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FOOD AND AGRICULTURE IN THE ARID ENVIRONMENT OF SAUDI ARABIA UNDER HUMAN PRESSURES AND CHANGES

By

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ABSTRACT

FOOD AND AGRICULTURE IN THE ARID ENVIRONMENT OF SAUDI ARABIA UNDER HUMAN PRESSURES AND CHANGES

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Saudi Arabia is a country with an area equal to two-fifths of the United States, with a population of about 8 million. Although the country is dominated by an arid environment, it was agriculturally self-sufficient until the 1940s, when the economy reached a turning-point with the discovery and exploitation of petroleum resources. Since then, the gap between food demand and supply has enlarged and been filled by importation. Throughout this period of economic change and development, there have been many studies and inventories by the government (represented by the Ministry of Agriculture) and by consultant firms and experts, to evaluate the potential production from agricultural resources, especially water resources.

Based on these studies, many agricultural projects have been implemented, but the positive results of these efforts are very limited—if any—and the country has become more dependent on imported food and other agricultural products, while domestic production contributes only about 20 percent.

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The aim of this study is to use the diverse information available to evaluate the environmental constraints and human pressures on food and agriculture.

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CHAPTER I

INTRODUCTION

Geographical Conception of Ecology—Development Relationship

Ecological knowledge has three dimensions. One relates to immediate effects, such as applying chemical fertilizers to increase crop production. The second involves long-run effects on the ecosystem. The third involves areal differentiation within the ecosystem—for example, the effects of irrigation systems in humid, semi-arid, and arid regions.

Human knowledge generally increased equally along these three dimensions prior to the nineteenth century. At that time, scientists began to specialize and emphasize the first dimension—that is, they began to study specific biological or physical phenomena isolated from their ecosystems with little regard for areal differentiation. Numerous disciplines and subdisciplines appeared, and specialization became a distinguishing feature of this period. Knowledge accumulated rapidly, but unevenly. Man's ignorance of the areal and ecological dimensions of the biological sphere (including human aspects) and the physical environment has caused many problems to emerge from man's economic activities on the earth's surface. The best examples are the spatial maldistribution, organization, and efficient utilization of natural resources; the failure to create a balance between the available food resources and exploding world population, of whom two-thirds have suffered malnutrition one way or another; and air, water, and soil pollution.

The science of geography, which deals with the spatial and ecological dimensions of human and natural phenomena on a regional, local, and global scale, is so comprehensive that geographers have been unable to agree precisely on the boundaries of geography as a discipline. These definitions usually focus on one area of geography and reflect the evolution of geographical thought from the end of its classical period in the mid-nineteenth century to the modern day. When physical geography dominated the field in the late nineteenth century and the first two decades of the twentieth, the emphasis was on the world's physical features. Starting in the 1930s, the focus of geography was on area and regional study, areal interrelationships, chronology, areal differentiation, and spatial concepts. More recently, especially since the 1960s, the environment, ecology, and systems concepts have been applied to the science of geography.

In his discussion of the position and role of geography in relation to the various human and natural sciences, Fosberg (1976, p. 120) said:

> The important consideration is the role of geography as the integrator of this diverse plethora of information to make it possible to view the earth, or any large part of it, or any major aspect of it, as a whole. This we must insist on, not just as a feature and justification of geography, but in the long run, as a sine-qua-non for the continued tenure of the human race, at least as we know it, on the earth.
>
> Haphazard, piecemeal, narrow approaches to the problems facing civilization have not only outlived their usefulness, but have brought us nearer to the brink of worldwide disaster than most of us either comprehend or are willing to admit. Geography alone cannot avert disaster, but if it can get a hearing, and if it effectively fulfills its integrative function, it may help government and private policy-makers get us on a path different from the catastrophic one we seem to be following. This consideration may, at least to some extent, support my idea, expressed at the beginning, that geography is one of the most important of sciences.

The growing human population and rising technological levels have put substantial pressure on the biosphere. Man's overexploitation of the earth's resources has created serious conflicts between short-term benefits and the capacity of the biosphere-ecosystem to provide benefits in the long run. Hill (1975, p. 218) has evaluated the current status of research on ecosystem stability in relation to stresses caused by human activities. He concludes:

> Research on ecosystem stability to date has been dominated by ecologists. In reviewing the literature it is evident that this situation has resulted in a tendency to concentrate on the analysis of biological properties, particularly diversity, in relation to stability. Moreover, until very recently few ecologists have emphasized the relevance of ecosystem stability to man's interaction with his environment. Consequently there is a great need for empirical research on ecosystem stability in relation to a wide variety of man-induced stresses. The development of a comprehensive understanding of the role of ecosystem structure and functioning in relation to resilience will also require an

expansion of the existing work of ecologists. The role of spatial organization and linkages between physical and biological components constitute two obvious areas of research which may be of particular interest to geographers.

Statement of the Problem

As a background for studying agricultural potential in Saudi Arabia, it is useful at the outset to note several important physical and human characteristics of the country's environment.

1. More than 95 percent of the country has annual precipitation of less than 100 mm. Two prominent features of Saudi Arabia are its tropical desert ecology and the absence of permanent flowing or standing bodies of water.

2. Cultivated land constitutes less than 0.5 percent of the total area of the country's 2.3 million square kilometers.

3. Between 50-60 percent of the country's population is involved in agricultural activities and lives in rural areas.

4. Domestic food production contributes only 20 percent of the country's demands.

5. The average farmer's holding is about two hectares.

6. Between 1.5 and 2 million workers from outside Saudi Arabia are employed in construction in growing and new cities, plants, roads, and many other facilities. This

imported labor roughly equals the domestic labor force, estimated at 1.5 million.

7. Annual oil revenues may amount to as much as $90 billion (an average per capita income of $15,000 for the country's population of about 8 million). Government expenditures for the second five year plan (1975-1980) were about $140 billion.

Given the importance of food and agriculture to Saudi Arabia, this study will investigate why there is a growing deficit of food and relate this problem to the viability of agricultural self-sufficiency, particularly in terms of human pressures and ecological potential. This cross-sectional assessment will focus on two main aspects. The first is the constraints and limitation imposed by the environment. Agriculture in Saudi Arabia is constrained, not only by the scarcity of water resources, as some specialists maintain, but also by the lack of a hydrological cycle which naturally adjusts soil salinity and fertility. Cultivated land has been threatened by the salinity problem in this arid environment. The second aspect is human pressure on the agricultural ecosystem. Its impact is felt in three areas: (1) an increase in the food deficit or the demand for food, exacerbated by population growth and the rising standard of living of urban residents; (2) overpopulation in rural areas in terms of land-water-man productivity; and (3) the ecological impact of urbanization, the major result of economic development and change, which competes with agriculture for land and water resources.

Information Resources and Method of Analysis

Obtaining adequate information and statistics about the negative aspects of the human pressure on the ecosystem is a major obstacle facing any scientific study especially in developing countries. There, environmental imbalance is a product of socio-economic conditions combined with population pressure on the biological and nonbiological resources and of technology maladaption and transfer. In developing countries, more attention has been given to the problem of poverty than to careless application of technology. As Walter and Ugelow (1979, p. 102) have indicated, societies suffering from malnutrition and disease, high infant mortality, low life expectancy, high illiteracy levels, and endemic unemployment are unlikely to perceive or emphasize the negative effect of development, change, and technology on environmental quality. These societies view development and new technology as the only means to break out of their circle of poverty.

In Saudi Arabia, as in other developing countries, assessments and surveys of human and natural resources, including agricultural resources, have often viewed the human and physical environment as static. The dynamics of the ecological context have not been fully examined. Little or no attention has been given to determining whether man can continue a policy of massive environmental manipulation without more-carefully evaluating the short- and long-run consequences, especially in terms of the ecological dimension of agriculture and the food-population relationship.

In this research effort, several types of source materials will be used. Documentary sources include such statistical material as Saudi Arabian government data, the Agricultural Census for 1973-1974, and various U. N. publications. Also included under this category are reports and special studies made by various agencies and companies on behalf of the Saudi Arabian government. Relevant books, articles, and dissertations by individuals or nongovernmental agencies are also examined. The second broad source of information was field observations. Notes were taken during a visit in the summer of 1979 to the Taif agricultural districts in order to provide better understanding of the information collected from various sources about the physical and human environments which affect agriculture in Saudi Arabia.

Method of Analysis

Inferential quantitative methods have been used extensively in geographical research since the 1960s as a means of testing an hypothesis. This approach is most applicable when comparing specific variables or the relationship of a number of isolated variables. Since the early 1970s, however, there has been a reaction against the use of certain quantitative methods. Many geographers had come to believe the qualitative approach in certain types of studies may provide a more-useful description of actual situations. In the literature, many exciting and innovative approaches to formulating concepts have appeared (P. James, 1972).

In this study, it will become clear that many physical and human variables interact spatially and ecologically to shape the present and future agricultural picture in Saudi Arabia. Descriptive statistics as well as tables, maps, and diagrams will be used in the analysis and interpretation of the data.

Organization of Thesis

The remainder of the thesis is divided into four chapters. Chapter II includes a literature review of the factors which created the imbalanced global food situation. These factors are world population growth and the resultant pressure on the biological system, the population pressure on agricultural land and water resources, ecological constraints on human activities and change in the land, and finally, the world food situation and trends. An analytic discussion of the study problem will be presented in Chapters III and IV. In the third chapter, characteristics of physical environments that affect agriculture will be discussed while the human aspect of pressure on food resources is the subject of Chapter IV. The conclusions of the analysis are presented in Chapter V.

CHAPTER II

REVIEW OF THE LITERATURE

Historical Trends of World Population

As early man grew in knowledge and in population, he began to domesticate plants and animals. This was a most significant step in history, for with it came permanent settlement. Throughout history, man has continued to improve his knowledge and tools for satisfying his demand for food, clothing, and shelter. Thus, throughout history, two important developments may be noted: the refinement of man's knowledge, implements, and techniques; and growth in population, which increased the demand for food and forced man to spread all over the world and resulted in today's varying density patterns.

Both population and knowledge increased slowly until the 1500s. It is estimated that the world's population increased about 2.5 to 5 percent per century between the birth of Christ and 1650; that is, from about 250 million to 500 million. Around the sixteenth century, the basic scientific ideas of our modern material civilization began to develop and the new world was discovered.

Population has grown about 65 percent per century during the last 300 years. The first billion was reached about 1820. Within 110 years, in about 1930, the second billion had been reached. In only thirty years, by 1960, the world's population was three billion, and by 1975 it was four billion. It is expected that there will be five billion people in the world by 1987 (see Table 1) (Ehrlich et al., 1977, p. 183; and Borgstrom, 1974, p. 109).

The world's current population growth rate is estimated to be between 1.9 and 2.2 percent annually—between 86 and 90 million people each year. This means that, every three years, world population grows by an amount equivalent to the entire population of North America, despite recent reports that the world population growth rate has been declining (Duncan, 1977, Table 2, pp. 7-10; and Allaby, 1977, pp. 63-65).

The highest population growth rates are in the hunger belt of South Asia, Africa and South America, where the rate of increase is over 2 percent and reached 3 percent in some regions, such as North Africa and Southwest Asia. It is expected that the world population figure will be 6 to 8 billion by the end of this century (Borgstrom, 1974, p. 109; and Hoy, 1978, pp. 1-19).

With this enormous spurt in population, mankind now faces the problem of securing sufficient and stable food resources. The world's billions have almost reached the point of absorbing all the earth's agricultural resources

TABLE 1

SPEED OF GROWTH OF POPULATION IN THE WORLD

Date	Population*	Time Required	Added Population
Christ Era	250	. . .	. . .
1800	500	1600	250
1820	1000	200	500
1930	2000	110	1000
1960	3000	30	1000
1975	4000	15	1000
1985	5000	(approx.)10	1000

SOURCES: Ehrlish, et al., 1977 "Ecoscience; Population, Resources, Environment." W. H. Freeman and Company, San Francisco.

*in millions

NOTE: These figures show the radical decline in required time for each additional billion of people.

TABLE 2

1976 WORLD AND MAJOR REGION POPULATION, DEMOGRAPHIC TRENDS, PER CAPITA ARABLE LAND, AND FOOD SITUATION

	Population Estimates (Millions) (Mid 1976)	Growth Rate (%)	Birth Rate (per 1,000 Population)	Death Rate (per 1,000 Population)	Number of Hectares of Arable Land Per Person	1974 Production Cereal Grains (1,000 Metric Tons)	1948-1952 Net Exports Cereal Grains (1,000 Metric Tons)	1974 Net Exports Cereal Grains (1,000 Metric Tons)
World	4,240.7	2.2	35	14	.324	1,333,864		
Africa	431.9	2.8	46	21	.486	67,921	-370	-6,936
North Africa	99.4	3.0	44	17	.2835	17,940	35	-6,249
Asia	2,475.9	2.5	40	15	.2	513,867	-5,845	-47,078
Southwest Asia	90.4	2.9	43	16	.4455	24,179	135	-4,880
Saudi Arabia	9.2	3.0	50	23	.08	556	(-101)	-693
North America	245.3	1.3	14	8	.9315	235,958	22,481	76,374
Latin America	333.5	2.6	39	10	.324	76,840	1,160	-443
Europe	475.8	0.6	15	10	.2835	235,076	-20,775	-28,470

TABLE 2—Continued

	Population Estimates (Millions) (Mid 1976)	Growth Rate (%)	Birth Rate (per 1,000 Population)	Death Rate (per 1,000 Population)	Number of Hectares of Arable Land Per Person	1974 Production Cereal Grains (1,000 Metric Tons)	1948-1952 Net Exports Cereal Grains (1,000 Metric Tons)	1974 Net Exports Cereal Grains (1,000 Metric Tons)
U. S. S. R.	256.8	1.0	18	9	0.9 ha	186,629	(2,050)	678
Oceania	21.5	1.8	23	10	2.2 ha	17,583	3,158	6.947

SOURCE: Duncan, E. R., Editor, "Dimensions of World Food Problems" 1977, The Iowa State University Press, pp. 7-10.

available at reasonable ecological and financial costs. The rapid increase in the human population, combined with increasing use of technology, has imposed severe pressures on the earth's resources, especially food resources.

Until recently, the relationship between humans and the earth's natural resources has been evaluated primarily by means of the economists' theories and equations, based on the monetary input-output relationship, with general ignorance of or disregard for both the ecological cost paid to increase the production of commodities, and the role of biological systems in the economy. Borgstrom (1979, p. 9) explains this situation by saying

> But this presupposes that economy is interpreted in its original sense as the guidelines for rational (wise) utilization of Nature's resources. It is encouraging to notice that a new generation of economists is now emerging who understand this and return to a complete accounting, thereby breaking loose from the dangerous play of their more tradition-bound colleagues. To put it in more blunt terms, we need to know the true cost in energy, land, water, etc., not as measured in arbitrary money terms. Too many economists have for far too long been engaged in the futile game of arbitrarily selecting credit accounts and thereby given poor guidance. Biological as well as economic balance are basic prerequisites for a viable strategem as to man's survival.

The human population is dependent on the biological system for food as well as many important raw materials such as wood, wool, etc. There are many ways of measuring human pressure on the biological system on different levels. One of them, on the global level, is the per-capita supply of the four biological systems: fisheries, forests, grassland, and cropland. As Table 3 shows, world production per capita of key commodities of biological origin peaked during 1960-1976. The turning point toward decline in the per-capita production of these commodities came as a direct result of the continuing growth of the world population: production of commodities since World War II has increased more slowly than has the population, and since the early 1960s production of these commodities, one by one, has stopped increasing and even started to decline (Brown, 1977, pp. 5-17).

The first decline in per-capita supply of a major commodity of biological origin was when wool production peaked at 0.87 kilograms/capita in 1960; since then, per-capita production has fallen by 28 percent (Table 3). The second decline, in per-capita production of wood, occurred in 1967 after a peak at 0.67 cubic meters. Since then production has been declining under growing demand pressure, while the area of the world's forests is shrinking each year by about 11 million hectares, an area the size of Cuba (Brown, 1979, p. 10).

The first decline in production of the major foodstuffs started in 1970 after per-capita production of fish peaked at 19.5 kilograms. Since then, the per-capita production of fish has decreased. In 1972 the per-capita production of mutton peaked at 1.92 kilograms; since then it has declined. Four years later, in 1976, the per-capita production of cereals and beef peaked at 342 and 11.81 kilograms, respectively, and since that time they have been

TABLE 3

WORLD PRODUCTION PER CAPITA OF KEY COMMODITIES OF BIOLOGICAL ORIGIN, 1960-1978, WITH PEAK YEAR UNDERLINED

Year	Forests	Fisheries	Grasslands			Croplands
	Wood	Fish	Beef	Mutton	Wool	Cereals
	m^3		kg			
1960	. . .	13.4	9.43	1.91	<u>0.86</u>	287
1961	0.65	14.3	9.67	1.91	0.85	278
1962	0.66	14.5	9.90	1.90	0.85	292
1963	0.66	14.7	10.25	1.89	0.83	286
1964	0.67	16.1	10.12	1.84	0.81	297
1965	0.67	16.2	10.09	1.82	0.79	288
1966	0.67	17.1	10.39	1.80	0.80	308
1967	<u>0.67</u>	17.7	10.59	1.92	0.79	308
1968	0.66	18.4	10.86	1.92	0.80	318
1969	0.66	17.7	10.90	1.88	0.79	316
1970	0.66	<u>19.5</u>	10.80	1.90	0.76	314
1971	0.66	19.2	10.57	1.91	0.74	335
1972	0.65	17.6	10.75	<u>1.92</u>	0.73	319
1973	0.66	17.5	10.63	1.83	0.67	337
1974	0.65	18.1	11.16	1.80	0.65	322
1975	0.62	17.6	11.49	1.80	0.67	321
1976	0.62	18.2	<u>11.81</u>	1.79	0.65	<u>342</u>
1977	0.62	17.4	11.53	1.78	0.63	333
1978*	0.61	16.6	11.21	1.77	0.64	340

*Preliminary estimates.

SOURCE: Food and Agriculture Organization and U. S. Department of Agriculture. (In Brown, p. 9).

declining along with the other major products of the biological system.

The decline in per-capita production of food is the warning signal of impending food crisis, as well as a sign of the pressure on natural resources in general, as Brown (1979, p. 26) explains:

> As world population moves toward five billion, there is widespread evidence of excessive demand. Overfishing is now the rule rather than the exception, forests are shrinking in most countries, overgrazing is commonplace on every continent, and at least one fifth of the world's cropland is losing at a rate that is undermining its productivity. Demand pressures appear to be converging as output per person of key resources of biological origin declines and in production per person of oil threatens to turn downward.

