

7) The NCARTT should work in close collaboration with other units of the MOA, UOJFA, Yarmouk University Faculty of Agriculture (as it is developed), JCO, ACC, regional and international organizations, and appropriate private sector companies.

8) The NCARTT should serve as a repository for information on rainfed agriculture in Jordan and participate in regional and global agricultural information networks.

In accordance with the above principles, the JHADP has instigated establishment of three important organizational components which must work together if agricultural development projects in Jordan are to be successful. They are described below.

Agricultural Development Steering Committee (ADSC). By action of the GOJ, this Committee will act as the coordinating body for establishing priorities and allocating responsibilities and resources for action programs that will cover the whole Kingdom, including the Jordan Valley and any future projects for the desert areas. It will also act as a review and approval board for recruiting and appointing staff for the project. The ADSC will be comprised of senior ministry and other GOJ officials plus representatives of farmers and the private sector. It will have a Secretary General and necessary support staff to handle day-to-day requirements.

National Center for Agricultural Research and Technology Transfer (NCARTT). This Center will be developed through resources and technical assistance provided by the JHADP and will have formal responsibility for the introduction and testing of technology and its extension to farmers, cooperatives, and the private sector. NCARTT will be comprised of a headquarters for its administrative and planning staff, central research laboratories, and the subject-matter specialists who carry out the SCRAD process and supervise the field work, and a series of Regional Agricultural Service Centers.

Regional Agricultural Service Centers (RASCs). These Centers will be staffed by Agricultural Service Officers (ASOs) and be the sites for applied research, on-farm demonstrations, farmer and private sector training, and other extension activities. These include testing and adapting new technology appropriate to their locality, demonstrating the technology to users, promoting its adoption, and providing training in its use. They may also provide facilities for JCO or other service activities. Five of these Centers are projected for the highlands and construction will be financed for the most part with loan funds under the JHADP. The existing Jordan Valley Service Project at Deir Alla will be the RASC for the Jordan Valley.

Planning, Management, Evaluation System (SCRAD Process)

One of the primary functions of the JHADP will be to establish an ongoing planning, management, and evaluation system based in the concepts of systems analysis. An overview of program elements for national, agricultural sector, and subsectors (crop and livestock) is shown in Table 1. Program elements for other programs, including those for soil water management, must be separately defined. As planned the Systematic Commodity/Resource Analysis Development (SCRAD) process would involve the following:

1) The Commodity Multidisciplinary Team Leader (CMTL), usually the subject-matter specialist for the commodity, forms a multidisciplinary team comprised of UOJFA and NCARTT researchers, other specialists, agents, and others most knowledgeable about the commodity/resource to: (a) analyze its economic potential as a commodity subsector; (b) identify the constraints preventing the subsector from achieving its full potential; and, (c) outline the steps needed to be taken by NCARTT/RASC, applicable GOJ agencies, donors, UOJFA and other research organizations, cooperatives, and the farmers themselves to solve each constraint. Each component is examined. For crops the elements are: land; water; labor; capital; improved cultivars; insect; disease; weed and other pest controls; culture and management (fertilization, spacing, cultivating, pruning, etc.); harvesting; post-harvest handling; processing; transportation of products to market; marketing (market development and promotion, supply, demand, and price analysis); waste management; cost of production; farm management; and government policies, laws, and regulations. Similar components with appropriate modifications are analyzed for livestock subsectors. This phase of the process results in a Commodity Analysis Worksheet. The preparation of the Worksheet is the responsibility of the CMTL. A sample Worksheet is shown in Table 2.

Table 1. Planning Overview and Program Elements

National Development	Agricultural Sector Development	Subsector Development	
		Crop Subsector	Livestock Subsector
Infrastructural	Long-Term Commitment	Water Resources	Water Resources
	Sustainable Natural Resources (Land, soil, water, forest, range)	Land/Soil	Land
Water/Wastewater	Infrastructural Requirements (water, transportation, energy, communications, etc.)	Capital/Credit	Capital/Credit
Land Use	Human Resources (training, staffing, personnel policies)	Labor	Labor
Transportation	Inputs and Services (cooperatives, credit, machinery supplies, etc.)	Improved Cultivars	Improved Breeds
Energy	Technology Development and Transfer	Insect Control	Control of Insects and External Parasites
Communications	Improved and Alternative/New Commodities (2)	Disease Control	Control of Diseases and Internal Parasites
Government/Legal	Crop Protection	Weed Control	Protection Against Toxic Chemicals, Poisonous Plants, and Other Hazards
Financial	Farming Systems	Control of Other Pests	Reproductive Performance
Social	Processing	Culture and Management	Nutrition
Housing	Marketing	Harvesting	Environmental Stress
Health	Nutrition and Dietary Improvement	Post-Harvest Handling	Production Systems
Education	Socioeconomic Considerations and Programs	Processing	Waste Management
Social Services	Private Sector Development	Transportation to Market	Slaughter
Arts & Culture		Marketing	Processing
Production/Service		Production Economics	Transportation to Market
Agriculture/Agroforestry/Forestry (1)		Farm Management	Marketing
Fisheries/Mariculture/Aquaculture		Government Policies, Laws & Regulations	Production Economics
Tourism			Pasture/Ranch Management
Industry/Manufacturing/Processing			Government Policies, Laws and Regulations
Business/Commerce/Trade			

Table 2. Example Work Sheet.

WORK SHEET____

Priority	Bottleneck	Action Required	Agency Responsible	Possibility of Success	Duration	Resources			Impact if bottleneck not eliminated
						Required	Allocated	Supplement Source	

2) The Worksheet is then circulated among members of the multidisciplinary team and to other GOJ agencies for comments, corrections, and revisions. Subsequently it is given full distribution, including interested leaders and representatives from the commodity subsector (e.g. farmers, producers, etc.), cooperatives, and the private sector. A notice of a meeting is also enclosed so that the individuals are able to study the Worksheet ahead of time.

3) A meeting of all participants is called, at which time the bottlenecks for each component are thoroughly discussed and revisions are made to the Worksheet. The constraints are identified and the subsector representatives, through open voting, set the priority order for solving each of the bottlenecks (the other participants may act as resource persons but do not take part in the voting).

4) After the priorities have been decided, the Worksheet is finalized into two documents. The first document provides a narrative analysis of the constraints for each component: land; water; labor; etc. The second document is the Draft Action Plan, which orders the constraints according to priority, the actions required to overcome each constraint, the agencies/farmers/private sector responsible for taking action, the possibility of success, the estimated time needed to complete the required action, the amount and source of available or required resources, and the impact if the constraint is not eliminated. For new commodities it may be necessary to rely on whatever information is available and the judgment of the commodity multidisciplinary team until subsector leaders begin to emerge.

5) The Analysis Action Plan is presented to the ADSC. Upon approval by the Steering Committee, the Analysis Action Plan becomes the official plan for development of the commodity/subsector.

