POLICIES AND MANAGEMENT GUIDELINES FOR OPTIMUM RESOURCE UTILIZATION AT AL-HASA IRRIGATION AND DRAINAGE PROJECT, SAUDI ARABIA

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CHAPTER I

INTRODUCTION

On November 6, 1962, the government of the Kingdom of Saudi Arabia issued a ten-point program for enhancing social and economic development in the country. The program pledged a sustained endeavor to develop the country's resources and economy, particularly water resources and self-sufficient agriculture (1, p. 171). This program subsequently evolved into a systematic and comprehensive socio-economic development process, hardly paralleled anywhere in the free world. The process was formally initiated in 1970 with the introduction of the first five-year development plan and will soon be perpetuated by launching the third development plan.

One of the fundamental elements of the overall development strategy in Saudi Arabia has been the strong emphasis placed on diversifying the economic activity so as to achieve a more balanced rate of growth in the productive sectors, consequently minimizing dependence on outside sources for consumption goods. Such emphasis has emanated from the government's deep concern about the present heavy dependence on revenues from oil exports, and from its full realization that oil is a stock resource, the income of which is exogenously determined. The long term strategic goal of economic diversification has, thus, been pursued through the implementation of a wide range of projects and programs aimed primarily at expanding agricultural and industrial domestic production through making more and better uses of available resources.

A series of area resource surveys carried out during the last 15 years by a number of international consultant firms, under contracts with the Saudi Arabian government, have indicated the potential for increased agricultural production in various parts of the country. Encouraged by this possibility, and alarmed by the failure of domestic farm output to keep pace with the growing demand for food stuffs, the government has adopted a policy to achieve a gradual but sustained growth in food production. The policy has been translated into a program for developing the agricultural sector within the framework of the more encompassing national development strategy.

The three main objectives for agricultural development in Saudi Arabia are to raise per capita income and improve the welfare of rural people, minimize dependence on imported food, and release surplus labor for employment in other fields (2, p. 123). These objectives are being achieved by raising the level of productivity and by bringing more land into production where water resources permit. Some of the policy tools employed in pursuing these objectives are research, extension, training, interest-free credit, input and output subsidies, and public investment in land reclamation projects.

During the first two development plans, expenditures and efforts were concentrated on the planning and execution of physical facilities deemed essential for the early stages of the development process. However, emphasis in the development strategy is currently being directed away from the construction of new physical facilities toward achieving better use of existing ones. More specifically, the attainment of a satisfactory level of economic efficiency in the utilization of existing infrastructure has been pledged as one of the major objectives of the third development plan (3, p. 6). In keeping with this overall objective, endeavors should concentrate on better utilization of land, water, and human resources committed to agriculture. Most of the projected growth in the agricultural sector should be achieved through exerted efforts to improve the efficiency with which available but scarce resources, especially irrigation water, are used. This study aspires to be a contribution to such efforts.

Statement of the Problem

Al-Hasa, often referred to as the largest and the oldest oasis in the Arabian Peninsula, is located in the eastern province of Saudi Arabia, some 150 km south of the port of Dammam, nearly 70 km inland from the Arabian (Persian) Gulf and about 320 km northeast of the capital city of Riyadh. It embraces the twin cities of Hofuf and Mubarraz in addition to 48 villages scattered throughout the 320-square kilometer L-shaped area (see map, Figure 1). There are more than 244,000 people living in the oasis, out of which some 101,000 live in Hofuf, and about 54,000 in Mubarraz. The remaining 89,000 inhabitants are distributed among the villages within the oasis domain (4, p. 7). An increasing number of the population is being attracted by lucrative employment opportunities in the non-agricultural sectors, especially the oil industry. However, agriculture is still the main occupation of the oasis and will, in all probability, continue to be so for some time to come. It is of paramount importance to the economy of the oasis both in terms of number of people currently involved and income generated.