Population Pressure on Agricultural Land and Water Resources

Population pressures vary around the globe as a result of the differences between regions in terms of agricultural resources, population density, skills, technology and knowledge. The population pressure (or overpopulation) may be measured in relation to an area's natural resources, standard of living, total area, tilled land, habitable terrain, self-sufficiency in food production, and general biological capability. Ehrlich and Holdren (1977, p. 277) indicated that population pressure should be perceived not in relation to absolute population size in a specific area, but in terms of population density and the resource base on which the people depend: that is, the productive agricultural land.

Outside the permanently ice-covered areas, there are about 13.4 billion hectares of continental land surfaces. About two-thirds of that area ia already under direct utilization to serve human survival needs. Crop production (including cereals) occupies 1.4 billion ha. For animals, which provide protein and other raw materials in addition to work power for land cultivation in large areas of the developing countries, about 3 billion ha are preserved as permanent meadow and pastures. Forested land amounts to about 4 billion ha (Table 4); the importance of forests for human survival goes beyond providing a source of wood products such as lumber, paper and firewood, to the ecological function of adjusting the environmental elements, both atmospheric and land surface, essential for the continuance of the biological system as a whole. The ecological importance of forest and of vegetation cover as a whole becomes clear in areas where the forest has been cut and pastures are overgrazed or turned over to cultivation. The removal of permanent vegetative cover is reflected in changes in an area's temperature, moisture circulation, soil erosion by flooding, desert encroachment, and many other ecological problems.

The distribution of agricultural land (including pasture and forest land) among continents, regions and countries is not equivalent to the distribution of the

TABLE 4

DISTRIBUTION OF LAND USE OVER THE WORLD

Country or Group	Total Area	Total Agricultural Land			Forested Land	Other Areas
		Total	Arable land and land under per- manent crop	Permanent meadow and pasture		
World	13,400	4,400	1,400	3,000	4,000	4,900
Africa	3,030	1,000	204	843	629	1,354
North America	2,241	627	253	374	815	799
South America	1,784	794	89	408	927	360
Asia	2,753	893	444	449	565	1,295
Europe	493	240	149	91	140	113
Oceania	851	505	43	462	82	264
U.S.S.R	2,240.2	598	224.3	373.7	910	732.2

*million hectares

SOURCE: Statistical Yearbook 1970

population. The Asian continent, with a population of 2,476 million (1975), or more than half (58.4 percent) of the world's population of 4.2 billion, has 444 million ha (1970), or less than one-third of the world's arable land, and an average per capita arable-land area of 0.2 ha, less than the world per capita average of 0.3 ha. Europe is second to Asia in arable land, 149 million ha, but has a relatively higher population—475.8 million, for 0.28 ha per capita. Technological development enables Europe to import foodstuffs and place it outside of the hunger belt. Per capita arable land in Latin America is almost the same as the world average of 0.32 ha; the region has a population of 334 million and 89 million ha of arable land. The African continent is a part of the world-hunger belt, along with Latin America and Asia, in spite of the fact that its per capita arable land amount, 0.49 ha, is greater than the world average. The Soviet Union in recent years has joined Africa in this regard: its per capita arable land is 0.9 ha, but its economic ability to compete in the world food market distinguishes it from Africa and puts it, with Europe, in the world food deficit belt but not in the hunger belt. Surplus food is produced on only two continents: North America and Oceania, with per capita arable lands of 0.93 ha and 2.2 ha, respectively (Table 2).

The interaction of the physical and human environments makes it difficult to determine figures representing a sufficient per capita area of arable land in any region of the world. But from a general perspective, it is clear that the larger amount of arable land per person in Africa and the Soviet Union, with tradition agriculture in the first and modern practices in the second, is still not capable of meeting human needs for agricultural products, especially food, because of unfavorable climatic conditions.

In suggesting expanding agriculture at the expense of natural vegetative cover, some writers and specialists disregard not only the contribution of pasture and forest land to providing agricultural needs, but also, the general ecological function of permanent vegetative cover, and the ecological problems which have emerged as a result of expansion of agriculture on forests and pastures. While these problems do not completely prevent extension of cultivated land at the expense of pasture and forest lands, as some writers and specialists suggest, they do threaten the existence of arable land which once was forest or pasture. Borgstrom (1973) believes that mankind has exhausted most of the readily available water and land resources and now faces many ecological, economic and technological obstacles to further cultivation. Borgstrom (1973, p. 40) explains one aspect of agricultural pressure on the ecosystem:

> The unrelenting increase in human numbers has forced man to expand his tilled acreage in order to procure more food. Beginning in the plains and fertile river valleys he was gradually forced to plant up the hillsides, to break the pastures through plowing and above all to

> clear the forest. In both Australia and Africa too many livestock on natural pastures were allowed to overgraze and destroy the vegetation cover. Many deserts and wastelands have been created in this way. This is still happening, evidenced by deserts expanding and intruding into such overused borderland.

Borgstrom believes the world's annual loss of tilled land to erosion is about 15 million acres, equivalent to twice the tilled acreage of Sweden or the total tilled land of Japan. This erosion has been caused by increased runoff resulting from the removal of forest and ground cover through agricultural expansion or overgrazing (1973, p. 40).

Salinity is another problem for agricultural expansion in dry regions. Analysts estimate that the productivity of at least one-third of the world's 200 million ha of irrigated land is being undermined to varying degrees by salinity (Eckholm, 1976, pp. 125-35).

Brown and Eckholm (1974, p. 45) summarize the ecological problems caused by agricultural expansion.

> The massive destruction of vegetative cover and the erosion of topsoil are apparent in the spreading deserts of Africa, Asia and Latin America; in the increasingly frequent and severe floods in some regions; in the silting of irrigation reservoirs and canals; and in the abandonment of millions of acres of arable land to erosion. . . .Efforts to increase the food supply—either by expanding the area under cultivation or by intensifying cultivation through the use of agricultural chemicals and irrigation—may cause ecological disasters, such as the inadvertant modification of climate, the entrophication of fresh water lakes and streams, the rapidly rising incidence of environmentally induced illnesses, and the threat of extinction of a growing number of wildlife species (pp. 45-46).

The ecosystem is showing many signs of stress from agricultural pressure: salinity and silting, disturbing irrigation systems in arid areas; flood, drought, soil erosion, and desertification, as a result of overgrazing or moving and burning of forests and grasslands; and soil, water, and air pollution, especially from the use of chemical fertilizers. These problems and many others make optimism unrealistic. The rigid compartmentalization of professions in the academic world and in private and governmental agencies has not helped.

> When reading the analyses of economists, foresters, engineers, agronomists, and ecologists, it is sometimes hard to believe that all are attempting to describe the same country. The actions of experts frequently show the same lack of mutual understanding and integration (Eckholm, 1976, pp. 21-22).

The Efficiencies of Modern and Traditional Agriculture

Concern must be turned from the general ecological problem created by agricultural expansion at the expense of natural vegetative cover to the inefficiencies resulting from the adoption of modern technology, combined with neglect of the ecological effects of technology, especially in the long run. The industrial revolution has created changes in the agricultural system during the last hundred years by providing fuel-powered machinery to replace human and animal power in farm work; through construction of large-scale irrigation systems to control, store, and use running water when and where needed; and through chemical fertilizers to replace farmyard manure, chemical poisons to control insects and weeds, and many other technological innovations which affect agricultural products from the farm to the consumers. These changes, known as the "Green" or Agricultural Revolution, have occurred in the agricultural systems of the developed countries, and there have been strong efforts to transfer modern agricultural technology to the developing countries in spite of the fact that the conditions under which the agricultural revolution were developed, such as industrial demand for labor in the cities and abundant land and cheap fuel and fertilizer, exist in few, if any, developing countries. The circumstances are different in some of the developed countries as well. Innis (1980, pp. 1-2) notes:

> Today the conditions under which the agricultural revolution began are changing. For a variety of reasons, including rapid population growth, many of the people now forced out of farming cannot find other work. Many parts of the world are running out of good new land to farm. And, as we are made aware every day, the era of cheap and abundant petroleum is over: fertilizer and fuel are rising rapidly in price and may, before long, become scarce.

This is one aspect of the obstacles to transference of modern Western agricultural technology to the developing countries or even to continuation in the developed countries in the long run. The other aspect is the efficiency of the modern Western agricultural system compared to that of traditional agriculture. Innis indicates that while "agronomists are proud that nutrient utilization in raising chickens is now so efficient that a pound of broiler can be grown for less than two pounds of feed," they are less careful in times of shortages of food, fuel, and fertilizers, when they assess the best agricultural system to maximize crop production from each kilogram of nutrients, liter of water and kilocalorie of solar energy, rather than measuring the labor input per product output. From this definition of efficiency, the traditional intercropping system used on small farms, which is characterized by growing two or more crops interspersed in one field, is seen to use sunlight, water and nutrients more effectively than the one-crop (monocrop) system in the developed countries. Because plants in the intercrop system differ in height, roots, depths, and time of growth and harvest, they can utilize sunlight and water more effectively. Semi-continuity of plant cover increases organic material, reduces soil and nutrient erosion through runoff, and increases soil nitrogen from the root nodules of legumes when they are grown mixed with other plants.

These ecological advantages do not exist in the monocrop system of large farms which depend on great consumption of energy in the complex production process (machinery fuel, fertilizers, pest and weed control, irrigation, processing, and distribution). The present system of Western agriculture not only faces the problem of relying on fossil energy and other vanishing resources, but also has created many ecological problems from air, water, and soil pollution. Greenwood and Edwards (1979, pp. 79-80) indicate that this system of agriculture "required an input of 10 calories of supplemental energy for each calorie of energy consumed as food." They add, in discussing the Indian attempt to adopt to Western-style modern technology:

> With millions of Indians on the point of starvation, it is a severe temptation to increase harvest yields in the short run by the quickest and easiest means. But the application of Western high-energy technology promises further conflict with natural systems, not only through pesticides, artificial fertilizers, and the disappearance of hardy though low-yielding grain varieties, but also through the urbanization of displaced peasants. On the other hand, by encouraging small farmers to stay on the land and by seeking low-energy improvements in agricultural technology, Indians may be able to increase agricultural production in a manner they can live with in the long run.

Ecological Constraints on Human Activities and Change in Arid Lands

Many of the global ecological problems mentioned in the review of the literature are to this point also occurring in arid lands—some, almost exclusively there. Since Saudi Arabia is the focus of this research, emphasis will now be placed on the literature on arid-land development and its ecological problems.

Aridity exists when water input from precipitation is less than water expenditure by run-off, evaporation, evapo-transpiration, and so forth. According to the estimates of Meigs (1953) and Petrow (1973), the total arid and semi-arid world area is 48,350,000 km^2, of which 5,850,000 km^2 are extremely arid, 21,500,000 km^2 are arid, and

21,000,000 km^2 are semi-arid. Although all arid and semi-arid areas lack water resources, each has its own environmental complexities and level of aridity (Kassas, 1977, p. 185).

Kassas (1977, p. 185) classifies arid lands into four categories:

1. Rainless deserts, where rainfall is not an annually recurring event, such as the Rub al-Khali of the Arabian Peninsula, the central Shara, and so forth

2. Runoff desert, where annual rainfall is low (less than 100 mm) and variable, and where perennial plant life is restricted to especially favored habitats (for example, runoff-collecting basins)

3. Rainfall deserts, where rainfall is insufficient for sustained crop production (100-200 mm per year), and where perennial plant life may be somewhat widespread and not confined to runoff-collecting habitats; and

4. Man-made deserts, parts of the semi-arid steppe country (rainfall 200-350 mm per year) that have been transformed into deserts due to man's overexploitation (desertification)

Desertification is one of the major environmental problems in semi-arid areas. The intensive or excessive use of these areas may be attributed to two factors. One is rapidly growing population and its pressure on existing land. This growth has been caused in part by the extension of medical care to combat common diseases, as in the Sahel. The second factor is the application of new technology extensively in agriculture, as in the semi-arid grasslands of the West Central United States (Great Plains).

Kassas (1977, p. 186) has estimated desert areas on a three-fold classification scheme as follows:

1. Deserts defined according to climatic data constitute 36.3 percent of the earth's surface of 7,115,000 km^2

2. Those classified on the basis of soil and vegetation account for 43 percent; and

3. Man-made deserts account for about 7 percent of the earth's surface

The margins of the Sahara offer an outstanding example of desert encroachment. The IUCN Bulletin of 1976 states that "the Sudan's desert is marching south slightly faster than 5 km a year," and that the southern boundary of the desert has shifted southward about 90-100 km between 1958 and 1975 (Rapp, 1976, p. 232).

Since the early 1950s, scholars, researchers, and governmental and U. N. agencies have studied and assessed the potential for new technology in arid lands. There are two reasons for this interest. First, arid areas account for about one-third of the total land in the world, but they contain only 14 percent of the world's people (about 630 million), most of them densely concentrated around water resources. Second, despite limited water, arid lands have several positive features, such as valuable natural resources (petroleum, phosphate, potash, and so forth), unoccupied spaces, clear skies and sunshine almost year-round, and warm temperatures (Brinck, 1976, p. 7; and Kassas, 1977, pp. 188-190).

In the past, discussion about the potential for increasing utilization of arid land have emphasized the scarcity of water as the main inhibiting factor. (See UNESCO Arid Zone research, 18, 1962; and International Symposium on Increasing Food Production in Arid Lands, 1969). But the scarcity of water in arid lands is caused by and interacts with the entire complex environment of arid ecosystems.

Ecological resistance to overexploitation of arid lands has existed since the emergence of ancient civilizations. As Emmel (1977, p. 4) states:

> Through unsound agricultural practices, deforestation and overgrazing, great civilizations—in Africa, Asia, Europe and Latin America—devastated their surroundings and thereby destroyed themselves, leaving littered ruins and bleak landscape as testimony to how nature fought back. The countries where these civilizations once flourished are today among the poorest in the world.

In the recent past, development technology has been introduced to areas throughout the world, including arid lands. It has taken the form of large dams, irrigation projects, oil and mineral exploitation, industrial plants, nomadic settlement, resettlement, medical facilities, chemical pesticides and fertilizers, road construction, and growing cities, to name a few features.

The export of development technology to arid lands has not only brought with it the ecological problems of developed countries, but also has created a transfer problem. Farvar and Milton (1968, p. xiii) explains:

> The problems of man's careless use of development technologies tend to fall into two general categories. In one, the fault is intrinsic to the technology on global scales. The environmental problems of application are present in developed countries and have been exported along with technology to less developed countries, where similar environmental impacts than have occurred. In the other category, there is a "transfer" problem: a technology which has been developed to suit conditions of temperate zone ecosystems will fail operationally when imposed on an alien, usually tropical environment (arid and humid).

Irrigation: Potential and Problems

Agricultural development in arid and semi-arid areas, including those that have seasonally dry periods, is dependent on irrigation systems. Accurate figures on existing irrigated areas are unavailable because of the lack or inadequacy of statistics in most developing countries. The newest estimations indicate that irrigated land totals 233.6 million ha—16 percent of all cultivated land, and 1.7 percent of the total land on earth. This area consumes about 1,400 billion m^3 of water per annum (Fukuda, 1976). Eckholm (1976, p. 134) mentions that one of the key factors permitting world food output to keep up with the surging post-war demand has been the historically unprecedented explosion in irrigation capacity. A total world irrigated area of 8 million ha in 1800 reached 40 million ha in 1900, 105 million ha in 1950, and then 140 million ha by 1970, thus growing faster than world population so far this century.

Although some observors believe that extensive development of irrigation in the future is mainly to be expected in Africa, the Middle and Near East, and Central Asia, others, including Borgstrom (1971), believe that expansion on a large scale has reached its end, and that most economically available arable land and water resources have been put to use.

Most irrigation is concentrated in seasonally dry areas, especially in southern and eastern Asia where monsoons occur. China has the largest amoung of irrigated land in the world, 76 million ha, while India is second with 39 million ha. The two countries possess more than half the irrigated land of the globe.

Although there have been magnificent achievements from irrigation projects intended to provide water in the right place, at the right time, and in sufficient quantity, many problems have arisen. The most severe is salinization. This process is the gradual deposition and accumulation of salt on the surface as a result of heavy watering accompanied by excessive evaporation, scarce rainfall, dry air, insufficient runoff, and strong winds. In arid regions, millions of hectares of tilled land have been turned into marshes, or all vegetation has been killed, through salinization. El Gabaly (1977), Houston (1977), and Fukuda (1976) estimate that at present, about 50 percent of the irrigated areas in Iraq and the Euphrates Valley of Syria, 80 percent in Pakistan, 35 percent in India, and 30 percent in Egypt suffer to varying degrees from salinity and water logging. Some experts believe that the highest priority for the future should be to renovate and improve the utilization of existing irrigation facilities. Houston (1977) mentions that reports presented at the 1974 World Food Conference suggest a desirable target: the improvement by 1985 of some 50 million ha of existing irrigation.

Sedimentation is another important problem. It occurs when the accumulation of silt in a dam or reservoir decreases its capacity. The retention of silt in these reservoirs prevents it from being deposited on the irrigated areas and increases the need for large compensating quantities of commercial fertilizers in order to maintain soil fertility in the irrigated areas (Borgstrom, 1971).

The establishment of an irrigation system also may create health problems. Water can carry toxic chemicals and many communicable diseases. The warm and dry climate surrounding irrigation systems in arid regions offers the best conditions for the spread of malaria. Bilharziasis, cholera, typhoid, and many other diseases may find favorable conditions along irrigation streams.

Ecological imbalance also may result from nomad settlement projects. Frequently these are intended to raise the nomads' standard of living, but they also may be aimed at gathering in one place nomadic peoples who are considered an obstacle to modernization and/or a military threat, and therefore politically undesirable. The result is often to intensify agricultural and grazing land uses. Many studies indicate that nomad settlement has failed to obtain its objective and has created many adverse ecological consequences. These studies conclude that in most areas nomads have better standards of living than do their sedentary countrymen (Darling and Farver, 1968, pp. 671-682; Heady, 1968, pp. 683-693).