6) A researcher or subject matter specialist (SMS), usually a member of the multidisciplinary team for that commodity, is asked to propose a research/extension project to overcome a priority bottleneck. The project, after approval of the NCARTT Director, is presented to the ADSC. Upon its approval, the ADSC will allocate funds to the project. A researcher or an SMS becomes the Project Principal Investigator and may request other researchers or specialists to participate as co-investigators. The project proposal will include a description of the project objectives, the research design or activities to be carried out, an estimated budget, and procedures for evaluating project accomplishments. Projects may also be proposed by UOJFA, international centers such as ICARDA, the JCO, or the private sector, in which case a contract would be drawn up between the ADSC and the contracting agency.

7) A project account is set up for each project to be conducted within the NCARTT, and expenditures are made in accordance with established fiscal and personnel procedures. Projects to be conducted by outside agencies under contract are also to be reviewed at least annually.

8) The commodity/resource analysis for a commodity/subsector is revised periodically (usually every two or three years). Revisions are based on a progress report for the subsector which is prepared through the same multidisciplinary team process. The report indicates the bottlenecks that have been resolved, the status of each remaining bottleneck and new problems or needs that have emerged.

9) The SCRAD process may be adapted to analyze other types of programs such as farming systems improvement and soil-water management programs at either the regional, national, or local levels.

Agricultural Development Fund (ADF)

The ADF is an extremely important component and perhaps the fuel that will drive the engine of the JHADP. It is the primary source of funds for allocations by the ADSC to finance follow-up actions. It will provide the incentives for farmers to participate in land aggregation and demonstration projects; the ability and flexibility to purchase contract services for research, farm machinery operation, or any other purpose from universities, international organizations, governmental and parastatal agencies, and the private sector based on who is best equipped or able to provide that service; and the financial means to lessen the risk taken by the farmers and others who provide inputs to the agricultural sector.

The USAID funded portion of the ADF has four basic components.

Land Consolidation ($1,000,000). Land fragmentation is a major obstacle to the economic use of mechanized farming. This account will be used to fund several land consolidation schemes on a demonstration basis. This can be achieved through a number of ways such as consolidation of family holdings, a cooperative such as JCO, a custom operator, village association, partnership, tenant farming, etc. The money will be used to realign walls, remove boundary fences, provide legal services to draw up agreements, surveys, and stake boundaries in ways that would not impede the use of tractors and other farm machinery, etc. The land consolidation account should be used only for those individuals that agree to participate in an on-farm demonstration. The criteria should be as follows:

1) Land titles are not in dispute.

2) There will be only one farm manager or operator for the whole combined parcel, there is agreement between all the landowners on that individual's choice, and the loan approval committee or its equivalent is satisfied as to the farm manager/operator's qualifications.

3) The owners agree to participate in an on-farm demonstration project, which will commit the farm manager/operator to follow prescribed methods, to allow publicity and visitations by interested parties, to agree to make cost and profit/loss data available to other farmers, and to cooperate in demonstration activities.

A number of demonstrations illustrating the different modes of consolidation should be utilized.

On-Farm Demonstrations ($650,000). This account will be used to underwrite the cost/risks of farmers who agree to participate in on-farm demonstrations. The funds will be used to pay or underwrite land rental and labor that the farmer contributes, plus the cost of production inputs such as custom operator fees, seed, fertilizer, pesticides applications, livestock animals, feed, etc. The net profit, after these expenses have been paid from the sale of the crop/livestock, should be divided between the farmer and the demonstration account. The share of profits accruing to the account should be sufficient to underwrite new demonstration projects on a revolving fund basis.

Equipment Loan Guarantee ($350,000). This account will be used as a fund to insure farm equipment loans made by the ACC against defaults on a self-insured basis. Borrowers will be required to make a down payment. Since the equipment is used as collateral, there should be little or no need to utilize this account if the loan program is administered properly.

International Technical Support ($1,000,000). This account will be used to acquire technical assistance and research services from international centers and other non-Jordanian sources on a contractual basis.

Other SCRAD Action Plans. The Jordanian portion of the ADF is expected to total $6,750,000 over the seven-year life of the project. It will be used to finance the priority actions developed through the SCRAD process. Allocations will be made to the appropriate public or private sector contractor as indicated in the SCRAD/action plans and as approved by the ADSC.

Implementation with Emphasis on Integrated Multidisciplinary Programs and Farming Systems

The Subject Matter Specialist (SMS) most familiar with a commodity will usually serve as a Multidisciplinary Team Leader (MTL). The team will be comprised of other SMSs, Regional Agricultural Services Officers, university and NCARTT researchers, and private sector specialists as appropriate. Related commodities will be aggregated into a program with one of the MTLs serving as Chairman for purpose of coordination. Programs, in turn, will be further aggregated into farming systems. Farming systems will have a designated overall coordinator chosen from among the Program Chairmen. Figure 1 illustrates the relationship of commodity/resource, programs, and farming systems.

There is a significant amount of improved agricultural technology available and deliverable to the Jordan highlands. This is particularly true in cereal grain production. It is estimated that only 20 percent of previous research results on wheat production in Jordan have been adopted to date. Livestock production could be substantially increased by improving the nutritional regimes and management of the animals. Range improvements could significantly increase grazing capacities. Forest watershed technology could result in fewer fires, reduced erosion, more grazing area, and forest products from existing and reforested areas. There is also extensive information on fruits, particularly olives and grapes, dryland vegetables, and trees that should be introduced and tested locally. The project will focus initially on these farm-ready technologies based on priorities revealed by the SCRAD analysis of each commodity/resource subsector. As of this Workshop (January 1986), the JHADP was only in the pre-implementation phase.

The Role of Soil-Water Management Programs in the Development of Rainfed Agriculture

The single most important limiting factor in rainfed agricultural production is rainfall, or water. Closely related to water are soils and plant nutrition. Additional important elements are temperature, air humidity, wind speeds, and solar radiation. Together they comprise the agroclimate which influences crop selection and other production management decisions.

At this point in time, temperature and solar radiation are factors largely beyond man's control, as is rainfall. Management of the soil and the water provided by rainfall, however, can be achieved and is necessary for the long-term improvement and success of rainfed agricultural production.

Although a separate project on remote sensing is planned, the JHADP has not provided explicitly for a soil-water management component. This Workshop has thus served as a strong reminder to correct this oversight when detailed implementation planning for the JHADP through the SCRAD process is carried out.

In the best of worlds, how would a planner approach agricultural development planning for a largely rainfed area such as the Jordan highlands, and what role would soil-water management play in that process? Recognizing that the preparation of such a plan would be highly complex and its implementation would require years, perhaps decades, of effort as well as an indeterminate amount of resources, a somewhat brief and simplistic analysis will be made of the basic steps involved.