Industry, Mining, and Tourism

Specialists in nonagricultural sectors of the economy maintain that the most effective use of water, as of any other resource, is that use which produces the maximum amount of wealth, not necessarily the use which produces the maximum amount of food, in arid and semi-arid lands. Thus, they claim, a specific water resource in an arid area might produce enough food to sustain 100 people, but the same quantity of water might be used in an industrial operation to create enough wealth to permit 6,000 people to purchase the food they need from other areas (Wells and Marmion, 1969, pp. 19-29).

It is clear that such specialists are concerned only about commercial profits in their investigation of arid land utilization problems. They do not consider whether the arid land is located in a developed or a developing country. There may be quite a difference between the two in terms of development goals and ecological and technological acceptability and capability. The objectives of arid-land development in developed countries are to strengthen or expand economic activities. That is, they try to complement activities in the humid regions to exploit the special potential of arid land. In most developing countries, especially those dominated by aridity, the objectives are to achieve economic and social change so as to meet basic human needs, mainly food supply.

Industry, mining, and tourism in arid lands have contributed to the growth of urbanization, which has brought new and severe problems in addition to the well-known difficulties of cities in humid areas. In addition to the water-supply problem, Amiran (1977) notes:

> In dry atmospheres this material—garbage and other solid waste—instead of disintegrating, is preserved. The absence of flowing rivers and the rarity of surface run-off in general leaves all waste in the city. Consequently, a considerable portion of land around certain arid-zone cities is covered by waste. Environmental malfunctions below ground include salinization of aquifers, water logging, and accelerated sedimentation in storage reservoirs.

Present Situation and Future Security of Food Supply

Estimates differ as to the number of malnourished or undernourished people in the world, depending on the definition of hunger. Mayer (1976, p. 14) believes that one-eighth of all humans live on the verge of starvation, while Nicol (1980, p. vii) indicates that 40 percent of the world's population lives in poverty. But according to Borgstrom (1973, p. 26), two-thirds of all humans suffer varying levels of food and water shortages in addition to lacking adequate shelter, clothing, education, and medical care. These people are distributed throughout the critically hungry belt which includes the southern half of Asia, Africa, and South America. More than one billion are malnourished (that is, they get enough food to fill their stomachs, but it lacks protein, minerals, and vitamins), and more than half that number are undernourished (they do not have enough food even to fill their stomachs). It is estimated that about 12,000 people die each day from starvation or the diseases of malnutrition (Borgstrom, 1973, pp. 54-57, and Ehrlich, 1970, p. 72). Borgstrom (1973, p. 57) mentions that if all the food available in the world were equally distributed and each human being received identical quantities, we would all be malnourished. He adds that global food production can feed about one-third of mankind at the United States level.

The so-called "Green Revolution" helped to increase food production during the 1960s and early 1970s at an average annual rate of 3 percent in the low-income nations and 2.7 percent in the high-income nations. But the high population-growth rate in the developing nations absorbed most of this increase (Crosson and Frederich, 1977, p. 15). Brown (1975, p. 1053) attributed this increase to the use of chemical fertilizer, which increases the productivity of each hectare and enabled India, for example, to double its wheat production within six years, while other countries, such as Mexico, the Phillipines, Pakistan, and Turkey, all increased cereal production dramatically. But while the population growth rate of developing countries remained high, the relief provided by the "Green Revolution" was only temporary, and it gave way in 1973 to a new decline in average output per hectare with use of a given amount of fertilizer.

Despite the long-term growth of global hunger, the problem began to attract serious attention only recently, when those who were able to pay became unable to obtain food. World reserves of grain in exporting countries dropped from 93 days of world grain consumption in 1969 to 39 days in 1973. The whole world began to make it from one harvest to the next (Brown, 1977, pp. 24-30).

Any nation's food security cannot be isolated from the context of regional and global food insecurity created by the continuous growth of population, weather fluctuation and instability, limitations of agricultural resources which can be used with reasonable financial or ecological costs, and frustrating environmental response to the so-called "Green Revolution" dependent on fertilizers and fuel-powered machinery. The interaction of these factors has changed four major regions—North Africa, Southwest Asia, Latin America, and the U. S. S. R.—from food-exporting to food-importing areas during the last 25 years (Table 2).

The food situation in less developed arid countries poses deeper troubles than in the world at large. This is especially so in countries in the wide Afro-Asian Desert belt. While worldwide grain production doubled between 1950 and 1975 and global grain output per person increased by more than a third over this period, only four countries of the sixteen in Table 5 were able to raise their per capita grain output. Those countries are Iran, Libya, Senegal and Sudan. In the other twelve countries, per capita grain output declined at different rates; in two countries, the per-capita decline was more than 50 percent (Algeria, 61 percent; Lebanon, 54 percent), and in the other four countries it was more than 40 percent.

Summary

The previous discussion demonstrates that up to two-thirds of the world's population suffers from malnutrition

TABLE 5

PER CAPITA GRAIN PRODUCTION IN SIXTEEN DESERT COUNTRIES, 1950-52 AND 1973-75

Country	Per Capita Cereal Production (Kilograms)		Change (Percent)
	(1950-52)	(1973-75)	
Afghanistan	263	234	-11
Algeria	221	87	-61
Ethiopia	220	190	-14
Iran	182	185	-2
Iraq	269	156	-42
Jordan	143	79	-45
Lebanon	44	20	-54
Libya	99	106	+7
Mali	267	146	-45
Morocco	272	213	-22
Niger	303	169	-44
Senegal	142	186	+31
Sudan	102	150	+47
Syria	315	241	-24
Tunisia	216	184	-15
Upper Volta	193	180	-7

SOURCE: U. S. Dept. of Agriculture in Eckholm and Brown, 1977, p. 20.

or under-nutrition in different degrees, and about 90 million people are added to these groups each year. There are serious ecological and economic constraints on the ability of agricultural expansion to produce more food and on the so-called Agricultural Revolution, which depends on increased use of fertilizers and fuel-powered machinery and faces serious problems (such as the declining agricultural output for each input unit of fertilizer, limitations of fossil-energy supply, and water, soil and air pollution). Under these circumstances, the food security of a country cannot be isolated from its human and physical environments nor from the regional and global context of these environments. Borgstrom (1977, pp. 321-322) suggests that any plan to create a food balance should depend on the adjustment of these six interacting factors: food production, population better storage and utilization, nutritional requirements, disease control, and resource appraisal (land, water, energy, minerals). All these factors interact to direct the food situation toward insecurity if one or more of these factors is ignored, as is the case in the present situation, or toward food balance of all these factors are considered in relation to all the others. The "ecology and economy are the two balancing wheels holding this system together—a responsibility which has thus far not been too well discharged by either group of proponents" (Borgstrom, 1977, p. 322).

CHAPTER III

PHYSICAL CONSTRAINT ON AND RESISTANCE TO AGRICULTURE IN AN ARID ENVIRONMENT

In the previous chapter, three major features of global agriculture were reviewed in detail: world population and the food situation, population pressure on agricultural land and water, and ecological constraints on human activities and change in arid lands. In this interdependent world, increasing pressure on the earth's four major biological systems—fisheries, forests, grasslands, and croplands—requires each human community—local, regional, national, global—to consider this situation in working for a secure food supply for the future, because the deterioration of the earth's biological systems, as a result of both population growth and irrational use, threatens the security of all nations. Lester Brown (1977) explains:

> The productivity of the earth's principal biological systems—fisheries, forests, grasslands, and croplands—is threatened by excessive human claims. . . .Global food insecurity and the associated instability in food prices have become a common source of political instability. The centuries-old dynasty in Ethiopia came to an end in 1974 not because a foreign power invaded and prevailed but because ecological deterioration precipitated a food crisis and famine. In the summer of 1976 the Polish government was badly shaken by riots when it sought to raise food prices closer to the world level. In 1977 the riots that followed official attempts to

> raise food prices in Egypt came closer to toppling the government of President Anwar Sadat than has Israeli military power.

In this chapter and the next, the viability of agriculture in Saudi Arabia is examined closely with attention to the pressures and constraints mentioned above. In this chapter, the discussion will focus on the physical environment and its agricultural capability; in the next chapter, attention will turn to human pressure on agriculture as a source of food supply for the country, as a source of livelihood and employment for 50 percent or more of the population, and, lately, as a competitor with other economic sectors.

Water Balance in the Aridity System of Saudi Arabia

Many approaches have been developed to measure climatic characteristics which interact to support different varieties and densities of plant life on the earth's surface. At first, attention was given separately to climatic elements such as wind, temperature, precipitation, humidity, etc. In 1948, C. W. Thornthwaite developed the concept of water balance, which is determined by the relationship between the actual precipitation in an area and the potential evapotranspiration in that area. This relationship is represented in the form of a surplus or deficit between the available, incoming moisture (precipitation) and the needed, outgoing moisture (evapotranspiration). As surplus moisture increases in an area, the area becomes more humid; and as a deficit increases, the area becomes more arid. Thornthwaite explains this idea by saying:

> We cannot tell whether a climate is moist or dry by knowing the precipitation alone. We must know whether precipitation is greater or less than the water needed for evaporation and transpiration. Precipitation and evapotranspiration are equally important climatic factors. (Lockwood, 1974, p. 23)

The water balance or precipitation-evapotranspiration relationship in Saudi Arabia is a product of interacting climatic factors which create an arid environment in which temperatures are high, rising to over 40°C (and as high as 50°C) during the summer in most of the country except the western highland strip (the Assarah Mountains). (See relief map, Figure 1) On the other hand, in most of the country, the temperature drops to freezing or below on winter nights, except in the western coastal strip between the Red Sea and Assarah Mountain Range (Burdon and Otkun, 1968, pp. 145-153; and Beaument, 1977, p. 44). This fluctuation is represented in Figure 2, which shows the mean annual maximum and minimum temperatures at eleven stations. The mean annual temperature is over 40°C at all stations except the western coastal stations of Alwagh, Jeddah, and Gizon.

Although the Arabian Peninsula is surrounded by water bodies on three sides, the effect of these bodies is limited to a very narrow strip along the coastal area because the Red Sea in the west and the Gulf in the east are relatively small compared to the extensive Afro-Eurasian land masses surrounding Saudi Arabia. The Arabian Peninsula is

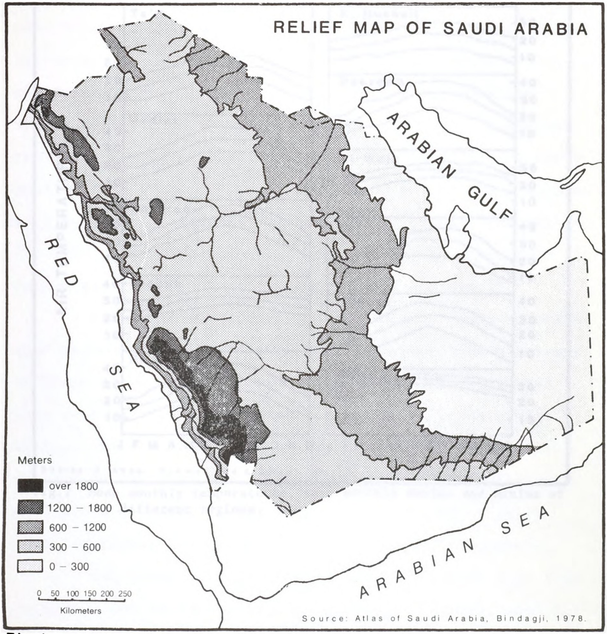
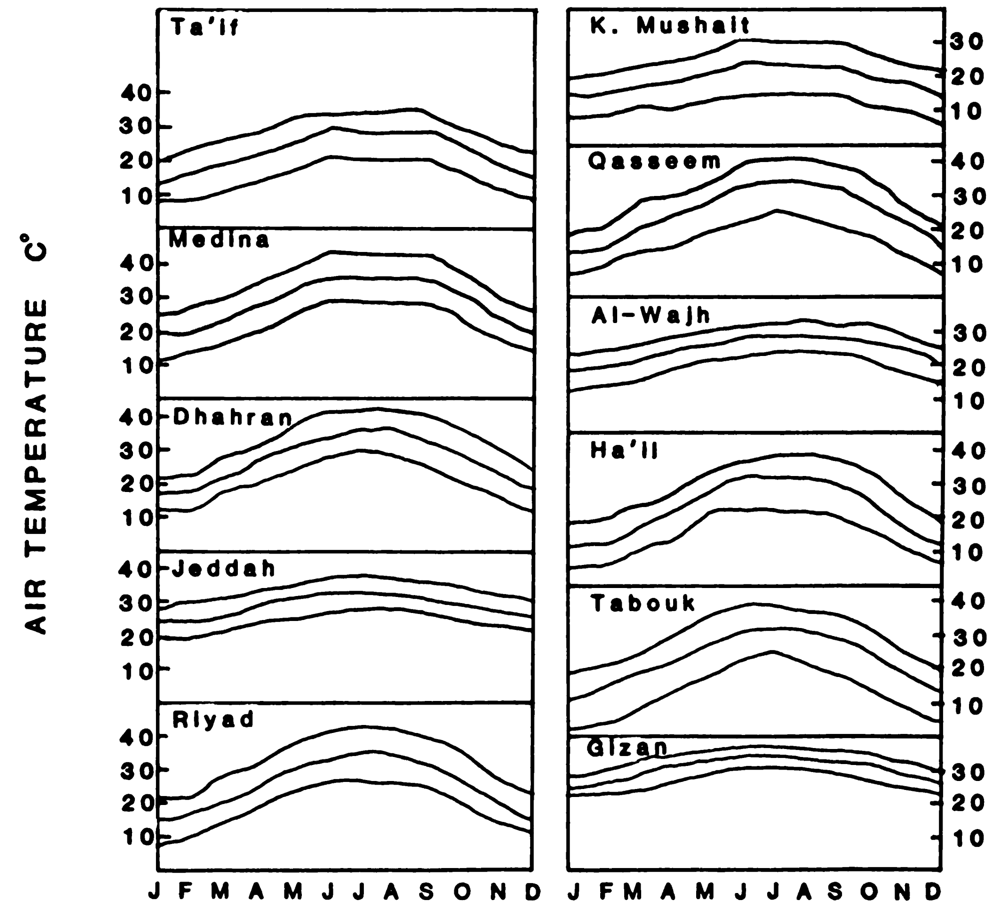

RELIEF MAP OF SAUDI ARABIA
ARABIAN GULF
RED SEA
ARABIAN SEA
Meters
over 1800
1200 - 1800
600 - 1200
300 - 600
0 - 300
0 50 100 150 200 250
Kilometers
Source: Atlas of Saudi Arabia, Bindagji, 1978.

Fig.1



Source: A. Abdel - Rahman and S. Balegh, 1974.

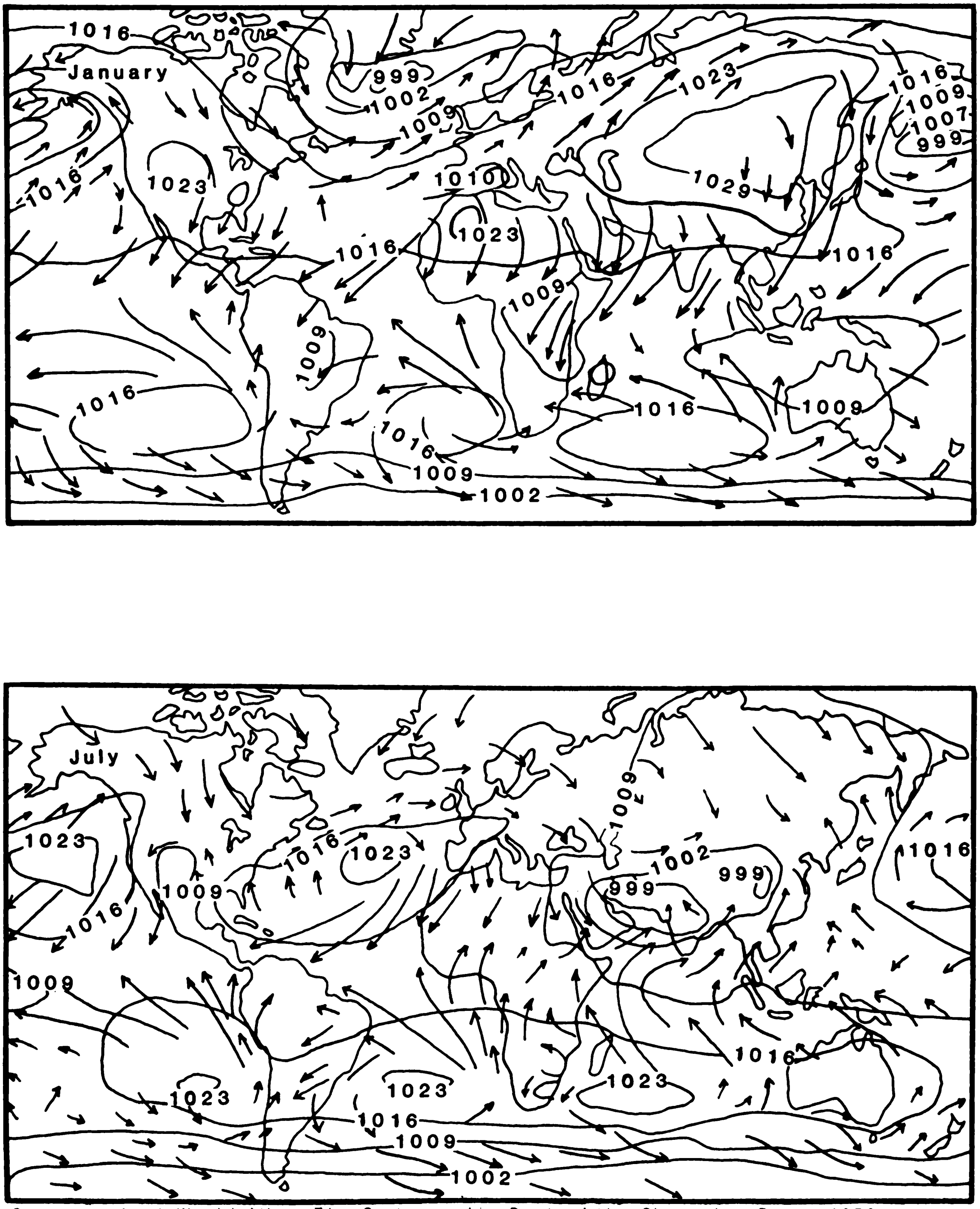
Fig.2 Mean monthly temperatures, mean monthly maxima and minima of the different regions.

between these two huge masses of land, which may be considered one body, but it is under the dry trade wind belt of the West Continents. The northeasterly trade wind system, which is supposed to dominate the area, is usually interrupted by regional and local wind systems which affect the Middle East during the summer, with a low-pressure system centered on the Arabian Gulf basin area. Local and regional wind is developed, coming from the north and northwest or from the southwest, and blowing toward the low-pressure center. In winter, the Asian high pressure extends to the area, and the continental polar air masses move into the region from Eastern Europe and Siberia. (Figure 3).

From this simplified picture of the very complicated wind system in the Arabian Peninsula, we conclude that most of these winds are dry because they are developed in and blow over extensive land masses, usually in Eurasia and Africa. They do not pass over relatively wide water surfaces. At the same time, these winds move from relatively cool areas to warmer ones; thus, their ability to carry vapor increases and their relative humidity decreases.

Two relatively moist winds provide relief from this dryness. One is irregular, cyclonic, and lifting, associated with the eastward passage of depressions from the Mediterranean area. It blows over the north half of the country during the winter. The average annual precipitation of this cyclonic wind usually fluctuates between 25 and 75 mm

PRESSURE/WINDS



Source: Oxford World Atlas, The Cartographic Dept. of the Clarendon Press, 1973.

Fig.3 Position of Arabian Pennisula in the world's pressure and winds system.

and rarely becomes more than 100 mm, so it has little or no direct effect on agriculture. However, it is very important to nomadic pastoralism.

The other wind is the southwest monsoon wind which blows on the mountainous southwest part of the country during the summer. (Figure 3) The southwest highlands also receive orographic rainfall during the winter. Because of this, these lands are regarded as the only part of the country which receives comparatively constant and reliable rain, although the part of the highlands which receives more than 150 mm accounts for less than four percent of the country's land mass. (Figure 4)

The three conditions of temperature, wind, and precipitation comprise one side of the water balance. The other side is the evapotranspiration potential, which is greatly affected by climatic elements already mentioned and is very important in determining efficiency of precipitation, as well as underground drainage and surface run-off. It is expected that, under conditions of aridity, there will be a high deficit between the outgoing moisture (mostly evapotranspiration) and incoming moisture (precipitation).

There are different estimates for the evapotranspiration potential of Saudi Arabia. For example, Burdon and Otkun (1968) estimated that it is between 1,500 mm and 3,000 mm, and Mather and Carter (in Beumont et al., 1976) estimate that the evapotranspiration potential in the western

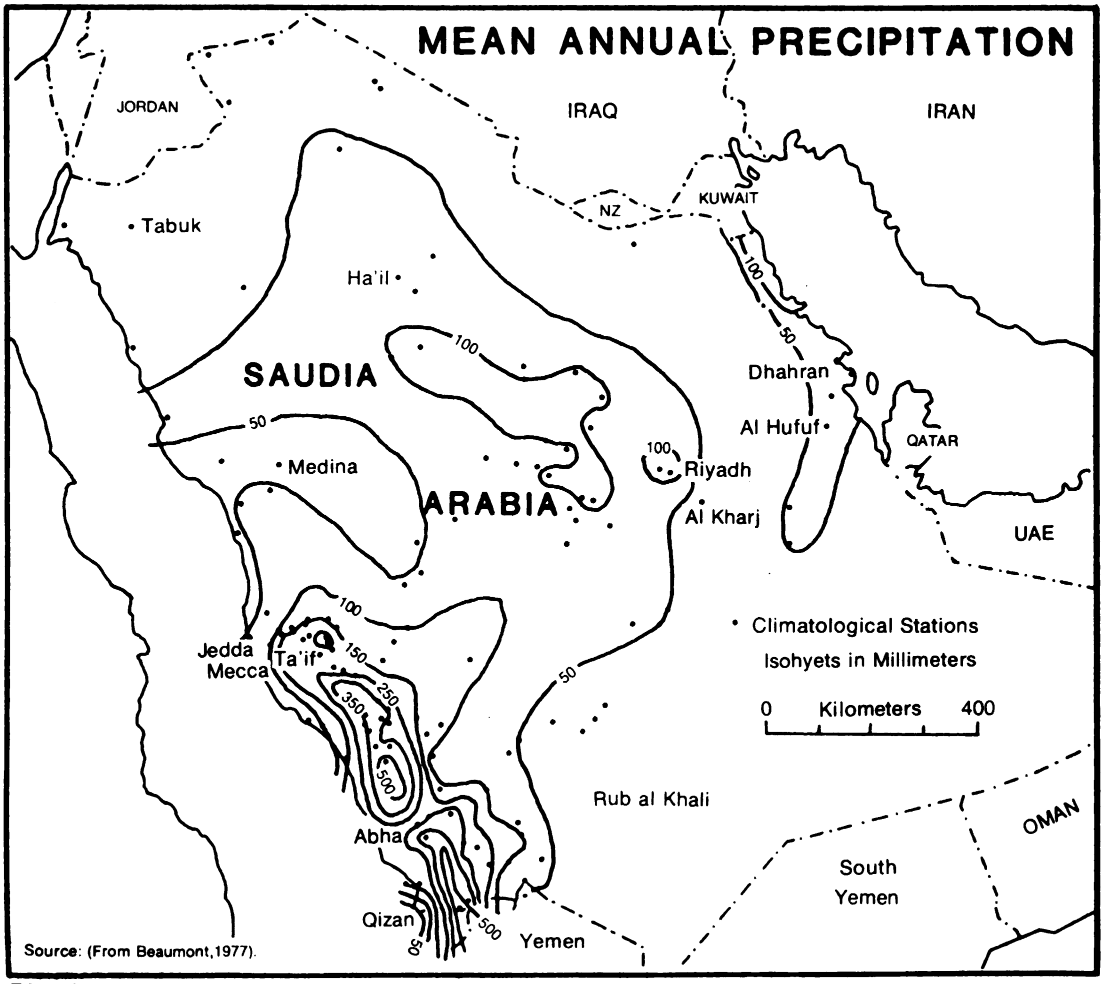
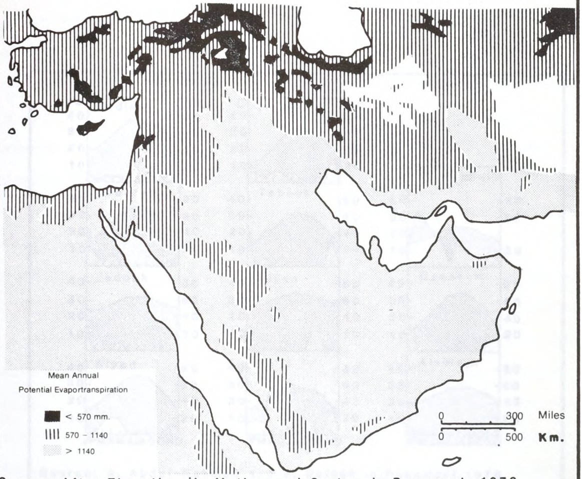

MEAN ANNUAL PRECIPITATION
JORDAN
IRAQ
IRAN
KUWAIT
NZ
Tabuk
Ha'il
SAUDIA
ARABIA
Medina
Dhahran
Al Hufuf
QATAR
Riyadh
Al Kharj
UAE
Jedda
Mecca
Ta'if
Abha
Qizan
Yemen
Rub al Khali
South
Yemen
OMAN
Climatological Stations
Isohyets in Millimeters
0 Kilometers 400
100
50
150
250
350
500
Source: (From Beaumont,1977).

Fig.4

highlands of Saudi Arabia is between 570 mm and 1,140 mm, and in the rest of the country is over 1,140 mm per annum (see Figure 5).

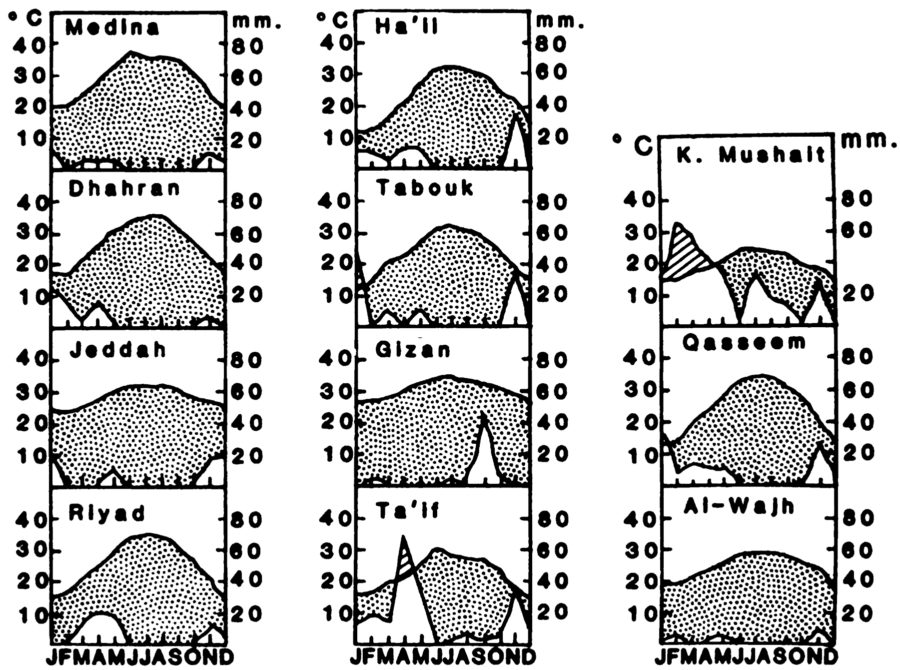
In an attempt to measure the efficiency of precipitation and the aridity in Saudi Arabia, Amin and Balegh (1974) used the available data for rainfall and temperatures recorded at eleven regional stations during 1963-1973. They applied the Clima-Diagrams method, developed by Walter (1955), in which the average monthly temperature and rainfall are represented by two curves on the same axis for each station. The concept of these diagrams is that the more the rain curve crosses over the temperature curve, the more the soil-water content is replenished. But whenever the rain curve lies below that of the temperature, the degree of aridity increases as the area between the two curves increases. The Clima-Diagrams show that at only two stations of eleven does the rain curve cross over the temperature curve for an average of about one month (Taif) and three months (K-Mushait); both stations are in the western highlands in the most humid part of the country. At other stations, and even throughout the rest of the year at Taif and K-Mushait, the area between the temperature curve and the rain curve indicates a large deficit of incoming moisture relative to potential outgoing moisture (Figure 6). It is easy to see that in this arid environment, characteristic of Saudi Arabia, the water balance represents a major factor in the

EVAPORTRANSPIRATION



Source: After Thornthwaite, Mather and Carter, in Beaumont, 1976.

Fig.5



Source: A. Abdel-Rahman and S. Balegh in Beaumont, 1976

Fig.6 Clima diagrams (rainfall efficiency) of the different regions of Saudi Arabia.

environmental capacity of agriculture. In this context, water balances means not only the available quantity of moisture, but also the ecological interaction of the climatic elements which affect the efficiency of the available moisture.

The water balance in Saudi Arabia, characterized by a high deficit between the precipitation and the potential evapotranspiration (in other words, characterized by the domination of an arid environment), suggests that agricultural activities are not expected to succeed except in that small portion of the southwestern highlands where the altitude is over 1,800 m and which receives over 300 mm of rain: the Assarah Mountain peaks. But people in areas where there is a precipitation deficiency, the arid and semi-arid areas, have tried to counter the water-balance deficit by irrigation. They have utilized available surface-water resources such as rivers, streams, and underground water. The magnitude of irrigation increases in areas where there is a seasonal or locational cycle of surplus and deficit of precipitation, such as in the monsoon area or the marginal areas between the humid and arid regions. In arid areas where there is a precipitation defict year-round and there is no surface-water resource, such as Saudi Arabia, groundwater becomes the main source for human needs, including agriculture, which exists in many dispersed oases despite the very small quantity of water available compared to the semi-arid or humid areas.

Considering the different factors which describe groundwater supply (quantity, major source of accumulation, recharge rate, and the quality of the water), Saudi Arabia has two groundwater systems that parallel its two major geological structures. One is the groundwater system of the western, pre-Cambrian complex, which occupies over one-third of the country's area, and the other is the eastern portion, consisting of sedimentary formations, occupying the remaining two-thirds of the country (Figure 7). Each of these hydrogeological systems will be investigated in terms of its characteristics and its environmental stress on agricultural activity (see Figure 8).

Environmental Characteristics of the Groundwater of the Aquifer Systems in the Sedimentary Formation

Sedimentary formations cover about two-thirds of the Arabian peninsula, dipping gently to the north, east and south of the pre-Cambrian basement of the western part of the peninsula. These sedimentary formations overlie the dipping extension of the pre-Cambrian complex. Their width reaches about 5,000 m in the eastern coast of the country, and their extension under the Arabian Gulf may reach 10,000 m. There are about thirty identified formations grouped into four major categories (see Figure 9). The oldest of these shallow-water marine rocks is the Paleozoic formation

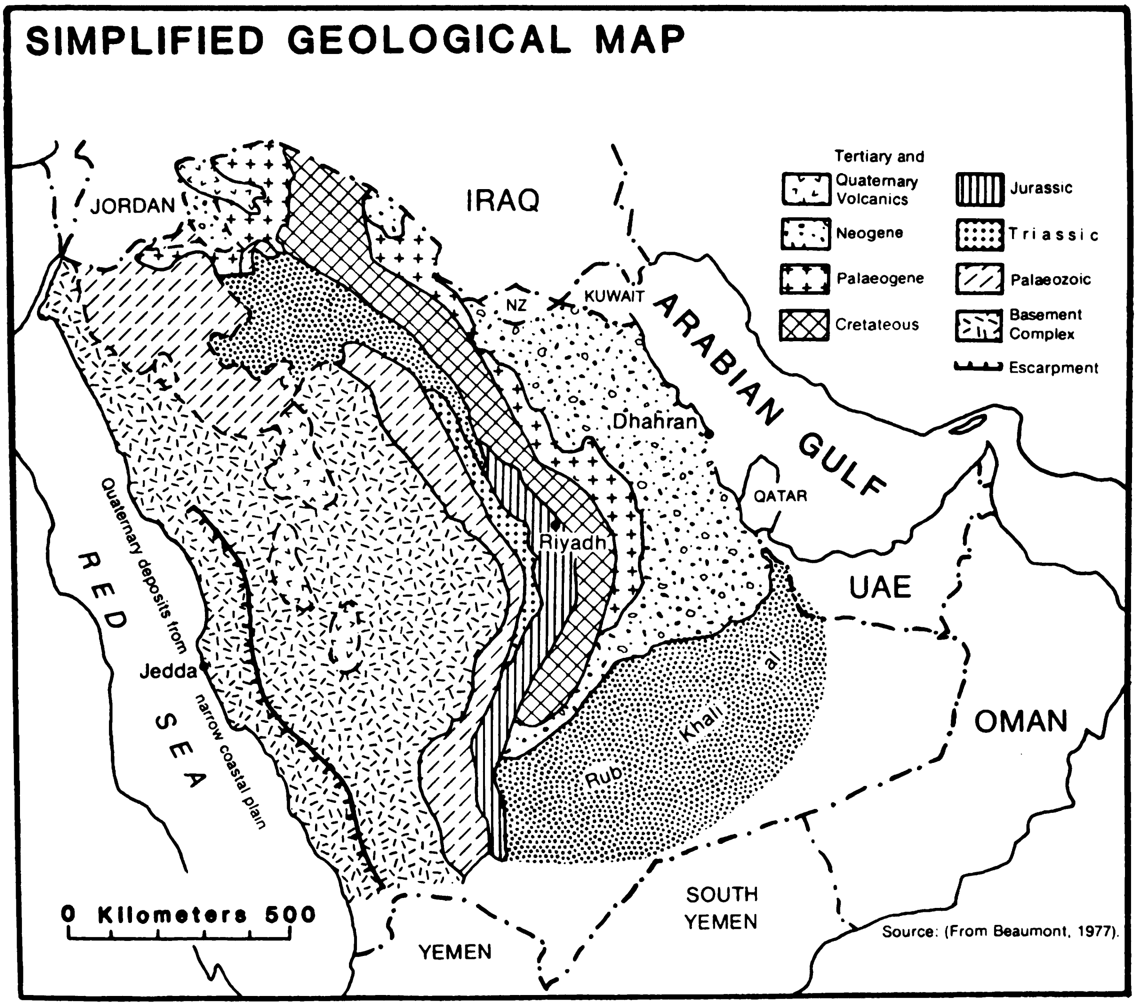

SIMPLIFIED GEOLOGICAL MAP
Tertiary and Quaternary Volcanics
Neogene
Palaeogene
Cretateous
Jurassic
Triassic
Palaeozoic
Basement Complex
Escarpment
JORDAN
IRAQ
NZ
KUWAIT
ARABIAN GULF
Dhahran
QATAR
Riyadh
UAE
RED SEA
Quaternary deposits from narrow coastal plain
Jedda
Rub al Khali
OMAN
SOUTH YEMEN
YEMEN
0 Kilometers 500
Source: (From Beaumont, 1977).