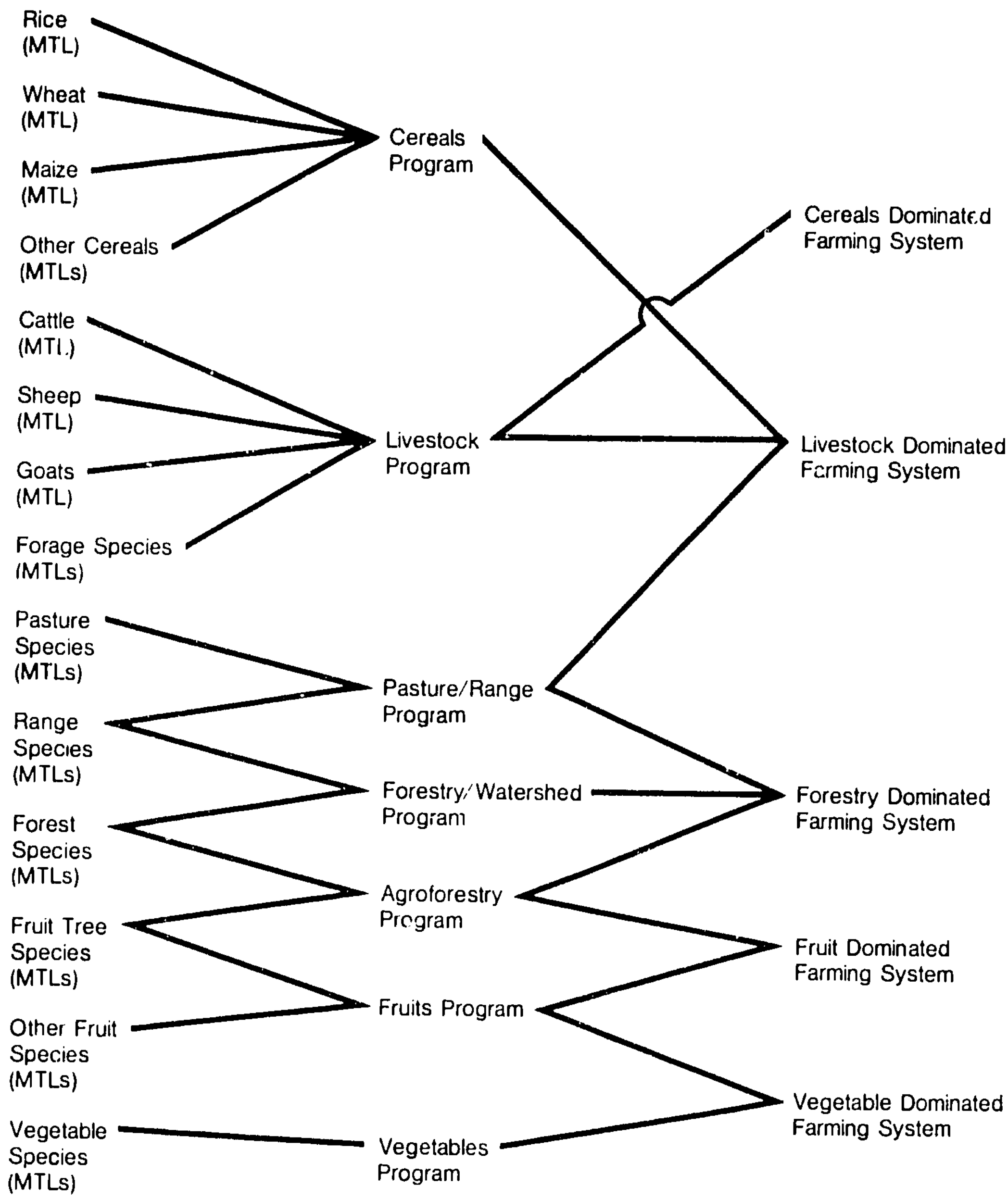


Figure 1. Interrelationships among Commodity/Resource Programs, and Farming Systems.

Land Use for Rainfed Agriculture

Because certain types of crops have specific agroclimatic requirements, it would be logical to identify suitable agricultural land use in a rainfed area based on agroclimatic zones.

Until recently, the classification of soils was not standardized and mapping of soils and topography have depended on extensive, time consuming, and highly expensive aircraft and ground survey methods. Because of its greater potential and use, the USDA Soil Taxonomy should be adopted. Space age technology offers powerful tools for soil mapping through satellite remote sensing that can subsequently be verified through less expensive methods such as selective soil surveys and analyses.

Rainfall, temperature, and solar radiation can be measured and monitored through agroclimatic data loggers. Advances in electronics have made battery-driven devices available for about $2,000 each, enabling installation in many more locations than previously possible.

Agroclimatic mapping is now reaching the realm of economic feasibility. Such mapping will provide the data needed to identify suitable agricultural uses by agroclimatic zones. The categories of agroclimatic zones/land uses are:

1) Forest/watershed;

2) Range/livestock;

3) Crop production; and

4) Nonagricultural/urban.

These are broad categories which require delineation.

Determination of Optimum Utilization Within Agroclimatic Zones

Soil classifications, indicative of the physical, chemical, biological, and behavioral characteristics of different soil types, together with the climatic factors of the locale, can be used to guide the optimum use of lands within agroclimatic zones.

The most pertinent factors, it would seem, are the water absorption/retention and nutrient availability/retention characteristics of the soil. Because certain trees and crops are known to be suited to certain soil and agroclimatic conditions, it is a matter of finding the right match. Crop selection can be based on crop performance data from other parts of the region and the world that possess similar soil and agroclimatic conditions. The proposed Rainfed Agriculture Information Network (RAIN) project is designed to provide such information on a systematic basis. Although additional trials should be conducted to determine the most suitable varieties and the best management techniques to be used, long and expensive experiments can be avoided.

Crop performance should be monitored under different rainfall and temperature conditions. It is known, however, that proper soil-water and cultural management practices can increase or maintain crop production even under poor rainfall conditions.

Forest/watershed zones should be subdivided into areas according to the most suitable varieties of trees and/or ground cover.

Rangeland zones should be subdivided into areas according to the most suitable varieties of range grasses and other vegetation and the type of livestock most suited to such vegetation and agroclimate.

Cropland zones should be subdivided according to the most suitable varieties based on soil types, agroclimate, and topography. Categories are fruits and their varieties, cereals/grains and their varieties, vegetables and their varieties, and so forth.

Such zoning does not mean that experimentation should be discontinued on new crops with potential for introduction. In fact, information from the RAIN and similar projects, such as the University of Hawaii's International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT), would encourage such experimentation through the transfer of agrotechnology among similar agroclimatic zones without the need for extensive research.

Storage, Conservation, and Efficient Use of Water

Another important component of effective rainfed agricultural production would be the capture, storage, conservation, and efficient use of scarce rain water.