Fig.7

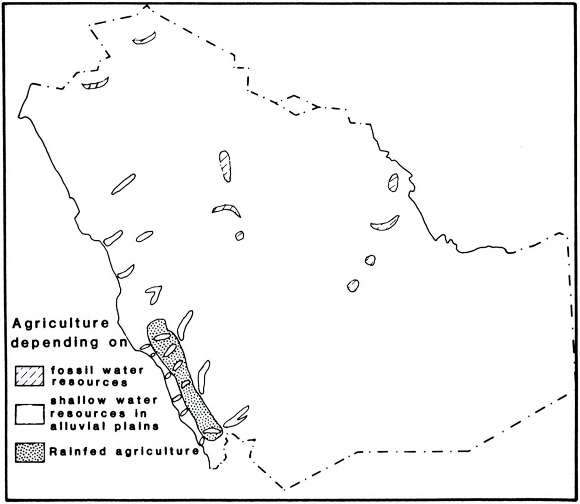
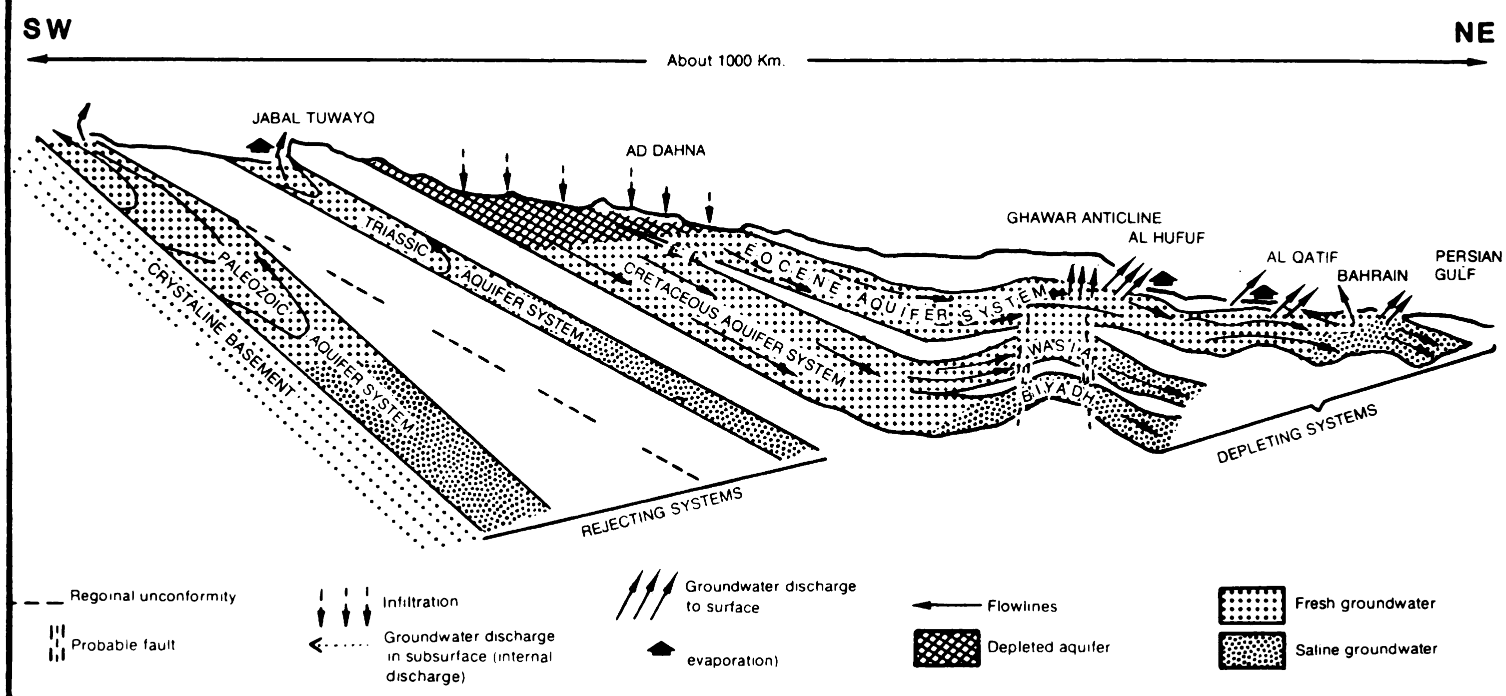


Fig.8 Approximate major agriculture concentrations and types according to the kind of water resources.

MAJOR AQUIFER SYSTEMS



Source: (From Beaumont, 1977).

Fig.9

which lies in a great, curved belt along the eastern margin of the Arabian shield. Other formations overlie each other, and their western edges appear as belts, the oldest in the west and the newest in the east; therefore, the newest formations are found in the eastern province of Saudi Arabia. The movement of groundwater within the sedimentary formation, in general, is down-dipping to the east; therefore, underground water tends to concentrate in the eastern part of the formations.

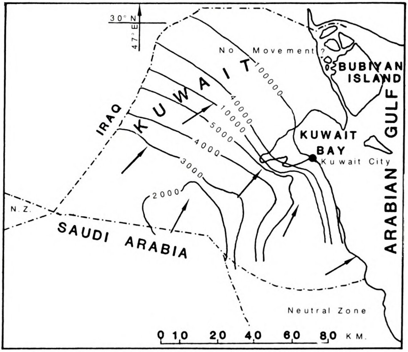
In terms of groundwater, the sedimentary formations have been grouped into four major aquifer systems. As Figure 9 shows, the first two, Paleozoic and Triassic, are the oldest formations, dating from the Cambrian to the Triassic ages. Unlike the third and fourth aquifer systems, these two are closed, so most of their infiltration groundwater has been held. The third aquifer system, the Cretaceous, consists of the Wasia and Biyadh formations; and the fourth, the Eocene aquifer system, includes Paleocene sediments and the Ummar Radhuma formation. This system is the largest of the four. Both the Cretaceous and the Eocene systems are being depleted, as water is transfered from the Cretaceous system into the Eocene system through sub-surface faults and reaches the land surface from the Eocene system through terrestrial and submarine springs in the Eastern Province and the Arabian Gulf.

Limitations of the Aquifer Water Resources

The groundwater of the sedimentary formations of the country has been utilized since ancient times through natural springs or hand-dug wells over the parts of the formations nearest the land surface. At some sites, when the upper part of the formation consists mainly of poorly cemented rocks and these sites stand in low elevations, then the groundwater level forms artesian conditions and flowing bore-holes are developed. Since the early 1950s, when the search for petroleum resources began, groundwater has been discovered with petroleum or alone in different geological formations. This discovery has brought hope for ending the scarcity of water and has been followed by relatively intensive exploitation of the groundwater through the installation of oil-driven pumps on traditional wells and bore-holes, or through newly-drilled wells in old oases or newly-created settlements. The ecological responses to such rapid modification of the hydrologic cycle in such an extremely arid system have been resoundingly negative. Shortly after this change began, there were rapid declines in the groundwater level leading to complete depletion or to increases in water salinity. Responses to agricultural irrigation included land salination and water logging.

From these experiences, and from data developed in an overall inventory assessment of the hydrogeology of the sedimentary part of Saudi Arabia, it has been found that in any aquifer or formation, there is a relationship between the percentage of water salinity and the down-deep direction of the aquifer or formation where fresh water exists in the upper part and water salinity increases to high salinity in closed sections, if they are found. Although there are no salinity line maps available for the sedimentary part of the country, such deposits are usually found in the Paleozoic aquifer system.

There is a salinity map of the Dammam limestone aquifer in Kuwait (Figure 10), which is the northern extension of the Dammam formation in the Eastern Province. The map shows that the salinity is about 2,000 ppm of total dissolved salts (TDS) in western Kuwait, about 50-80 km from the Gulf, and becomes between 10,000 and 40,000 ppm under the coastline (40,000 in the Arabian Gulf), rising to 100,000 ppm in northern Kuwait, where the groundwater is static. In Saudi Arabia, in shallow groundwater, the salinity is less than 1,000 ppm, but the salinity increases in the aquifer water, in general, from between 1,000 and 3,000 ppm of TDS in the aquifer or formation system, to 10,000 ppm or more in the older water in the deeper section of the aquifer. This rapid increase in salinity parallels the increase in the depth within an aquifer and is not restricted to the eastern part of the sedimentary formation of the country. It also exists in the southwestern section: in Wadi



Source: D. Burdon and A. Al - Sharhan, Journal of Hydrology, 6, 1968.

Fig.10 **Isosalinity (ppm of 705) lines for the groundwater of the Dammam aquifer in Kuwait which is a North extension of the Dammam formation in Eastern Saudi Arabia**

Dawasir, salinity of less than 1,000 ppm is found in shallow groundwater in or near the recharged area of the aquifer, but salinity increases to about 6,000 ppm in some wells discharged from the Minjun-Dhruma aquifer (Triassic system) (Italconsult, 1969). In addition, analysis of groundwater samples from different aquifers in different parts of the country has been done at depths beyond 1,200 m (more than 2,100 ft) and distances from the aquifer's outcrop of 24 to 250 km. It has been found that groundwater age in the aquifer increases with increase in water depth and distance from the aquifer's outcrop, usually toward the east. Water ages of the samples were estimated to be from 22,000 to more than 30,000 years. (Thatcher, Robinson, and Brown, 1961).

Other important factors connected with groundwater are the discharge and recharge rates, which explain the incoming and outgoing water balance and establish a link between existing exploitation and ecological capacity of the water resources in an aquifer system. Although complete and accurate information about the rates of groundwater discharge, recharge, and related matters is hard to find, it is estimated that the total discharge is about 1,660 million^3 yearly, distributed as follows: 300 million^3 are discharged yearly through springs, 300 million^3 are discharged yearly by the extraction of groundwater for domestic and agricultural use, 500 million^3 are extracted yearly for injection into the petroleum reservoirs, and evaporation losses in Sabkhus are about 500 million^3 yearly (Italconsult, 1969, in Dincer, et al., 1973). This estimation does not include discharge through the submarine springs in the Gulf.

On the other hand, there are many indications that there is little or no recharge in the aquifer system. Pike (1970) indicated that the total rainfall over the superficial and Neogen outcrops (see Figure 7) is equivalent to approximately 8 percent of the evaporated water loss from the Sibakh Playas. Also, El Khatib (1974) found that, from a total of 22,000 mcm estimated to fall yearly in the form of rain on the Great Nafud Basin (one-sixth of the country's area), only 1 percent (220 mcm) infiltrates into the ground. All of this infiltrated water returns to the atmosphere very near the location where it falls except on rare occasions.

It has also been found that the same situation exists in the confined aquifer systems. The confined Paleozoic aquifer system overlying the pre-Cambrian rock is supposed to receive the rain runoff from drainage networks in the Arabian Shield, the most rainy and runoff-producing area in the country (Figure 4). However, different studies indicate that the recharging process occurs only in the shallow groundwater while analysis of the Saq formation, which is part of the Paleozoic aquifer system, indicates that the water in this system is quite old and there is no effective recharge process (Job, et al in Al-Suyari, 1978).

These facts outline major features of the sedimentary groundwater phenomenon. The most important characteristics of this picture are:

1. Relatively fresh water (usually 1,000-3,000 ppm of TDS) forms a small part of the upper section of the water in a formation or aquifer system, and salinity increases with the depth until the water becomes brackish or salty (brine)

2. The quantity of discharge, naturally or through pumping, exceeds the quantity of recharge (which is very limited if it exists at all). This is clear from the water age determination, the increase in salinity as water is pumped or flows, and the decline of the groundwater level which has led to the drying of some wells or springs (Italconsult, 1969, in Tayeb, 1978)

The Agricultural Situation in the Sedimentary Part of the Country

Agricultural statistics of Saudi Arabia released during the last two decades are very confusing and conflicting because most of them are products of estimation rather than of accurate surveys. Therefore, they are affected by different impressions generated through the misunderstanding of or disregard for the ecological dimension of the available water resources during the investigations, which concentrated on the groundwater in sedimentary rocks during the 1950s and 1960s and changed to the water resources of the western highland region since 1970. This situation has led to two kinds of overestimations related to cultivated land in both the Arabian Shelf sedimentary sections first and the Arabian Shield later:

1. Early overestimation of the percentage of the country's cultivated land in the sedimentary section: estimations in the early 1960s indicated that about 60 percent of the total cultivated area was located in the sedimentary part of the country and depended on the fossil groundwater (Nyrop, 1977). The exaggeration in this percentage may be attributed to the more-visible extension of the agricultural area in the oases compared to the very scattered farms in small segments throughout the western, mountainous highlands, and to the discovery of groundwater in many aquifer systems, encouraging expansion of cultivated areas through individual initiatives or through governmental projects

2. Overestimation of the percentage of the country's agricultural land contained in dry farms (non-irrigated agricultural areas) in the early 1970s: rain-fed (dry-farm) agriculture was estimated to be about 75 percent (404,000 ha) of the total cultivated land in the country, which was estimated in 1971 to be about 525,000 ha. Of this total, 75 percent was said to be in the western region, compared to only 40 percent in earlier estimations (Nyrop, 1977, p. 279; and Second Development Plan, 1975, p. 119).

This overestimation is a reflection of the ecological difficulties which have faced the existence or expansion of agriculture in the fossil water dependent region, and may be attributed to the attraction of public and government attention by the exceptional environment of the highland (at an altitude of more than 1,800 m) which recently came into focus after the development of a transportation system with highways and airports.

It should be mentioned that even recent statistics contain confusion about the distribution of cultivated land between the Arabian Shield and the Arabian Shelf. According to the government's Statistical Year Books (1975-78, Vols. 12-14), total cropland is estimated at 600,859 ha, of which only 145,993 ha, or about 24 percent, is located in the Arabian Shelf (the sedimentary area) and dependent on the fossil-water resources. About 76 percent is reportedly in the Arabian Shield, dependent on rain or on runoff and infiltrated, shallow groundwater.

On the other hand, statistics from the Comprehensive Agricultural Census of 1973-74 indicate that the country's total cultivated land (both temporary and perennial crops) is 395,248 ha, of which 184,410 ha, or 47 percent, is in the Arabian Shelf. The discrepancy may be due to the fact that a considerable amount of the agricultural area in the Arabian Shield is cultivated more than once a year, and that some areas in the Arabian Shelf that were classified as cultivated lands are unproductive because of water shortages or the salinity problem.

Salinization is a major ecological problem threatening both new and traditional agricultural areas. There is no statistical information about the agricultural area affected by salinity problems, but it is believed to comprise the heavily cultivated area in the regions of sedimentary rocks in which the irrigation process depends on groundwater. Compared to the irrigated area in the Nile, Indus, and Euphrates-Tigris valleys, where salinization eliminates considerable area from farming each year, the Arabian Shelf is a more-favorable environment for the emergence of this ecological dilemma: groundwater with 2,000 ppm of TDS or more, low rate of atmospheric humidity, and absence of perennial running water to carry away the accumulated salt, even with construction of drainage systems. There are still major unsolved difficulties such as the lack of sufficient water to supply the root zone to meet the needs of plants and counteract soil leach. Therefore, it will not be surprising if the 112,117 ha appear in a column entitled "temporary wasteland" or "useless lands" as a result of salinity, with about 86 percent, 96,024 ha, of this abandoned land being in the Arabian Shelf.

Although there are no available statistics on the magnitude of the expansion in exploiting the groundwater to increase cultivated land in the Arabian Shelf area, it is believed that the available figures for the Eastern Province may reflect, to some extent, the rest of the Arabia Shelf. Twitchell (1944) stated that several wells had been drilled since the early 1940s by the oil companies, the government, and individuals, but he did not give a number of wells and springs. In 1951, Vidal reported that there were only five wells and sixty-two springs (Tayeb, 1978). Drastic increases in wells (336) and springs (162) were reported by a Swiss consulting firm in 1963-64 (El-Khatib, 1974). During 1964-1967, the number of wells was up to 887, but the number of springs had dropped to 102 (Italconsult, 1969).

Lately, it has become clear that the groundwater potential in the Arabian Shelf was exaggerated or poorly estimated. An investigation of the Al-Hassa Oasis agricultural potential was conducted by the United States Agricultural Mission, led by K. S. Twitchell, and the Swiss firm Wakuti, which surveyed the area in 1963-1964 and again in 1966 as a potential base for the Al-Hassa Irrigation and Drainage Project and the Faisal Settlement Project of Harad. The goals of both projects are to add about 16,000 ha of new cultivated area (12,000 ha in Al-Hassa) and to improve the traditionally irrigated area of 8,000 ha in Al-Hassa. Although there are no specific statistics for the direct ecological response to this expansion of regional capability, the existence of a problem may be assumed based on the previous discussion and on El-Khatib's indication that the average discharges of the springs have declined since Wakuti's survey. This consultant firm had overestimated the groundwater potential (El-Khatib, 1974).

It is possible to make simple computations for water consumption in agricultural and non-agricultural activities through the Arabian Shelf from its almost unrenewable water resources. It is estimated that 20,000 ha of cultivated land in the Al-Hassa Agriculture Project require quantities of water for irrigation equivalent to the regular flow of Al-Hassa Springs in 1963-1964, about 360 mcm, with an additional 25 to 30 percent needed for soil leaching. It is reasonable to multiply that quantity of water (360 mcm) by seven to obtain an approximate estimation of water consumption for the total cultivated land in the Arabian Shelf in 1973-1974, about 140,000 ha. According to this estimation, the required quantity is about 2,520 mcm in addition to non-agricultural consumption which may reach between 1,000 and 1,500 mcm.

Environmental Characteristics of the Western Pre-Cambrian Highland of the Arabian Shield

The western pre-Cambrian highland is the outcrop of the basement complex which underlies the sedimentary formation. The topographical features of the highland are generally classified as follows:

1. Tihama: a narrow strip of coastal plain extending from the Gulf of Aqaba to the Yemen border. The width of this plain varies from about forty kilometerd minimum in in the south to almost nothing in the north. It separates

the Red Sea from the east scarp of its depression

2. Higaz Highland: the western upper part of folded shield, the Arabian part of the African Shield. It has different local names such as Higaz, Assir, and Assarah Mountains. The elevation of some of its peaks may reach 2,400 m above sea level in the Assir Mountains. The western slope is a very deep scarp created by the separation of the Arabian Shield from the giant African Shield (see Figure 11). The eastward slope is very gentle

3. Higaz Plateau: a vast peneplain extending directly east of the highland. It slopes slightly toward the northeast and east and extends inside the Arabian Peninsula to about 150-200 km west of Riyadh, Unayzah, and Hail

From agricultural and hydrological points of view, the Arabian Shield may be classified into two regional systems:

1. Mountain Zone: including the mountainous area and its foothills, an area over 1,400 m above sea level, with mild temperatures and precipitation over 200 mm. It is possible to divide this area into two subsections: the dry farming system on the terraced mountain slopes over 1,800 m in elevation with rainfall over 350 mm per annum, and the irrigated terraces in the tributaries and valley bottoms between the mountains and foothills with elevations of 1,400-1,800 m and rainfall of 200-350 mm per annum. Rain-fed crops, such as wheat and barley, occupy the terraced slopes,

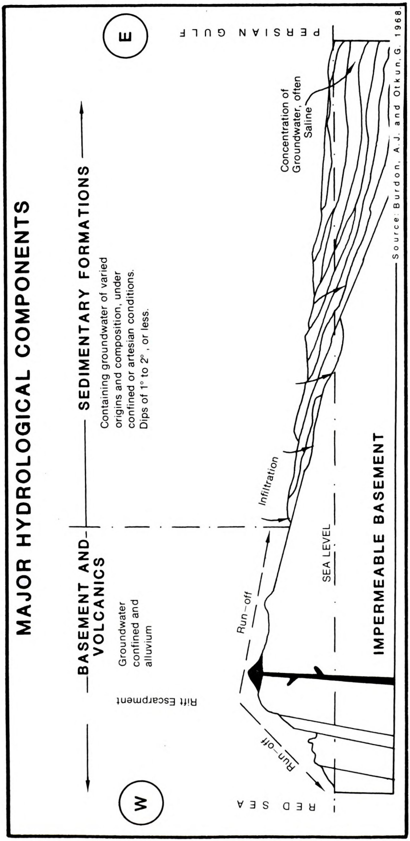
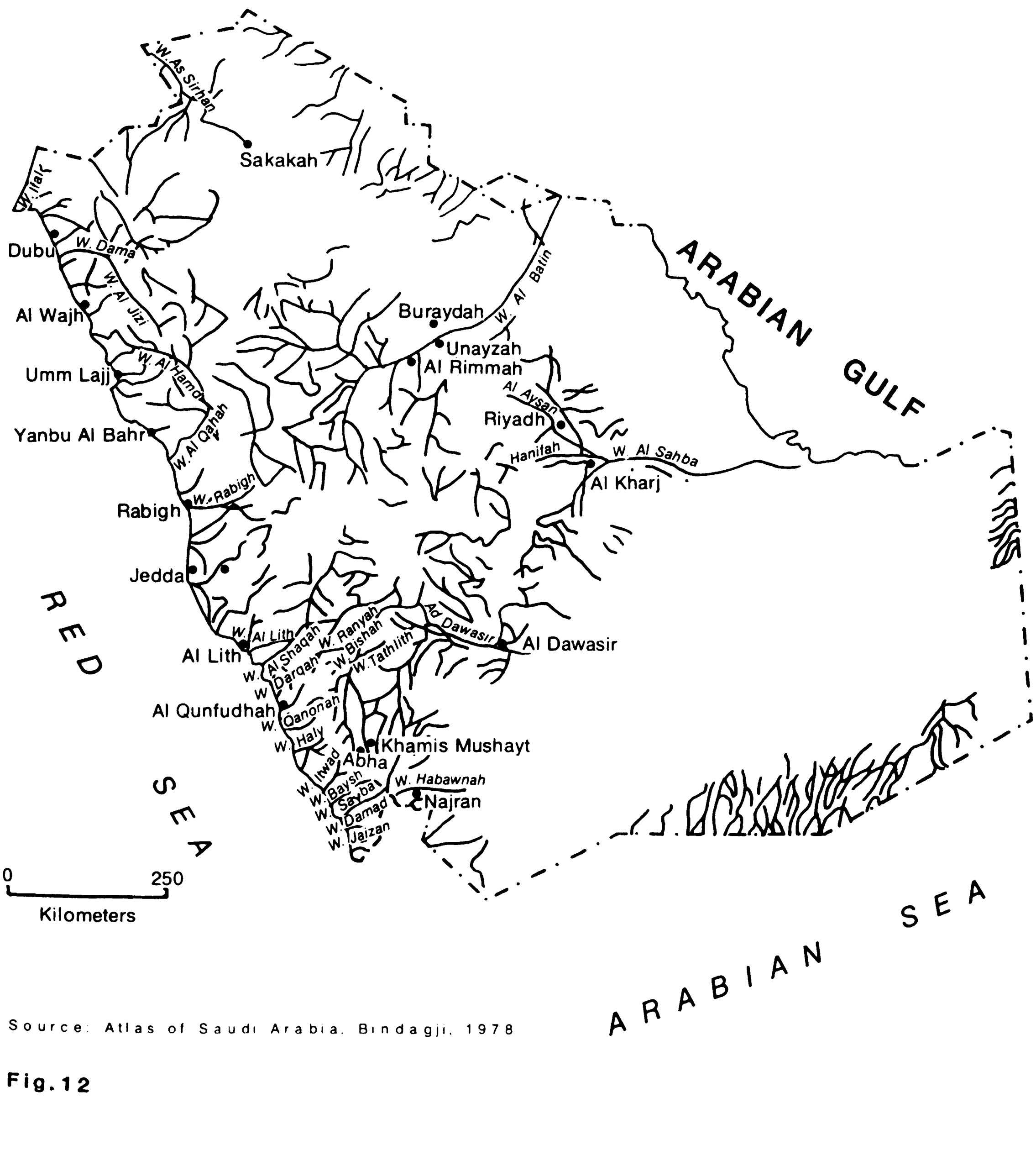

MAJOR HYDROLOGICAL COMPONENTS
BASEMENT AND VOLCANICS
Groundwater confined and alluvium
SEDIMENTARY FORMATIONS
Containing groundwater of varied origins and composition, under confined or artesian conditions. Dips of 1° to 2°, or less.
W
E
RED SEA
PERSIAN GULF
Rift Escarpment
Run-off
Run-off
Infiltration
SEA LEVEL
Concentration of Groundwater, often Saline
IMPERMEABLE BASEMENT
Source: Burdon, A.J. and Otkun, G. 1968.

Fig.11

while fruit trees and vegetables dominate the valley bottoms (Figure 12). El-Khatib (1974), using 1971 estimates, indicates that the agricultural land in this zone accounts for 92,000 ha, of which only 15,000 ha is under irrigation. But, as mentioned previously, the dry farms were overestimated in the early 1970s. According to the 1974 agricultural survey, the dry-farm area is assumed to be represented by the difference between the total irrigated area of 374,830 ha and the total area of temporary and permanent crops of 395,248 ha; this leaves only about 20,000 ha. The overestimation of the dry farms in the mountain zone may be attributed to classifying irrigated areas as a complement to the rainfed and runoff-flooded agriculture in the valley bottom within the mountains and their foothills.

2. The irrigated agriculture in the desert and coastal major valley: more than 90 percent of the Arabian Shield lies in elevations between 900 and 1,400 m and receives less than 200 mm of rainfall. This area extends from the eastern mountains and their foothills to the western edge of the sedimentary formations in the shape of a plateau, its drainage toward the east through major valleys in which agricultural activities concentrate, dependent on runoff and the resultant infiltrated groundwater of the relatively shallow alluvial deposits along the valley bed. The valley extends toward the east beyond the 100-200 mm rain belt, but the runoff from the rain belt has created a

WADIES OF SAUDI ARABIA



Source: Atlas of Saudi Arabia, Bindagji, 1978

Fig. 12

hydrological system able to support many agricultural oases in this dry part of the Arabian Shield where fossil groundwater does not exist

On the western scarp of the mountains, the major valleys emerge through the scarp and dip deeply to sea level through the narrow coastal plain of Tiharma between the highland west slope and the Red Sea. Intense runoff is generated on the scarp, which faces the rainy southwestern monsoon winds. It is clear that, in this portion of the country, the runoff plays a vital role in the hydrological balance, particularly as the only source of recharge to the groundwater in the relatively shallow alluvial deposit in the major valleys (Figure 11). The most important runoff-generating area within the Arabia Shield as a whole lies in the median 100-300 mm rain belt. Unlike the high part of the mountains, which receives more rain, these areas are wider and their soil contains less organic matter; consequently, its permeability is very low, which positively affect the runnoff accumulation after rainfall in these areas.

Runoff Water:
New Approaches, New Problems

The negative ecological responses to increased groundwater utilization through expanding and intensifying agricultural activities in the Arabian Shelf (the sedimentary regions) have forced government planners to turn more attention to the more-rainy area of the country, the pre-Cambrian highland or Arabian Shield. An inventory of the country's water resources, both surface and groundwater, in the Arabian Shield and the Shelf had been started in the 1960s. Also at that time, the Al-Hassa Project was undertaken to increase the utilization of fossil groundwater, while the Wadi Jizan Dam was constructed to increase the utilization of runoff. But more recently, efforts have been increased in the western highland valleys to impose more control on their present flow systems and, consequently, the traditional utilization of water. Experts and consultant firms have made several studies and assessments and have suggested the possibility of achieving more success in overcoming the ecological constraints to agricultural expansion, particularly the scarcity of water. Two dams have been built in the Arabian Shield: Jizan Dam (1971), mainly for agricultural purposes, and Abha Dam, mainly for domestic supply. A third, the Turabah Dam, is under construction, and there are many valleys under investigation for possible additional dams. Available information is not adequate for comparison of the situations before and after construction of the Jizan Dam—for example, to evaluate the benefits and costs, including the ecological cost in the long run—although all agricultural projects are preceded by studies and recommendations from experts and consultant firms. The ecological logic gained through experience with the aridity of the region was applied in the evaluations and recommendations by one of the consulting firms that recently studied the eastern slope of the South Arabian Shield (MacLaren International Limited [M. I. L.]); and there is a possibility that on the basis of those recommendations, some agricultural projects, mainly dam construction, will be implemented. The findings and recommendations of the consulting firm are summarized in these points:

1. The direct use of surface water, in the sense of using flood water, has been almost non-existent with a few exceptions

2. Preliminary evaluations indicate that catchment of 30-40 km^2 can provide a yield of good-quality water of 0.7 mcm per annum in the 450 mm rainfall zone

3. Aquifers in the Mountain Region consist of major alluvium deposits that do not have sufficient storage capacity to be attractive for extensive exploitation for agricultural purposes. They do contain good quality groundwater

4. Aquifers in the Desert Region are generally long, narrow, and shallow. They are relatively complex from a geological standpoint. There are multi-aquifer systems in some locations. The exception to this description is the acquifer system in Habawnah where two relatively isolated aquifers exist

5. The crystalline rocks of the pre-Cambrian basement complex underlying most of the area do not function as a major aquifer

6. The groundwater resources of the Arabian

Shield-South will not support significant expansion of horizontal agriculture except in Wadi Habawnah

7. No immediate horizontal expansion of development is recommended; rather, a vertical expansion, or intensification, of agricultural activity is proposed in both the terrace system of the mountains and the agricultural oasis system of the desert region

8. To supply the extra water required by this intensification, surface-water impoundments are proposed in the form of big dams on the major valleys such as Wadi Bishah, with an annual flow of 450 mcm, and Wadi Ranyah, with 267 mcm; and small dams or cisterns are proposed for the narrow and steep valleys of the mountain zone (M. I. L., 1978, Annex 10)

Examination of the proposal for building dams to obtain more output from each input unit of available water, according to the ecological problems experienced in similar environments, the above findings, and some additional facts about the present situation, indicates that the ecological potential of available water resources not only is under full use, but is already over-exploited in many cases. Thus, the proposed dams will create ecological problems rather than producing any considerable benefits. These conclusions originated from these analytical views:

1. The mountain zone is not a runoff-generating area, especially in areas which receive more than 400 mm per

annum (elevation over 1,800 m), because the terrace system is efficiently utilizing the rainfall and the runoff. This essential fact was realized by the consulting firm, which suggested the building of small dams in the rain-fed agricultural area to supply required irrigation water to supplement the existing dry farms (M. I. L., 1978, Annex 10). In lower-elevation parts of the mountains and in their foothills (elevation 1,400-1,800 m, rainfall 300-400 mm), the terrace system is concentrated in the valley bottoms where the runoff is utilized directly by flooding agricultural land or indirectly by increasing the recharge of groundwater which is then used as a supplement to rain- or runoff-fed agriculture

2. Runoff water is generated mostly within two areas in the Arabian Shield. One is the marginal area between the mountains and the desert. It receives a rainfall of 100-300 mm, and its elevation is between 900 and 1,400 m. The second and more-important one is the west mountain scarp. The runoff in both areas drains through major valleys which extend beyond the runoff-generating area to the desert in the east and to the coastal area in the west. This surface and ground water may be overestimated by consultants and experts who disregard the ecological function of the flowing surface and ground water in their estimation of the input-output relationship of that water. They conceive the input water required for any agricultural area as

only that quantity sufficient to convey nutrition from the root zone to the plants and being lost by evapotranspiration. They believe that technology is able to develop an ecological adjustment at the root zone resulting in less consumed water compared to the flooding of water through the valley beds. So four major dams are suggested to be constructed on the southern Red Sea Coast, in addition to nine other irrigation projects, mainly small dams, to be constructed in smaller valleys (Sogreah, 1968, in El-Khatib). Other major dams were proposed by M. I. L. in 1978 to be built on the eastern slope of the Arabian Shield highland in places such as Wadi Bishah and Wadi Ranyah, and smaller dams were suggested in the smaller valleys in the mountain zone

The construction of surface-water improvements will create two major ecological problems. The first is that the quantity of water lost by evaporation from water accumulating in a reservoir is greater than if that quantity flows along any valley bed where the infiltration potential is greater than the evaporation, especially since silt accumulation decreases the permeability of the reservoir bed. In the eastern slope of the Arabian Shield, the alluvial deposit is relatively shallow and underlain by an impermeable complex; therefore, there will be little or no infiltration of the collecting water in the reservoir.

The second problem originates from the fact that surface water storage will end the natural process of fertility and salinity adjustment by flooding water. Modern technology has failed to control the fertility and salinity of the root zone in arid and semi-arid areas by irrigation and drainage systems because the ecological characteristics of the root zone cannot be isolated from the ecological context of the sub-root zone. Although technological failure in this respect has been experienced in all arid and semi-arid zones, many specialists disregard, underestimate, or misunderstand the ecological complexity of fertility and salinity of agricultural land, especially in arid systems.

Contrary to the assumptions of M. I. L. and other consulting firms, runoff water is already fully utilized directly by flooding valley beds as well as the cultivated land; and through this flow, ecological adjustment has been made not just for the root zone, but for the whole sub-root zone and marginal soil and groundwater. The total cultivated area in the Arabian Shield is about 210,838 ha (Agriculture Census, 1974), of which 191,169 ha is dependent on irrigation. The consultant firms Sogreah, Italconsult, and M. I. L. estimated water consumption in the area to be about 650 mcm/year, including both runoff and groundwater. But this figure is an underestimation because of about 140,000 ha in the valleys in the coastal strip and desert region, where the annual rainfall is less than 100 mm. Any agricultural area needs as much water for irrigation as the quantity needed by the same area in the 100 mm or less belt, including the eastern region. M. I. L. estimated the present consumption of the irrigated 8,000 ha in sub-Wadi Bishah to be about 90 mcm/year; that is, the 140,000 ha require about 1,600 mcm/year if modern irrigation and drainage systems are not applied to this agricultural area. With reservoir construction, the water required for irrigation and drainage is about 2,100 mcm, while the total runoff water in the Arabian Shield which is subject to the proposed storage facilities is estimated to be about 2,000 mcm/year (Sogreah; Italconsult in El-Khatib; and M. I. L.) and a considerable quantity of it will be lost by evaporation. If a reservoir is constructed, the groundwater will not be an additional source as assumed, because it is a link in the hydrological chain, and if the storing process of the runoff water is interrupted, the quantity and quality of groundwater will be deeply affected. Loss of the ecological function of flowing water will affect the recharging of groundwater and adjustment of ferility and salinity of soil and groundwater to a greater extent than is intended.

It is clear from the foregoing discussion that the available water resources not only are under full use but, in some cases, are overexploited. Water consumption for irrigation of about 375,000 ha of agricultural land and non-agricultural uses is an estimated 6 to 9 billion m^3 yearly. This figure is far higher than the government estimation of

3.7 billion m^3 per year (Second Development Plan, 1975-1980).

CHAPTER IV

HUMAN PRESSURE ON AGRICULTURE

In many arid countries, including Saudi Arabia, economic and development planners and specialists usually consider the population density to be very low or the country to be underpopulated because its population density is one, five, ten, or even fifty persons per square km compared to high-density areas of several hundred to a thousand or more per square km. This would be correct if the human being were not a part of the biological system and dependent on its products. Because of the organic relationship, however, the number of people should be linked with the area's biological capacity to produce food and drink, rather than merely described as a number of people per unit of space without consideration of the biological system's capacities. In this respect the hydrologic cycle is the main factor that determines capacity to support the human population and, consequently, a square km of hot and arid desert with a population density of one person may be considered biologically more populated than a square km with more water and a population density of a thousand or more. The following discussion will explain some aspects of human pressure on the biological system from the agricultural perspective, such as the major demographic characteristics of the population, the food situation, and the agricultural socioeconomic system under the present, rapid economic changes.

Demographic Aspects and Population Trends

It is impossible to evaluate the capability and efficiency of the biosphere in a specific area to support a human population at present and in the future without knowing the demographic trends of that population. Demographic information for the population of Saudi Arabia is characterized by conflicts and lack of confirmation. The first official Saudi estimation put the population at about 6 million for January 1, 1956, and on the basis of this figure, the United Nations population division developed its projections during the 1960s and early 1970s. It estimated the population to be aboue 6.7 million in 1965, 7.7 million in 1970, and 9.9 million for 1975 (Europe Pub. Lt. 1978-1979, pp. 618-619).

The government has held two censuses. The first was held in 1962-1963, but its results were not released and were repudiated. The second census was held in 1974 and the figure of 7,012,642 was announced, but many writers believe that the population is less than this figure and quote 4-5 million as a more-realisitic figure for that time (Europe Pub. Lt. 1978-1979, pp. 618-619; Birks and Sinclair, 1979, p. 303; and Knauerhase, 1975, pp. 12-14). The confusion about the real native population is compounded by these facts: that about 40-50 percent of the population is concentrated in the urban areas; that about one-fifth of the people currently in Saudi Arabia are workers from outside the country and most of these are concentrated in the urban centers; that more than half the entire Saudi Arabian labor force is comprised of foreign workers; that the number of people in the urban centers is 2-3 million; and thus, that at least one-third of the urban people are foreign workers and the remaining 2 million are citizens. If these 2 million comprise 40 percent of the native population, the total native population will be about 5 million. If the official figures for urban residents did not include the foreign workers, the native-population figure of the 1974 census (about 7 million) would be realistic, but as it stands, this assumption is unlikely to be correct. In any case, in the following analysis, the major demographic aspects of the population will be discussed according to the 1974 census.

Until the end of World War II, population growth was adjusted generally to local food-production capability. Since then, the growth rate has started to increase as a result of the decreasing rate of death. There are no records for these demographic changes during the 1950s and early 1960s except the United Nations estimations, which differed from time to time and from reference to reference. An approximation from these sources indicates that the increase during the period 1952-1964 was 1.7 percent per year, and the rate continues to rise even with a slight decline in the birth rate because the decline in the death rate is greater. By 1979 the growth rate was estimated to reach 3.1 percent (Table 6). Therefore, Food and Agricultural Organization (UN) estimations for the population during the 1950s and 1960s are more consistent with the results of the 1974 census. It was estimated that the population was about 3.2 million in 1950 and 4.1 million in 1960; and almost double the 1950 number by 1970-1971, as external immigration shortened the time required for the population to double naturally. The latest estimation, in 1979, indicates that the population reached 8.1 million and the growth rate is at its highest level, 3.1 percent, which will enable the population to double within 23 years or less if the growth rate continues to increase (Figure 13).