This aspect of soil-water management would fall into several broad categories as follows:

Runoff/Erosion Prevention/Water Catchment Techniques. There is a wide variety of actions that can be taken, ranging from damming, afforestation and ground cover, retaining devices and walls, terracing, and small-scale water catchment techniques.

Tillage/Mulching Techniques. There is growing awareness of the importance of conservation tillage based on the soil, topography, climatology, and the crop involved. The benefits of mulching seem to be more universally acknowledged. Some preliminary work done in the West African Sahel at Niamey, Niger, indicates that mulching has a long-term, cumulative beneficial effect even under the poorest soil and drought conditions.

Fallow Techniques. It would seem that proper fallowing can make a significant difference in the moisture retention capacity of cropland soils, and that this can have an impact on whether next season's crop has a good or poor start, especially if it is a dry year.

Effects of Livestock and Crop Residue Practices. Traditional grazing practices leave little or no crop residues during fallow for replenishment of organic matter in the soil, water conservation, and erosion control. The most effective way of overcoming this problem would be to develop barley/legume forage crops to replace the use of crop residues (mostly wheat hay), that have little or no nutritional value as feed. Another option is to develop compost from treated sludge and garbage to replenish organic matter.

Stress Resistant Cultivars. Many existing plants are acclimated to the local agroclimatic environment. The search for new or improved cultivars should be continued through the introduction and testing of promising varieties from similar agroclimatic areas of the world. Pest as well as drought resistance should be sought.

Control of Weeds. Weeds and other harmful plants are fierce competitors for scarce water and must be controlled. Weeds also can be the hosts for insect pests and plant diseases.

Potential Applications of Biotechnology. Control of soil and water behavior through biotechnology, development of stress resistant cultivars through genetic engineering, and growth and yield regulators are some of the obvious biotechnological applications that have potential for improved soil-water management practices.

All of these soil-water management practices should be incorporated into farming systems for both large and small scale operations. The right combination can be found through experiments which also serve as demonstration trials.

Legal, Social, Economic, Organizational, and Management Aspects of Soil-Water Management Programs

There are many soil-water management practices that can be implemented inexpensively through existing research and extension programs. However, many projects are large and expensive. An example is comprehensive watershed development. It is crucial, therefore, that economic analysis be performed to ensure that the benefits will justify the costs.

Important legal considerations are land inheritance, landlord-tenant arrangements, agricultural and conservation zoning, and soil and water development, use, and conservation laws. Other laws that provide disincentives or incentives to land-owners/tenants to practice proper soil-water management should also be reviewed. Traditional land inheritance laws have resulted in excessive land fragmentation which makes mechanized operations uneconomical. The needs of women who are important participants in the agricultural sector also need attention.

Finally, institutional staff and management capabilities must be developed if they do not exist. Otherwise, even the best of plans will not materialize.

The JHADP places primary emphasis on reorganization of the research and extension functions of the Ministry of Agriculture and the adoption of new management systems adapted from Hawaii to the Jordanian situation. Similar efforts will be needed in those countries of the region where effective agricultural technology development and transfer capabilities do not exist or are inadequate.

Application of Basic SCRAD Concepts to Soil-Water Management Program Planning

So far, the SCRAD process has been used successfully in Hawaii to analyze and prioritize action plans for 24 commodities and one major natural resource—forestry. It was decided to test at this Workshop whether the SCRAD process could be adapted and applied to plan a soil-water management program. Accordingly, this paper has approached soil-water program planning from the point of view of a management/planning specialist rather than a soil or water resource scientist. The technical aspects of soil-water programs were discussed in papers presented at the Workshop by soil, water, natural resources, and crop management scientists and economists.

Unfortunately, there was insufficient time to fully apply the SCRAD process. Rather, participants were divided into working groups to carry out the first three steps of the SCRAD process: 1) to identify the components of an effective soil-water management program, 2) to identify the constraints that prevent the realization of those components, and 3) to identify some actions that could be taken to overcome the constraints. Results of the exercise are presented below.

Current Status and Potentials of Soil-Water Management Programs for Rainfed Agriculture in the Region

Historical Perspectives. Many areas throughout the region were once covered by forests. The cutting of the trees to clear farm lands and for fuel has virtually eliminated the forests. Attempts at reforestation are making progress but there is a long way to go.

There is evidence that water catchment techniques such as retaining walls and terracing have been practiced quite widely and this provides an historical basis for renewed efforts in this area.

Current Status. The combination of dry years and decades of overgrazing has caused adverse effects on vegetation, low organic matter in soils, and poor water retention/soil erosion, especially in rangeland areas. However, recent demonstrations in Tunisia and Morocco point out that range revegetation and grazing management are feasible and can yield immediate and long-term benefits.

Partly in response to governmental pricing policies, there has been a tendency to push crops beyond their suitable agroclimatic zones. For example, wheat is grown at elevations and on topography where fruit and other trees should be grown, and in drier areas where barley should be grown or rangeland grasses and shrubs would be more suitable. This practice not only places considerable stress on soil-water resources and management but it results in poor yields. It would be better to get a good yield of barley or forage, use it to feed the sheep, and sell the lamb and milk products, which would bring more profit than a poor yield of wheat.

Due to lack of knowledge a[illegible]economic factors, very few modern soil and water management practices have be[illegible]opted by the average dryland farmer in Jordan and in other parts of the region. Alth[illegible] there are many projects (some very large) dealing with watershed and soil-water mana[illegible]ent, few are part of comprehensive program plans. Although implementation of long-range plans must be done incrementally in projects that are economically feasible, such projects should be part of a comprehensive soil-water management program.

There are abundant technologies throughout the world that are available for transfer, but there is a lack of mechanisms for systematic information exchange, and little organizational capacity and few personnel trained to receive and carry out such technologies in an institutional framework.

Future Potential. The importance of soil-water management programs in rainfed agriculture has been recognized and actions are being initiated to begin planning on a national and international/regional basis. This Workshop was a prime example, and it is hoped that it will provide just such an impetus.

The RAIN project would be crucial to facilitating information exchange and technology transfer in the Near East region, and concomitantly lessen the economic burden of each country having to develop knowledge and technology from scratch. It would be extremely shortsighted not to proceed with the RAIN project since it can supplement the IBSNAT project (which is worldwide) by providing more intensive information and technology transfer within the region and can serve as a prototype for similar regional networks.

Comprehensive approaches such as the JHADP and the Zarqa Watershed Project in Jordan will yield valuable information. Outputs from these and other projects throughout the region will be put into the RAIN data base. Because soil-water management is a crucial element common to all rainfed agriculture, it is the ideal prototype program for regional information and technology exchange through the RAIN project. The JHADP hopefully can become a model for institutionalizing comprehensive agricultural development capability at a national level

From the regional standpoint, soil-water management will be a key element of the RAIN project while, from the national point of view, it will be a major component of rainfed agricultural development in Jordan through the JHADP.