Saudi Arabia's Food Situation

Saudi Arabia's Belt System of Food Deficit

Most physical and human features are not compatible or consistent with the political boundaries and often extend within more than one political body in the shape of belts. These belts include many common features and impose many responsibilities upon the political bodies within these belts.

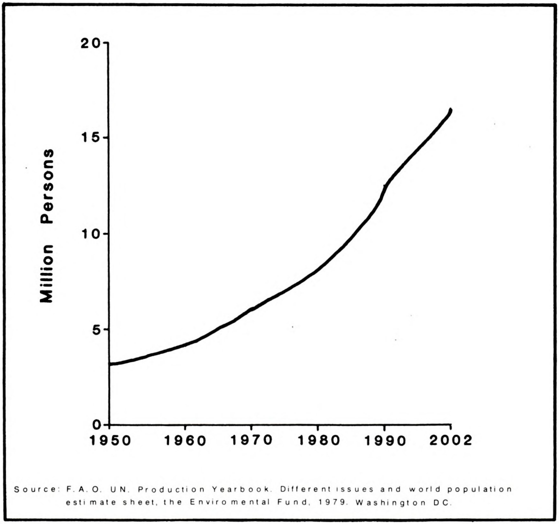


Fig.13 The population growth in Saudi Arabia since 1950 and the projected growth until the end of the century.

TABLE 6

MAJOR DEMOGRAPHIC ASPECTS OF THE POPULATION OF SAUDI ARABIA

Time Period	Rate of Increase (Percent)	Crude Birth Rate	Crude Death Rate
1958-1964	1.7	n.a.	n.a.
1965-1970	2.7	50	22.7
1970-1975	2.9	49.5	20.2
1979	3.1	49	19

Source: FAO. U. N. Production Yearbook, different issues and World Population Estimates Sheet, the environmental Fund, 1979, Washington, D. C.

There are arid and other climatic belts; mountainous, plain and vegetation belts; developed and underdeveloped belts; deficit and surplus food belts; religious, and cultural and other social phenomenon belts, which extend across different political organizations and communities. So it is necessary to evaluate problems and propose solutions related to any physical or human feature or problem in specific areas with consideration for their belt contexts, and not just political boundaries. Saudi Arabia is a part of one of the four major food-deficit belts of the developing countries: the Near East Belt, which includes North Africa and the Middle East. This food-deficit belt is characterized by these important and dynamic facts:

1. Although its population is numerically less than that of the other three major food-deficit belts (Asia, sub-Sahara Africa and Latin America), it is second in quantity of food imported (after the Asian Belt) (Table 7)

2. The population growth rate in the Near East region is one of the highest in the world and expected to remain high for at least the next two decades, until the population explosion reaches its peak

TABLE 7

FOOD-DEFICIT BELTS

Belt	Population (Millions)	Index of Imported Agricultural Products in 1978 1969-71=100	Imported Cereal (MMT)
Africa	348	194	11.3
Latin America	347	186	18.5
Near East	201	253	16.5
Far East	1,183	147	17.4
Developing Countries	3,038	183	78.7

Source: FAO, Trade Yearbook, 1978 and U. N. Statistical Yearbook, 1978.

3. Agriculture in this belt is concentrated in the marginal area between the Afro-Asian desert mass and the surrounding semi-humid and humid belts, and has faced many ecological problems such as salinity, water logging, drought and desert encroachment

Food Situation Characteristics

The biosphere of the Arabian peninsula has supported the Arabian people for thousands of years. During this long period, there have been adjustments between the number of people, demand for food, production techniques, and the area's biological capacity. Since the end of World War II, modern technology has entered the Arabian peninsula, along with the process of searching for and exploiting petroleum resources. The application of modern technology has changed the human role in the very sensitive biosphere of the arid system. Many drastic changes have occurred, creating new imbalances and features which in turn affect food-production trends. Distinguishing characteristics to be discussed briefly include:

1. The considerable nomadic sector of the population, which had depended on the light but widely spread pasture (about 1,200,000 km^2), has abandoned this traditional and important source of food. As a result of their migration to the urban centers in large numbers and to agricultural settlements in smaller numbers, the nomads, who

accounted for about half of the country's population in the 1940s, have declined drastically, to not more than 8 percent (Second Development Plan, 1975). The nomads' migration to the cities has not just led to the loss of traditional sources of food, but has added a new demand on the limited agricultural food resources, and consequently has worked to effectively enlarge the food deficit in the country.

Furthermore, in terms of economic attractiveness, the urban centers, where most oil revenue is absorbed, have competed with subsistence agriculture. A large sector of the rural population has moved to the cities; consequently, the population distribution has changed from less than 10 percent urban to about 50 percent.

2. The lifestyle of many people has changed as a result of the increase in income, which is reflected in the quantity, quality, and even kinds of foods eaten by individuals.

3. The population growth rate has increased during the last three decades; it is currently one of the highest rates in the world. The population is expected to double naturally every 23 years. Further, the intensive economic changes planned to absorb the high oil revenues have brought in a foreign labor force of 1.5 to 2 million workers. All these rapid changes in the population situation have disrupted the traditional balance between the biosphere and its human burden.

Food-Situation Trends

The economic changes now taking place have created an imbalanced ecological relationship between traditional, limited food resources and rapidly growing demand. The deficit in local food supply has been met by importation.

Local Food Production

The lack of accurate statistical information on food production before and during the last three decades, which have witnessed the deep conversion of the economic structure of Saudi Arabia, is a major obstacle to presenting the real picture of the situation. Even the statistics available for the last fifteen years in the statistical yearbooks of Saudi Arabia and the United Nations are mostly estimations; and there is contradiction among these figures. For example, in the statistical yearbooks of Saudi Arabia, the total estimated area of all crops in the country in 1973-1974 was 600,859 ha, of which about 76 percent were in the Arabian Shield. But the agricultural census of 1974 indicated that the total actual cultivated land (the sum area of temporary and perennial crops) in that year was 395,248 ha, of which only 53 percent was in the Arabian Shield. In any case, some important facts about food production help to draw a clearer picture of the situation. First, local agricultural production supplies only about 30 percent of the country's needs and only about 15 percent of the cereals. The rapidly growing deficit between food production and demand has been covered by importation. Second, although the production indices show an increase of 13 percent from the average in 1969-1971 to that in 1978, this slight increase is far behind the growing demand. Production has fluctuated from year to year due to the exploitation of the groundwater in the Arabian Shield where 75.7 percent of the country's cultivated land is concentrated and mostly irrigated from infiltrated rainwater. So the yearly fluctuation in rainfall is reflected directly in each year's production, unlike traditional agriculture, which had adjusted according to the average hydrological capacity over longer time periods.

The third important fact is that the rapid growth of urbanization has led to alteration of the traditional crop patterns. Vegetable and fruit production has increased at the expense of previously dominant crops such as dates and cereals. The average cereal production during 1969-1971 was about 456,000 MT; in 1978, cereal production declined to about 300,000 MT. Date production has dropped from about 363,911 MT in 1973 to 256,903 MT in 1976. Meanwhile, vegetable production has increased from an average 304,000 MT in 1969-1971 to 515,000 MT in 1978. Fruit production has increased from an average of 280,000 MT in 1969-1971 to about 377,000 MT in 1978. (Table 8). Obviously, the fast-growing urban market is responsible for this change because it creates tremendous demand for fresh vegetables and fruits.

TABLE 8

LOCAL AGRICULTURAL PRODUCTION
(1,000 MT)

Products	1969-1971	1976	1977	1978
Cereals	456	282	265	274
Vegetables and Melons, Total	304	504	502	515
Fruits (excluding Melons)	280	331	340	377

Source: FAO. U. N. Production Yearbook, 1978.

TABLE 9

NUMBER OF LOCAL ANIMAL
(1000 HEAD)

	1969-71	1976	1977	1978
Cattle	201	321	330	340
Sheep	1,950	2,243	2,300	2,400
Goats	735	1,577	1,600	1,700

Source: FAO. U. N. Production Yearbook, 1978.

Additionally, the government subsidizes food, especially cereals. Vegetables and fruits are excluded. This has kept the price of local cereals relatively low compared to local vegetable and fruit prices, making fruits and vegetables more profitable for farmers, but increasing the country's dependence on imported cereals.

The worldwide increase in food shortages in 1973-1974 prompted the government to offer a subsidy of S. R. 25 for each kilogram of cereal produced regardless of whether the farmer used or sold it. In 1980, the government offered to buy local wheat at a price of S. R. 3.5 (more than a dollar) for each kilogram; that is, about 150 percent of the retail price of imported cereal. But there is doubt that this will be sufficient to cause farmers to increase cereal production instead of continuing to expand production of high-priced vegetables and fruits.

Although the number of nomads has declined, statistics show an increase in the country's livestock. (Table 9) But it was observed that the high price of indigenous animals has encouraged many nomads to raise sheep and goats in permanent settlements. They depend on the imported feeds included in the food-stuff subsidies; most of the subsidized imported maize and barley is used as livestock feed. On the other hand, the government offers direct annual subsidies for each animal raised, so the traditional way of utilizing the pasture resources, by herding, has been replaced by a new system of livestock farms dependent on imported feeds and direct financial support. There are no accurate figures on the production of meat from slaughtered indigenous animals, but it is believed that most of the country's livestock and animal products are supplied by importation.

Food-Deficit Trends

The gap between local food supply and demand has widened drastically, especially in cereals, where local production has declined in recent years. The quantity and growth rate of imported food are good indicators of that gap. (Table 10) Cereal importation has increased from 584,740 MT in 1970 to 1,118,250 MT in 1978. Local production now contributes only about 20 percent of the 1,456,250 MT of cereal consumed. Although vegetable and fruit production has increased at the expense of cereal, the value of imported vegetables and fruit has increased from $40 million in 1972 to about $277 million in 1977. Keeping inflation in mind, if the price increased two- or three-fold, the quantity imported doubled two or three times within five years.

This drastic increase in the gap between the ecological agricultural potential and the people's rising food demands is one side of the picture. The other side is represented by rising importation of animal-protein products in the form of live animals or fresh chilled and frozen meats or other animal products. This is in spite of the fact that

TABLE 10

IMPORTED AGRICULTURAL PRODUCTS
(QUANTITIES OR VALUES)

Products	70-72			
Cereals (MT)	582,423	923,200	914,810	1,182,250
Cattle (Head)	55,232	59,704	63,429	70,000
Sheep and Goats (Head)	1,222,014	1,295,819	1,855,209	2,400,000
Meat (MT)	9,452	78,858	123,034	143,720
Agricultural Products Total Value ($0000)	24,701	99,526	155,242	192,434

Source: FAO, UN Trade Yearbook, 1974, 1978.

the country was self-sufficient in this respect three decades ago, when animal products and dates were the bulk of the population's food resources. As Table 10 shows, imported sheep and goats have increased from an average of 1,222,014 head in 1970-1972 to about 2,400,000 head in 1978, about a 100-percent increase in eight years. The number of imported cattle has increased from an average of 55,232 head in 1970-1972 to 70,000 head in 1978. Even the amount of imported meat—fresh, chilled, and frozen, which was unpopular—has risen from only an average of 9,452 MT in 1970-1972 to 143,720 MT in 1978. The value of imported products rose from an average of $247 million in 1970-1972 to almost $2 billion in 1978--a 700% increase.

The above figures demonstrate that the new economic structure has profoundly changed the people's economic role within their ecological system from the standpoint of their production and consumption of food. The society has converted from agricultural self-sufficiency to a consuming society dependent on imports to supply most of its food needs as well as other needs. If the food situation and physical environment are considered together with the intensive economic changes from development, on which $140 billion will be spent during the five-year plan for 1975-1980, it is surprising that nearly 60 percent of the population of 8.1 million in 1979 still resists the severe socioeconomic and ecological changes and lives in the rural areas, depending one way or another on agricultural activities.

Agricultural Population, Economic Change and Internal Immigration

Among many human and physical environmental factors, two are visible reflections of economic developments in agriculture as a sector in the economic structure. The first is the declining percentage agriculture contributes to the total national income because of the transition in human activity from agriculture to non-agricultural economic activities such as industry or because of the exploitation of valuable natural resources such as petroleum and minerals. The second reflection is the reduction of the share of the population engaged in agriculture. Agriculture has changed from the economy's backbone to a contribution of 1 percent in 1975 (Wilson, 1977, p. 179). This is an indication of the speed of conversion of the society from food production within its biospheric capacity to food consumption beyond that capacity. Surprisingly, the portion of the population engaged in agriculture is still very high, considering the magnitude of the oil revenue which has been the means of physical and social change, positive or negative. According to a UN estimation, the rural population has declined from about 72 percent of the total in 1960 to about 61 percent in 1978 (Table 11).

TABLE 11

TOTAL POPULATION, AGRICULTURAL POPULATION AND ECONOMICALLY ACTIVE POPULATION

Year	Population		Economically Active Population		
	Total	Agricultural	Total	in Agriculture	% in Agric.
1960	4,100	n.a.	n.a.	n.a.	71.5[1]
1970	6,199	4,094	1,699	1,122	66.0
1975	7,180	4,534	1,909	1,205	63.1
1976	7,398	4,627	1,954	1,222	62.5
1977	7,624	4,723	2,001	1,240	62.0
1978	7,860	4,822	2,051	1,258	61.4

NOTE: All figures in thousands.

SOURCE: FAO, Production Yearbook, different issues, U. N. Demographic Yearbook.

[1]estimated.

But the decline in the percentage of the population engaged in agriculture does not mean that the number of agricultural people has decreased. In fact, the opposite has happened: 72 percent of the 1960 population is less than 61 percent of the 1978 population. This implies that the natural increase of the rural population during the past three decades has exceeded the rural-to-urban immigration. A similar development occurred in Europe in the nineteenth century and has taken place in some of the developing countries since the Second World War (Grigg, 1974, p. 414), although their biosphere systems and agricultural populations were much greater than those of Saudi Arabia and their economic changes were slower and less extensive.

The situation is different in Saudi Arabia from the point of view of its population of about 8 million. Its biosphere is predominantly arid. Its vast economic changes cost $142 billion during the just-ended five-year plan and will cost about $300 billion during the new five-year plan (Madinah, 1980, p. 9; and Second Development Plan, 1975, p. 529). These intensive economic changes not only absorbed the local urban labor force, but also created a labor-force deficit that has been filled by more than 1.5 million imported workers—about 25 percent of the population, according to some estimations (Birks and Sinclair, 1979, p. 305).

In spite of these unique characteristics of economic change or "development," the agricultural population still

accounts for about 61 percent of the country's total population, while in most developing countries in Asia, Africa, and Latin America, immigrants from rural areas have flooded the cities beyond the labor market's needs. This exceptional feature may be attributed to a complex of social and economic responses to "development" in the urban areas and other social and economic aspects of the rural area.

The vast, hurried economic change has combined with rapid growth of urbanization to produce a lack of adequate basic facilities: domestic inflation; real-estate speculation; and very high housing prices and rents. In addition, economic circumstances are more favorable for unskilled foreign workers: temporary housing for groups of foreign workers is less expensive than permanent homes for native families, and the savings accrued by foreign workers are more valuable because of the lower living costs in the countries from which the workers come, such as Egypt, Yemen, Pakistan, and South Korea. The local rural workers cannot compete with the foreign workers and immigrate to establish permanent homes, even if their incomes are very low compared to the wages in the cities.

Furthermore, the relationship between farmers in Saudi Arabia and the farms is not controlled by purely economic values and considerations. People look to the newly emerging non-agricultural activities and collection of material possessions as secondary goals that lose their value when the basic food needs are exposed to serious danger. Their long history of dependence on their limited agricultural land has created emotional ties and ethical obligations that make farm ownership and conservation a social value and a key to future security.

Finally, farmers near cities have found that it is very profitable to invest their limited water resources in planting fresh vegetables and fruits even if their land holdings are small. This change to cash-crop production is at the expense of cereal production.

For all these reasons, farmers move to urban centers only when the farm cannot provide the minimum subsistence living for a rapidly growing peasant family. But an emerging factor which may encourage migration to the cities is the rapid expansion of schools in the rural areas. It is rare to find a person who has completed school beyond the elementary level and stayed on the farm except one who gets a job in his village. This phenomenon raises the farmers' concern about their farms' future.

Farm Size, Subdivision, and Fragmentation

According to the 1974 agricultural survey, the country's farmlands are divided into about 180,670 land holdings. The actual cropland of 395,248 ha comprises only about one-third of the total agricultural land holding area of 1.2 million hectares. So the average holding of actual productive land in 1974 was about 2 ha. (Table 13)

Under Islamic law, Sharia inheritance is divided among all heirs. Sons receive an equal number of shares because they are responsible for the expenses of their families, and daughters receive half-shares because wives, in general, do not have any financial responsibilities for their families. This inheritance system, including water rights which can be sold, rented, and inherited independently of land, has caused the subdivision of agricultural land into small holdings. As Table 12 shows, about one-third of the land holdings, 69,235, are less than one hectare each and only 40,252 holdings, or about one-fifth of the total, are 5 hectares or more. Farms of 10 ha or larger are 22,530, about 12 percent.

Farm subdivision is a well-known phenomenon in the developing regions and not just a characteristic of the Islamic inheritance system. It is an indication of the population pressure on the agricultural land. For example, in a Serbian village, in 19th-century Europe, farms of 5 acres of less comprised only 23 percent of the total in 1859; by 1924, the percentage had increased under population pressure to 70 percent (Grigg, 1974, p. 155).

Economic development in Saudi Arabia has no serious impact on the average farm size because most of those who immigrate to the cities usually do not sell their farms; they leave them to their closest relatives. Also, there is

TABLE 12

SIZE OF FARM HOLDINGS

Area Categories	Number of Holdings	Percentage of Holdings	Accumulated Percentage
less than 1 ha	69,235	38.3	38.3
⩾ 1 - < 5 ha	71,173	39.4	77.7
⩾ 5 - < 10 ha	17,722	9.8	87.5
⩾ 10 ha	22,530	12.5	100

SOURCE: Ministry of Agriculture, statistical section, Comprehensive Agricultural Census, 1973-74, part 5.

TABLE 13

LAND HOLDINGS BY REGION

Region	Number of Land Holdings	Area of Land Holding	Area of Cultivated Land	Number of Plots	Average Plots per Holding	Average Farm Size, Ha
Entire Country	189,670	1,213,462	395,248	491,665	3	2.2
Arabian Shelf (Sedimentary Section)	36,674	596,740	184,410	51,999	1.4	5
Arabian Shield	143,996	616,722	210,838	439,666	3	1.5
Riyadh and Qassim	16,835	535,715	159,482	20,091	1.2	8.9
Assir	36,564	534,801	39,705	. . .	5	1.1

SOURCE: M. A., statistical section, Comprehensive Agricultural Census, 1973-74, part 5, Riyadh.

no tax on agricultural land, whereas in other countries, the taxation system plays a major role in pressuring land owners to sell their lands when their incomes become insufficient to support their financial responsibilities of subsistence and taxation.

Farm fragmentation is a visible phenomenon in the agricultural land of Saudi Arabia, where a farm consists not of one consolidated block of land, but a number of scattered fields, separated from each other by wastelands or by plots of neighboring farmers. Subdivision has played an important role in physical fragmentation, especially in the eastern sedimentary regions, and in the western highlands, where it has affected the physical environment of the region, which is characterized by a combination of mountains and hills, and water resources which depend on rainfall directly or via runoff. So the cultivated land has developed in the shape of terraces of small plots on the slopes of higher parts of the mountains, over 1,800 m elevation, that receive more than 300 mm of rainfall, and in the valley bottoms, as mentioned in the previous chapter. The physical environment requires people to build terraced plots to catch both running water and soils, and to dig numerous wells to exploit groundwater in shallow alluvial deposits. There is a well, on average, for every two hectares, so wells themselves, and water rights, have contributed to the fragmentation of individual farms. Each land owner, on the average, has three separate plots, according to a 1974 survey (Table 13). The fragmentation increases, in general, from the east toward the west, and reached its peak in the Assir region, where the average is five plots. The 1974 survey did not include the number of wells, but the 1978 survey of the Assir region revealed that there are 18,500 wells on about 40,000 ha of cultivated land, an average of one well for each 2 hectares (M. I. L. Main Report, 1978, pp. 5-14).

Subsistence Agriculture and the New Economic Competition

The agricultural system in Saudi Arabia, in relation to the economy (or market), might be classified in two major groups:

1. Subsistence-oriented agriculture, where most of the farms' products are devoted to the producers' consumption and the cash required to market the goods and services usually is obtained by one or more of these means: selling surplus farm products, adopting supplementary crops, and working outside the farm for wages when the farm size or physical condition does not allow for surplus or for cash crops. Working outside the farm is more common

2. Cash-oriented agriculture with supplementary subsistence—In this kind of farming production is adapted mainly to meeting market needs, but some food and other necessities may be home-produced. This kind of farming is

more common near the urban centers, since transportation costs and time are less

According to the 1974 agricultural survey, of the 180,670 land holdings, 128,670 (or about 71 percent) are subsistence farms cultivated mainly to meet the direct needs of the farmers' households (Table 14). Most of the subsistence agriculture is concentrated in the western regions such as Assir, Albaha, Jizan and some remote parts of the Mecca region. Within this type of agriculture, the dominant products are grain (maize, barley, or wheat) and dates.

TABLE 14

CASH-ORIENTED VERSUS SUBSISTENCE HOLDINGS

Type of Holding	No. of Holdings	Percentage	Perennial Crop Area, Ha		Total Area of Holdings	Percentage
Cash-oriented	52,063	29	62,992	79%	657,887	54
Subsistence	128,607	71	17,002	21%	555,575	46
Total	180,670	100	79,994	100%	1,213,462	100

SOURCE: M. A. statistical section, Comprehensive Agricultural Census, 1973-74, part 5, Riyadh.

Despite the massive economic changes, Saudi Arabia subsistence agriculture is not exceptional for the human and physical environment of a country characterized by great population pressure on the biological system, food shortage with rapid population growth, and a harsh, arid ecology. But in spite of these circumstances, the government's subsidy of imported grains to keep the local prices low, and the demand for fresh vegetables and fruits in the cities, have induced farmers near the urban centers to invest their limited water resources in growing cash crops of vegetables and fruits; the result will be more dependence on imported cereals. The agricultural census of 1974 did not identify the amount of area devoted to cash-oriented products. In spite of this, Table 14 shows that less than one-third the number of holdings had been converted to meet market demand. These holdings comprise more than half of the total area of the holdings, of which only one-fourth was actually cultivated in 1974.

Cereal production through the subsistence agricultural system occurs in two circumstances:

1. When the distance of farms from the major urban centers, because of transportation costs or time, does not enable the farmers to change to cash crops. This is the case in the Assir region, the south Red Sea Coast valley, and many other isolated areas. For example, in the Assir region, where the topography is rugged and mountainous, the urban centers are still small and the major cities are far from the region. Cereal production predominates, as subsistence agriculture. But the new economic competition and pressure on cereal production and on subsistence

agriculture as a whole result from urban growth and the expansion of transportation networks

2. When the environmental constraints prevent the adoption of cash crops even with the existence of economic pressure or market attractiveness. Thus, grains are the only possible alternative on dry farms, and in the terraces on the mountain peaks, even in those near the cities, because of the lack of groundwater to irrigate cash crops

There are no available statistics measuring the economic competition of vegetables and fruits against subsistence agriculture, or against cereal and date production in the country as a whole. But in 1977-1978 the M. I. L. consulting firm conducted a comprehensive agricultural survey in the south Arabian Shield, from which Table 15 was excerpted to give an idea of the new economic pressure even in the areas distant from urbanization, such as Wadi Bishah. (See Figure 12)

Considering total cash cost, in spite of the fact that the cash cost of wheat is the least compared to other crops, return is very low. If a farmer sells his crop in the market, the hectare income (or return) is only S. R. 83 or about $25 even with the government's subsidy; with the government's new offer to buy each kilogram of wheat for S. R. 3.5 (a little more than one dollar), the net return will rise to S. R. 2,564 (about $700), which is still only about 40 percent of the return of the least profitable non-cereal

TABLE 15

ESTIMATED YIELD, TOTAL REVENUE AND NET RETURNS FOR ONE HECTARE OF CROP FOR THE AVERAGE FARM UNIT IN BISHAH (1977-1978)

Crop	Yield (kg)	Unit Price (SR)	Subsidy (SR)	Total Revenue (SR)	Total Cash Costs (SR)	Net Returns Over Cash Costs (SR)
Dates	6,765	2.82	1,691	20,768	7,851	12,917
Oranges	22,000	2.25		49,500	8,552	40,948
Alfalfa	80,000	.66		52,800	5,374	47,426
S. Tomatoes	15,000	2.41		36,150	13,252	22,898
W. Tomatoes	25,000	1.65		41,250	19,377	21,873
Okra	4,000	5.78		23,120	10,482	12,638
Eggplant	15,000	2.15		32,250	10,679	21,571
Water-melon	5,000	.78		11,700	4,662	7,038
Squash	6,000	3.06		18,360	8,677	9,683
Onions	18,000	1.55		27,900	11,572	16,328
Cabbage	20,000	1.58		31,600	9,332	22,268
Wheat	1,800	1.82	540	3,816	3,733	83

SOURCE: Maclaren International Limited, "Water and Agricultural Dev. Studies, Arabian Shield-South; Agricultural Economics" Annex 2, Riyadh, Dec., 1978.

crop.

From the total cost point of view (including labor hours), the labor required for each kilogram of cereals and wheat yielded is very high because the wheat yield in each hectare is far less than the quantity of any non-cereal crop produced in one hectare.

Traditional and Modern Agriculture: Efficiency and Acceptability

Saudi Arabia is not an exception to the efforts of developing countries to replace traditional agriculture with modern agriculture (regardless of environmental acceptability). Subsidies have been offered directly to farmers to encourage them to apply fertilizers and machinery in their farming; the government pays 45 percent of the cost of machinery and 50 percent of the cost of chemical fertilizers. Table 16 shows the amount of agricultural machinery and fertilizers, and the number of land holders who were using them.

Important conclusions from an environmental perspective may be reached even in the absence of information about the positive and negative effects of the adoption of new technology. Agricultural machinery was applied in two processes: the first was in pumping water from wells by irrigation machines (pumps), which comprise 96 percent of the 64,634 agricultural machines used. The other was ploughing cultivated land with tractors instead of animal-powered

TABLE 16

NUMBER OF HOLDINGS USING MODERN AGRICULTURAL METHODS

Type of Crop	Total Holdings	Chemical Fertilizer		Mechanical Power	
		Holdings	%	Holdings	%
Cash-oriented	52,063	12,056	23	40,109	77
Subsistence	128,607	1,787	1	46,211	36
Total in Country	180,670	13,843	8	86,320	48

SOURCE: M. A. statistical section, Comprehensive Agricultural Census, 1973-74, part 5.

ploughs, done by about 64,000 landholders, or 36 percent of the total, with about 850 tractors; about 62,158 land owners, or 97 percent of those who used tractors, used rented tractors. (1974 Agricultural Census) Mechanical power, mostly for irrigation and ploughing purposes, was used in cash-oriented farming more than on the subsistence farms. Mechanical power was used on about 77 percent of the 52,063 cash-oriented farms, while it was used on 36 percent of the 128,607 subsistence farms. (Table 16)

Only about 1 percent of the subsistence farms used chemical fertilizer, while 23 percent of the cash-oriented farms did so. Although these figures are old and were compiled only a year after the subsidy act was issued, recent United Nations statistics indicate that the adoption of agricultural machinery is still very limited and has not increased considerably (Table 17). So there has been no positive effect of the subsidy act on agricultural mechanization, and this is attributed to limited acceptability and strong resistance by both physical and human factors in the arid system: the small, fragmented farms, and the high number of agricultural workers per square kilometer (49), third in the Middle East after Egypt and Sudan. (Edens, 1979, p. 12)

TABLE 17

USE OF AGRICULTURAL MACHINES

Type of Equipment	1969-1971	1975	1977
Agricultural Tractors	617	800	850
Harvester-Threshers	160	280	320
Irrigation Machines (pumps)	. . .	62,319*	. . .

*1974 figures

SOURCES: FAO, Production Yearbook, 1978 and M. A. Comprehensive Agricultural Census, 1973-74, part 5.

In spite of the rapid economic change in Saudi Arabia which led to a decline (to less than 1 percent) in the percentage of the agricultural contribution to the total national income—as a result of the greatly increased oil revenues—the agricultural system has remained different from that of developed countries, which are characterized by rapid declines in the percentage of the agricultural population and increases in the average farm size combined with decrease in number of farms.

Urbanization Pressure on Agriculture

About 40 to 50 percent of the population of Saudi Arabia is concentrated in the urban centers. Seven cities have populations of 100,000 inhabitants or more, according to the 1974 census (Table 18). It was estimated that the combined average growth rate for the largest three cities during 1960-1970 was 4.7 percent, compared to the average growth rate of the world's dry-land cities of 3.93 percent (Potters, 1978, pp. 349-379).

It is expected that drastic increases will be found to have occurred in growth of urbanization, considering both population and physical construction, especially the period of the last five-year development plan (1975-1980). The growth rate might rise higher during the new five-year development plan (1980-1985), with its expenditure twice that of the last plan—that is, about $300 billion.

The intensive process of development which began to increase the human and physical environmental acceptibility and capacity has created complex problems for agriculture in general, and for the food balance specifically, from these

TABLE 18

POPULATION OF MAJOR URBAN CENTERS, 1974

City	Number of Residents
Riyadh	666,840
Jeddah	561,104
Mecca	366,801
Taif	204,857
Medina	198,186
Dammam	127,844
Hufhuf	101,271

SOURCE: Potter, P. and Potter, V. "Urban Development in the World Dryland Regions, Inventory and Prospects," Geotorum, vol. 9, pp. 379, 1978.

perspectives:

1. The intensive economic changes, including expansion of labor demand beyond the population's labor force, have led to a large deficit of locally available labor, and the gap has been filled by labor importation. The estimated incoming labor force of 1.5 million, twice the local non-agricultural labor force, has increased the human burden on the biosphere system, and consequently, has helped to enlarge the food deficit

2. The rapid growth of the cities has combined with rising demand for water supply. Table 19 shows preliminary

TABLE 19

NON-AGRICULTURAL WATER DEMAND
(MILLIONS OF CUBIC METERS)

Type of Demand	1974	1975	1976	1977	1978	1979	1980
Domestic (City Population Greater Than 5,000)	150	166	182	148	214	230	250
Oil Injection	300	390	480	570	660	750	850
Mining	30	50	70	90	110	130	150
Industry	. . .	. . .	. . .	. . .	42	48	48
Total	480	606	732	858	1,026	1,158	1,298

SOURCE: Ministry of Agriculture and Water, Development Plan 1975-1980, part 11—the water section, Riyadh.

estimates that indicate that the non-agricultural water demand will increase from about 480 mcm in 1974 to about 1,298 mcm in 1980, an increase of 170 percent within six years. Most cities compete with agriculture for water resources, and many agricultural areas in the major valleys which had been blooming for thousands of years have changed into abandoned areas because the water resources of these valleys were diverted to supply the cities. Although huge desalination plants have been built in recent years and more will be built in the near future to produce 1.6 mcm per day by 1983 (Dodson, 1978), the capital and energy cost—80 cents per cubic meter—is high in the long run even in oil-rich countries. This cost and the pollution factor were recently recognized by the former director of the desaliniation program in Saudi Arabia (Dodson, 1978, and Al-Faisal, 1980)

3. The expansion of urbanization has threatened the country's 1,800-plus small, partially forested mountain peaks (about 1.5 million ha) which, unlike the rest of the country, are characterized by mild climate and relatively considerable rainfall (over 300 mm per year). Many areas of this scarce vegetation cover have been subject to real-estate speculation and increasing demand by wealthy people to build summer homes

4. The combined phenomena of massive urbanization and great expenditures produce inflation, a major economic pressure impacting directly on the farmers. The average daily wages for unskilled workers in the country's labor market for agricultural and non-agricultural activities are about 100 S. R., or an average yearly income of S. R. 36,000 (about $11,000), while the highest income for a cash crop on the average farm in the Assir region does not exceed two-thirds of that amount (about S. R. 23,700) (M. I. L., Annex 2, pp. 5-18). This is an indication not only of the financial obstacle to the farmer who needs additional labor at harvest time, but also of the cost-of-living level with which the traditional, subsistence farmer has to interact by selling his crops for less and obtaining his needs at

higher prices

CHAPTER V

CONCLUSION

The foregoing discussion of the natural and human environments of Saudi Arabia indicates that the country's food deficit will continue to grow in the future as a result of the limited agricultural potential of the environment and the rapidly growing food demand.

Available water resources in the country not only are under full utilization, but in some areas, such as the sedimentary part of the country, have been overexploited, causing increased salinity in pumped water. The salinity in the water of the sedimentary region seriously threatens the existing agriculture and restricts the potential for increased food production; and modern drainage systems—costly in terms of water and finances—have been unsuccessful in providing relief.

In the western region, the situation is not much better. Rainfall and runoff, and the shallow, infiltrated groundwater, are already fully utilized. Therefore, construction of new dams, recommended by various consulting firms and other experts, will not support expanded or intensified agricultural development. Instead, such construction will increase water loss through evaporation, and will eliminate the beneficial ecological role now played by flooding, which adjusts soil fertility and salinity naturally without a need for drainage systems and artificial fertilizers.

Human pressure on Saudi Arabia's arid environment has widened the gap between local food production and demand. This gap, which first appeared after the early 1940s, has been filled by importation of food: currently, 70-80 percent of the food consumed in Saudi Arabia is imported.

Three major human factors contribute to the increase in food demand. The first is an increase in the native population at a time when agricultural production has remained stable or even declined. Population pressure is reflected in the rapid growth of the cities and the decreasing size of the average farmer's land holding.

The second factor is the influx of 1.5-2 million foreign workers. They have become an additional burden on the Saudi Arabian food supply. Meanwhile, their emigration has forestalled the necessary adjustment in food production in their native countries, and when they seek to return home, they will place a sudden, increased burden on the food supplies of their own nations. Turkey and several Northwest African countries that have exported labor to Western Europe are now facing this problem; as economic difficulties abroad have caused their workers to return home, these countries have imposed restrictions on immigration, and have tried to send away foreign workers now residing within their borders in order to reserve the shrinking number of job opportunities for their own citizens.

The third factor causing increased food demand in Saudi Arabia is the rise in the standard of living among a sector of the population. Average per capita food consumption has increased, and it will continue to increase as the percentage of the population in this higher-standard sector grows. This increase in demand will result in greater dependence on imported food.

The population-food dilemma must be considered in the economic development policies of Saudi Arabia, the Arab countries, and the entire world. The Middle East and North Africa have suffered rapidly growing food deficits as a result of their population explosions. Regional cooperation is needed in order to balance food supply and demand. Delay in implementation of regional efforts makes it more difficult, if not impossible, to balance the food-population relationship. Such cooperation should have been initiated a long time ago, when population pressure was less intense than it is today.

Even with its wealth, a country like Saudi Arabia wil have a difficult time insuring a secure food supply in the long run if such efforts are made in isolation from the surrounding countries in the region. The power of the petro-dollar, which currently enables the country to import foodstuffs, is insecure in the long run, because of both diminishing petroleum resources and changeable interests

of the food-exporting countries such as the United States, which may turn more economic and political attention in the years ahead to other regions, such as China and Mexico.

All of this does not mean that the present economic development efforts should be halted. Rather, these efforts should be continued, but under the guidance of human needs and with respect for the limits of the country's biological capacity. Six interrelated factors must be manipulated in concert in efforts to meet food demand: food production; population planning; better appraisal and utilization of water, land, energy, and mineral resources; better facilities for storage and utilization of human food, animal feed, and plant fertilizer; other efforts to guarantee the minimum food requirements of the population; and disease control among people, animals, and crops.

Changing the earth's surface and using specific natural resources are not objectives in themselves, but rather are means for benefiting people as greatly, and for as long a time, as possible. The extensive economic changes adopted to date, combined with the influx of foreign laborers, have moved a large part of the local labor force from productive activities (such as agriculture) to easier earning opportunities, such as real estate speculation, retail and wholesale trade, government service, and the personal-service industry. These circumstances have created a sector of the population that consumes but does not produce and is therefore dependent on others to build the foundation of the economic system. If such a trend continues, these people will lose their self-dependent lifestyle and will have failed to learn the lessons to be gained from the changing economic conditions in Saudi Arabia.

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