Identification of Components, Constraints, and Actions Needed

The first three steps in the SCRAD process require: 1) the identification of the key elements and components that are necessary in order to achieve an effective soil-water management program; 2) the constraints relating to each component that are preventing the program from reaching its full potential; and 3) the actions necessary to overcome the constraints. In Section 3 of this paper some of the key elements of a soil-water management program were discussed. The absence of, or partial lack, in each of the components constitutes a constraint. Other constraints can only be identified through analyses by multidisciplinary teams. As each constraint is identified the multidisciplinary team must also identify the actions necessary to overcome that constraint. The participants of the Workshop were divided into three groups simulating SCRAD multidisciplinary teams with the exception of Group I. The working group leaders were University of Jordan faculty members who would follow up with the additional steps of the SCRAD process to develop Action Plans for a Soil-Water Management Program for Jordan.

The last one and one-half days of the Workshop were devoted to the working group discussions. Six key elements and six working group discussion leaders were designated. The elements chosen by the Workshop organizers were: 1) agroclimatology, land use, and crop selection; 2) soil/water conservation; 3) efficient use of water, 4) soil, water, plant nutrient relationships; 5) effects of livestock and crop residue practices on soil-water conservation (due to its special concern in Jordan and other Near East countries); and 6) farming systems and socioeconomic aspects. It was the task of the discussion group leaders, along with the simulated multidisciplinary groups, to define the components within each key element area, identify the constraints for each component, and suggest actions that could be taken to overcome each constraint.

The first day of the working group sessions did not go well. Unfamiliarity with the SCRAD process on the part of both discussion leaders and participants and the large size of at least one of the groups inhibited discussion, the discussions were often off target, and the components, constraints, and actions suggested were not organized in the systematic manner required to formulate a comprehensive soil-water management program. The day ended with considerable uncertainty and apprehension among the Workshop organizers.

That night a key procedural adjustment was made and implemented the next day. Each participant was given a blank worksheet and asked to write down what he or she thought were the important components, constraints, and actions needed. After 20 to 30 minutes of writing, participants were asked to present what they had written, and to comment, discuss or present their own views. Not only did participation increase markedly, but the comments became more systematic from the standpoint of defining a comprehensive soil-water management program. The discussions finally began to resemble the exchange of professional views and ideas expected of SCRAD multidisciplinary groups.

The second set of group discussions began with each participant filling out a worksheet and presenting his/her findings. The discussion groups were able to finish their work in less than half the time that they needed previously.

The working group sessions concluded by each of the six discussion leaders summarizing his group's findings in a plenary session. The key conclusions that could be drawn were as follows:

1) The SCRAD process is logical and sufficiently uncomplicated so that a diverse group of professionals can learn it and begin to make it work in a couple of days.

2) The SCRAD process induces people from a wide range of disciplines to think systematically, to view the various elements of a program as an interrelated system and to look at programs as part of the whole agricultural sector as well as the larger socioeconomic system. This was evidenced by the fact that quite a few of the components and constraints were repeatedly brought up by several or all of the discussion groups indicating that each element could not be discussed in isolation from the rest of the soil-water management/cropping/livestock system.

3) The technical papers presented at the earlier sessions of the Workshop as well as the discussions that ensued in the working groups indicated that there is plenty of available technology. The major constraints that are preventing the adoption of sound water management practices, as well as other available technology, are decidedly socioeconomic in nature:

a) Lack of knowledge, priority, or willingness to assume/manage real or perceived risks of weather, higher cost, yield, market, and price.

b) Lack of capital to make the necessary investments in machinery, fertilizers, pesticides, etc.

c) Land fragmentation resulting from inheritance laws that prevent mechanization and result in diseconomies of scale.

d) Governmental pricing, marketing, and crop allocation policies which over the years have created a general distrust of government programs among farmers.

e) Traditional livestock ownership and grazing practices and the small size of farms have resulted in overgrazing, soil erosion, and low soil organic matter, and will make it difficult to achieve integrated crop-livestock systems.

f) Low salaries and indiscriminate transfers of key personnel have resulted in generally weak research and extension organizations that are not effectively serving the needs of farmers, women in agricultural activities, and rural families/communities.

These socioeconomic constraints must be overcome if effective farming systems and increased production are to be realized.

The results of the discussion groups are indicated on the pages following the text.

Other Steps of the SCRAD Process

As indicated previously, only the first three steps of the SCRAD process were simulated by the discussion groups/multidisciplinary teams. Even if the remaining steps of the SCRAD process as described in Section 2 of this paper were carried out, it would not have resulted in a workable Action Plan. The reason is that the constraints, actions required, the agency or organization(s) responsible for the action, the probability of success, duration of action, resources required, and impacts all differ, sometimes markedly, from country to country and, therefore, the SCRAD analysis must be country-specific in order to constitute an executable or real life Action Plan.

It is the intention of the Workshop organizers that the Jordanian discussion group leaders will continue with the remaining steps of the SCRAD process to produce a Soil-Water Management Action Plan for the rainfed highlands of Jordan, and that this will serve as a model for developing similar Action Plans for the other countries in the Near East region through the proposed RAIN project.

Conclusions

This paper has described the successful efforts of the University of Hawaii to take a systems approach to commodity/resource planning and development, and the attempts being made to adapt that system to the agricultural development of the Jordan Highlands. This Workshop has attempted to define the first component of the proposed RAIN project, that is, to define the parameters of a regional soil-water management program within the RAIN framework. Such a soil-water management program for Jordan will be both an important component of the JHADP as well as Jordan's segment of the RAIN soil-water management component.

The SCRAD process is simply the application of logic, common sense, and the concepts of systems analysis to agricultural development planning. It can be a very powerful and versatile planning tool. If administered properly with the kind of wide participation and decision-making that has been achieved in Hawaii, it can also be a powerful mechanism for coordinated, committed actions based on a rationally derived set of priorities. It is also a device to efficiently allocate increasingly scarce resources.

This Workshop has demonstrated that the basic concepts of the SCRAD process can be used as a potential management tool for analyzing and planning soil-water management programs. It is hoped that follow-up actions will be taken by the countries represented at the Workshop to develop Action Plans that will result in the adoption of sound soil-water management practices by farmers throughout the rainfed agricultural regions of the Near East.

Group Discussions

Group I. Agroclimatology, Land Use, and Crop Selection (Discussion Leader: Dr. Ian Stewart, USAID/ANE-S&T, Davis, California).

Component	Constraint	Action
Agroclimatic classification of lands.	Lack of official soil classification/ evaluation system.	Adopt USDA Soil Taxonomy since it is the most comprehensive and is used by agro-technology transfer networks such as the ISBNAT Project.
	Lack of systematic data bank.	1. Review available data on rainfall, temperature, and soils.
		2. Install agro-climatic (rainfall, air and soil temperatures, solar radiation, evapotranspiration) data loggers at experiment stations and other major agricultural producing areas, especially in marginal/transitional areas.
	Lack of soil survey/ interpretation/ evaluation capability.	1. Establish soil survey unit as part of soil-water management program.
		2. Provide technical assistance and training as necessary.

Group I (continued)

Component	Constraint	Action
		3. Secure long-term commitment of necessary resources by cognizant government authority.
Soil/land resources mapping.	Expense and time involved.	1. Utilize satellite remote sensing to develop broad scale zoning for agriculture (watershed/ forestry, crops, range, desert, etc.) 2. Conduct spot soil tests to verify/refine satellite based zonings. 3. Develop computerized overlay maps based on data logger findings.
Crop selection based on topography, soil, and agroclimatic environment.	Crop selection based on tradition or perceived profits, which often tends to push crops beyond their suitable agroclimatic zones.	1. Based on known crop requirements for soil-water and temperature, develop cropping pattern by agro-climatic zones (e.g. fruits, vegetables, cereals, pulses, forages, range grasses, etc.) 2. Conduct soil-moisture tests for specific farms and recommend appropriate crops. 3. Confirm or recommend changes based on actual experience.

Group I (continued)

Component	Constraint	Action
Selection of suitable crop to plant based on projected rainfall for the season.	Lack of information for farmer to make such a decision.	Recent research indicates a strong correlation between the date of the onset of the rainy season and the total rainfall for the season. The earlier the onset, the longer the season and more rain. Farmers can decide whether it would be better to plant wheat or barley, depending on the date of first rainfall. Also the IBSNAT project is trying to develop decision support systems that could aid the farmer.

Group II. Soil/Water Conservation (Discussion Leader: Dr. Theib Oweis, Faculty of Agriculture, University of Jordan, Amman, Jordan).

Component	Constraint	Action
Minimize runoff/ soil erosion.	Current plowing practice is to plow up and down the hill.	Adoption of contour plowing.
	Land fragmentation (narrow strips) prevents contour plowing.	Land aggregation and demonstration projects through agricultural development funds.
	Cost of contour plowing.	Underwrite cost of custom plowing through demonstration funds.
	Terracing, water retention walls are expensive.	Experiment with ridging practices.
	Farmers cultivate steep hills with vegetable crops adding to erosion.	Consider adding ground cover for grazing or planting trees.

Group II (continued)

Component	Constraint	Action
	No practices to reduce wind erosion.	Experiments/demonstration on ridging of soils through tillage which is known to reduce wind erosion by as much as 85 percent.
	Reduced ground cover vegetation through over-grazing.	Improve grazing capacity of range through re-vegetation/grazing management projects to decrease grazing pressures on erodable areas.
Management practices to maximize water infiltration and moisture retention/ minimize moisture loss.	Hard soil surface prevents infiltration and causes runoff.	Adoption of tillage practices prior to rainfall to roughen soil surface.
	Crop residues are used for feed and grazing.	Experiments to establish proper balance/tradeoffs between residue usage for soil-water conservation versus livestock feed.
	Use of traditional, less effective methods of fallow by farmers.	Use of fallow practices that (1) utilize pre-rainfall tillage/surface residues to maximize water infiltration, (2) loosen soil/mulch after rains have stopped to minimize evaporation, (3) use of chemical weed control practices to lessen unbeneficial transpiration, (4) reduce soil surface temperatures.
	Farmers do not want to incur extra cost of proper tillage/ fallow.	Experiment/demonstration through demonstration funds.

Group II (continued)

Component	Constraint	Action
	Lack of weed control practices.	Adoption of weed control regime as part of fallow and crop management through demonstration project funds. Factors such as timing of weed control practice are crucial.
	Lack of appropriate herbicides.	Test and clear herbicides for crop use or use EPA cleared pesticides only.
	Lack of machinery for spraying.	Develop/use custom operations through cooperatives and other private operators.
	Lack of non-chemical methods of weed control.	Experiments on (1) various tillage/cultivation techniques, (2) biological control of weeds, (3) crop cultural practices (early establishment of crop, etc.)
Proper mulching.	Lack of mulching material such as crop residues due to grazing.	Experiment with (1) soil mulching techniques, (2) other organic wastes, (3) plastic mulches.
Soil amendments.	Lack of national organic materials.	Experiment with (1) green manuring, (2) composting with sludge and other wastes, and (3) nitrogen fixation through use of legumes.
Developing soil water conservation system.	Lack of analysis and action plans.	Through application of full SCRAD analysis, identify priorities and actions needed.
	Lack of commitment of resources.	Redirect resources to developing soil-water conservation program as critical component of soil-water management system for rainfed agriculture.

Group III. Efficient Use of Water (Discussion Leader: Dr. .dullah Jaradat, Faculty of Agriculture, Yarmouk University, Irbid, Jordan).

Component	Constraint	Action
Capture and store runoff for supplemental irrigation.	Lack of water catchment practices.	1. Experiments/demonstrations on small scale water catchment techniques. 2. Give attention to development of and water catchment from springs, especially winter springs which give off considerable volumes but are ignored.
Use captured water for supplemental irrigation for maximum benefit to plants.	Lack of knowledge of how to use supplemental irrigation effectively for specific crops.	Experiments on supplemental irrigation techniques for different crops.
Use of waste water for supplemental irrigation in rainfed agriculture.	Waste water is used for intensive irrigation rather than for supplemental irrigation.	1. Initiate plans to have future waste water available for supplemental irrigation in the rainfed areas. 2. Look at supplemental irrigation for cereal crops as well as vegetables and fruits.
Cultivate water efficient crops that are more suited to the agroclimatic environment.	Because of government price support, large areas (approximately 80%) are devoted to wheat.	1. Areas of shallow soils and slopes should be planted with tree crops, especially fruits. 2. Barley should be grown in areas below 280 mm of rainfall since it is a more efficient user of water than wheat.

Component	Constraint	Action
		3. Areas of lesser rainfall should be considered for revegetation as rangeland using drought resistant rangeland shrubs and grasses.
Use of water efficient cultivars.	Local small grain crops are not efficient water users due to their low yield potential.	1. Screen available local germplasm for water use efficiency. 2. Introduce and test new breeds that are faster growing and of of shorter life cycle to escape drought, and/or are more resistant to drought conditions.
	Available gene pool may not have been evaluated thoroughly for water use efficiency.	Test local gene pool to select cultivars that can adjust phenotypically to available moisture.
	Field and laboratory techniques and instruments for physiological studies relating to water use efficiency are either not available locally or expensive to obtain.	1. Utilize cooperative arrangements with international centers or develop a technical assistance project to secure needed capabilities. 2. Explore tissue culture and biotechnology as rapid means to develop or introduce drought resistance/ water efficient cultivars.

Group III (continued)

Component	Constraint	Action
Make more effective use of stored moisture during summer.	Traditional weedy fallow since summer periods are devoid of rainfall. Farmers do not realize that weeds are using stored moisture that could be used to grow crops.	1. Test suitable summer crops with object of reducing areas left in inefficient weedy fallow. 2. Consider water efficient and/or drought resistant forage crops for livestock use during summer periods when fields and range areas are dry. (Perhaps answer lies in weed varieties that have nutritional content for livestock.)
Make more efficient use of winter moisture.	Lack of local disease resistant cultivars adapted to winter conditions.	Introduce winter legumes from temperate zones for testing to take advantage of winter rains/moisture.
Develop system of cultural practices that make efficient use of water or moisture.	Lack of knowledge and data	Conduct experiments on tillage methods, timing of plantings, sowing depth, optimum fertilization/moisture relationships, supplemental irrigation, etc., to develop water efficient cropping systems.

Group IV. Soil, Water, Plant Nutrient Relationships (Discussion Leader: Dr. Sayed Khattari, Faculty of Agriculture, University of Jordan, Amman, Jordan).

Component	Constraint	Action
Determine soil fertility and fertilizer requirements (N,P,K) for different crops for major soil types found in Jordan Highlands.	Lack of data specific to Jordan Highlands.	Carry out fertilizer trials involving various soil types and major crops found in the Jordan Highlands to establish standards for soil testing/recommendations. Develop prescriptions based on soil taxonomy.
Determine optimum water/fertilizer (N,P,K) relationship in different soil types found in Jordan to maximize nutritional benefits and crop yields.	Lack of data	1. Design water/fertilizer/nutrition measurements into fertilizer trials to find optimal amount and regimes. 2. Test for fertilizers that require less water or are water efficient.
Provide soil and plant tissue analysis capabilities for experimental and farmer recommendation purposes, including micronutrient deficiencies.	Lack of capability to provide timely information.	1. Secure technical assistance if needed to develop labs and trained personnel. 2. Provide training to farmers on how to take soil and leaf samples at critical times for corrective actions to be taken on a timely basis.
Promote efficient use of fertilizers.	Cost of fertilizer to farmer and lack of proper machinery.	1. Acquire in bulk through cooperative and develop capacity to mix formulations at cost savings to farmers. 2. Train custom operators to apply fertilizers by machine.

Group IV (continued)

Component	Constraint	Action
		3. Experiment with crop rotations to take advantage of fertilizer residues.
Maximize root development and water/nutrient uptake by plants and crops.	Lack of attention to this aspect of plant physiology in Near East region.	1. Test cultivars with strong root stock development, water efficiency, and drought resistance. 2. Test fertilizers that promote early and rapid root development.
Protect plants from diseases and other pests that retard efficient use of water and nutrients.	Lack of effective plant protection/ pest control programs.	Develop integrated pest and disease management program with emphasis on: • Introduction/development of disease, and nematode resistant cultivars. • Biological control of pests, disease, and weeds. • Chemical control as necessary utilizing EPA-registered chemicals. • Non-chemical control methods such as hot water, dry heat, irradiation, etc. • Improved methods of handling and propagating disease free plant stocks. • Protection from introduction of pests and diseases from foreign areas.

Component	Constraint	Action
		• Importation or development of plant disease treatment methods, such as inoculants. • Systems/multidisciplinary approach, including biotechnology.
Promote soil amendments.	Lack of organic matter in soils.	Carry out program of retaining crop residues for soil amendment purposes (See Group V findings).
	Scarcity of natural organic matter.	1. Develop composting through use of sludge and garbage for restoring organic matter. 2. Develop green manure techniques.
Provide for nitrogen fixing crops.	Lack of knowledge and experience.	1. Carry out program of crop rotation using nitrogen fixing legume crops as a forage in conjunction with barley or wheat. (In Jordan, the Australian Dryland Farming Project has carried out on-farm demonstration projects.) 2. Develop capability for biological nitrogen fixation through FAO Technical Assistance/Training Program.

Group IV (continued)

Component	Constraint	Action
Provide for treatment of saline and sodic soils found in highlands.	Lack of program for naturally saline soils (as opposed to irrigated soils).	1. Develop research program specifically aimed at high-lime and other types of saline soils found in rainfed areas. 2. Treat saline and sodic soils as separate resources cutting across all aspects of a soil water management program.

Group V. Effects of Livestock and Crop Residue Practices on Soil-Water Conservation (Discussion Leader: Dr. Nasri Haddad, Faculty of Agriculture, University of Jordan, Amman, Jordan).

Component	Constraint	Action
Maximize use of crop residues for soil and water conservation.	Beneficial effects of crop residue for soil-water conservation are not known by farmers.	On-farm demonstrations should be conducted to show beneficial effects of residues on water infiltration, lessening evaporation, runoff, and wind erosion.
	Lack of knowledge about optimum amount of residue needed for effective soil moisture conservation.	Conduct research at various levels of residue to determine optimal residue/moisture balance.
	Residue is used for grazing and is not available for soil and moisture conservation.	1. Agreements should be reached between farmers and sheep owners/grazers to keep livestock out after hay has been cut. 2. Provide alternative sources of summer feed through forage crops or baled hay.

Component	Constraint	Action
		3. Till the fields immediately after harvest to prevent grazing. 4. Fencing, if appropriate. 5. Educate farmers and livestock owners/ herder about the poor nutritional value of residue as feed and its high value as a soil-water conservation agent.
Make excess hay available for livestock use.	Lack of machinery to cut and bale the hay.	1. Make combines or baling machines available through cooperatives or custom operators. 2. Treat hay to add nutrient value before feeding to animals.
Minimize soil compaction and soil erosion caused through excess grazing.	Lack of knowledge on what degree of grazing can be tolerated without damage.	Conduct experiments on soil compaction, lack of infiltration, runoff, and erosion at different intensities of grazing.
Increase organic matter content of soil through other types of organic matter supplementing crop residues.	Lack of programs to convert waste into usable organic matter.	1. Develop a waste disposal/treatment plant that will convert garbage into usable compost. 2. Develop a sewage treatment/composting plant to convert treated sludge into usable composting materials. 3. Both would be good bricks and mortar type of project if USAID funds for Jordan remain at a high level or are increased.

Group V (continued)

Component	Constraint	Action
Develop rangelands as alternative to heavy grazing of crop residues.	Rangelands, which typically constitute a much larger area than croplands, suffer even more from overgrazing due to scarcity of edible rangeland vegetation.	1. Undertake a rangeland revegetation project through AID, UN and other sponsors. 2. For example, rangeland revegetation technology developed in Tunisia should be tested for adoption by other countries in the Near East region.
Develop forage crops/intensive grazing techniques using supplemental irrigation during sparse rainfall and dry summer periods.	Lack of knowledge and technology adapted to Near East rainfed conditions.	Technology in intensive rotational grazing has been well developed in New Zealand and should be investigated as to whether it can be adapted to rainfed areas with supplemental irrigation.

Group VI. Farming Systems and Socioeconomic Aspects (Discussion Leader: Dr. Suleiman Arabiat, Faculty of Agriculture, University of Jordan, Amman, Jordan).

Component	Constraint	Action
Establish basic farming systems capability among extensionists.	Lack of knowledge and training among staff.	1. Establish a subject matter specialist position in farming systems. 2. Develop program and train staff in farming systems methodology. 3. If necessary, bring in experts to provide technical assistance during early phases of implementation.

Group VI (continued)

Component	Constraint	Action
Improve cropping and livestock systems and farmer practices.	Lack of data.	1. Conduct baseline study to obtain information on typical practices in the region. 2. Bring in new technology or conduct research to improve farming systems. 3. Develop models of optimal farming systems based on cropping and livestock patterns suited to the agroecology of the area, including sound soil water management practices. 4. Take practical approach and allow farmer to experiment and adjust. Taking a time and motion/ operations analysis approach for each farm is too expensive and probably unnecessary.
Convince farmers to adopt new technology system.	Since many farms are operated by short-term tenants rather than owners, there is no incentive to invest in new technology.	1. Enact appropriate legislation to protect tenant farmer as well as the landowner. 2. Encourage use of custom operators who use improved technology.
	Farmers do not want to incur higher cost of machinery, fertilizers, pesticides, etc.	Conduct on-farm demonstrations to show that higher yields and profits will more than compensate for the higher cost.

Group VI (continued)

Component	Constraint	Action
	The farmer views the additional cost as being too risky in view of the uncertainty of rainfall.	Research needed on risk management and weather prediction techniques to reduce the margin of risk.
Adopt governmental policies and programs that assist farmers.	Farmers have strong distrust of governmental policies such as pricing practices, crop allocation/control, red tape, ineffectiveness of extension services.	1. Government should provide incentives to farmers to increase or improve farm inputs instead of price subsidies to consumers at the expense of the farmer. 2. Government should coordinate importation of food commodities so as not to flood the market at the expense of local products. 3. Free market factors, and not crop allocation, should be allowed to deal with problem of overproduction. 4. Build governmental competence and effectiveness through institutional development projects such as the Highlands Agricultural Development Project. 5. Policies that encourage plowing of rangeland for crops and encourage the growing of wheat beyond suitable ecological zones should be abolished.

Group VI (continued)

Component	Constraint	Action
		6. Legislation should be passed to protect agricultural lands from urban development (such as zoning). 7. Concentrate on both local and export market development for agricultural products.
Adoption of mechanized farming.	Land fragmentation makes it impractical to use mechanized operations.	Undertake land aggregation through incentives and legislation such as prohibiting physical division of farm lands below a certain minimum size.
Promote integrated crop-livestock systems.	Small size of farms makes it economically unfeasible to have integrated livestock systems except for a few goats.	1. Land Aggregation should be pushed. 2. Concentrate on larger operations for integrated systems.
	Traditionally the farmer and the livestock owner or herder are separate individuals and compete for the residues.	Shifting to barley-legume systems with livestock as the main income producer can generate more income for the farmer than wheat or barley/fallow systems.
Promote improvements in small farm/family systems.	Technical assistance projects and studies have largely given only lip service to the needs of the small farmer, women in agriculture, and the farm family.	1. Initiate a small farm implements project to relieve the farmer of hand labor. 2. Provide programs for women in agriculture and family resource management. Provide women extensionists in the field to concentrate on these programs.

Component	Constraint	Action
		3. Develop crop management techniques specifically geared to small scale operations. 4. Develop soil water management as part of the small farming system.
Maintain a strong agricultural sector.	Urbanization and development is taking agricultural lands out of production.	1. Agricultural zoning legislation. 2. Make farming more profitable. 3. Take other measures to restrict urban development (restrict infrastructure development, provide improved services and amenities in rural communities, family planning programs, etc.).
	Young people are leaving the farms for white collar jobs.	1. Have programs that promote agriculture as a business and profession. 2. Exploit the trend toward off-farm income for the family but promote the need to keep the family lands in agricultural production.

Group VI (continued)

Component	Constraint	Action
	Water is the key limiting factor in agricultural development for rainfed areas.	1. Have strong and viable soil-water management program as part of crop/livestock production systems.
		2. Action plans should be developed for each country through application of remaining steps in the SCRAD process.
		3. Long-term, sustained effort is necessary to make lasting impacts.

References

Chase, R. 1986. TROPSOILS research strategy in the West African Sahel. Agronomy & Soil Science Seminar, Texas A&M University. 3 January 1986, College Station, TX.

College of Tropical Agriculture and Human Resources. 1984. Macadamia nut industry analysis No. 3. Chia, C.L., N.P. Kefford, B.W. Post, and W. T. Harada (ed.). Also Worksheet No. 3, Macadamia nut; Progress report on Macadamia Nut Action Plan March 25, 1981 to December 31, 1983; and Macadamia Nut Action Plan No. 3. Univ. of Hawaii, Honolulu, HI.

Cooperative State Research Service. 1982. Manual of classification of agricultural and forestry research, Rev. IV. USDA-CSRS, U.S. Gov. Print. Office, Washington, DC.

Feller, I. *et al.* 1984. The agricultural technology delivery system executive summary: Findings, policy issues, and options. Institute for Policy Research and Evaluation, The Pennsylvania State University, University Park, PA.

Izumi, T. 1985. Highland Agricultural Development Project, Hashemite Kingdom of Jordan: A report on implementation of organization and management. (A consultant report submitted to USAID/Jordan). July 1985.

Izumi, T. 1984. Reorganization of the Ministry of Agriculture, (A consultant report submitted to USAID/Jordan). August 1984.

Kallender, R.M. (ed.). 1981. Forestry and related natural resources of Hawaii: An agricultural industry analysis. College of Tropical Agriculture and Human Resources. Univ. of Hawaii, Honolulu, HI.

Russell, M.G. (ed.). 1982. Enabling interdisciplinary research: Perspectives from agriculture, forestry, and home economics. Misc. Publ. 19. Agric. Exp. Stn., University of Minnesota, Minneapolis, MN.

Swindale, L.D. (ed.). 1978. Soil-resource data for agricultural development. Hawaii Agric. Exp. Stn. College of Tropical Agriculture, University of Hawaii, Honolulu, HI.

U.S. Agency for International Development, Jordan. 1985. Project paper Highland Agricultural Development Project.

U.S. Agency for International Development, Jordan. 1984. Jordan Highlands Agricultural Development Project. (A report prepared by a study team containing analyses and recommendations, project concepts, sociological considerations, deliverable technology, and project requirements).

☆ U.S. GOVERNMENT PRINTING OFFICE: 1989— 2 4 2 - 1 2 3 /0 3 0 0 8