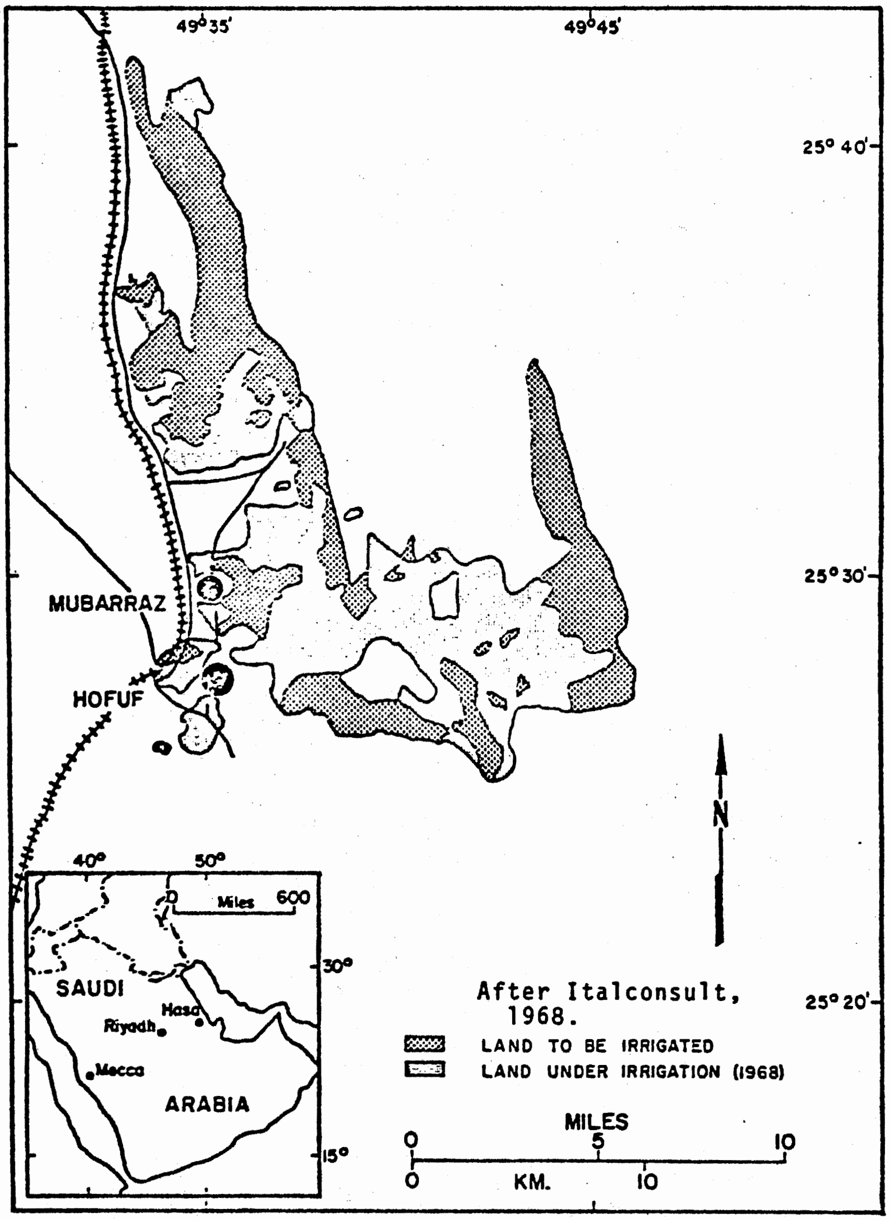

Figure 1. Locational Map for Al-Hasa Oasis

Al-Hasa is endowed with a large number of artesian springs that have been for centuries a reliable source of abundant fresh water for irrigation. In a country where there are no rivers, streams or lakes, and where rainfall is scarce and irregular, the existence of these springs gave the oasis in the past a unique role as a supplier of vital staple foods, particularly dates, to the less fortunate communities in the area. The abundance of water, together with the availability of an ample supply of labor and arable land, gave the oasis relative economic stability and made it one of the most intensively cultivated centers in Arabia. For decades, the amount of produce grown there offered enough surplus to be exported to other parts of the country and to neighboring states.

Studies indicate that until recently the area under intensive cultivation in Al-Hasa was as large as 20,000 hectares. However, poor drainage, increasing soil salinity and encroachment by sand dunes initiated a process of gradual but continuous decline in soil productivity and area under cultivation. Sand dunes advancing mainly from the northeast swallowed a sizeable portion of the oasis, covering at least five outlying villages. Inefficient traditional irrigation practices and inadequate drainage system resulted in waterlogging and untolerably high salt concentration in large sections of the oasis, forcing many farmers to abandon their fields in face of the deteriorating productivity. Much of the drainage water accumulated in saline swamps or evaporated due to the intense heat and dry winds, leaving a white, toxic crust behind. Thus, dying inwards from the edges, the cultivated land in Al-Hasa had shrunk to about 8,000 hectares by 1963 (5, p. 26).

In an effort to reverse this trend, and in pursuance of the government policy of utilizing oil revenues to diversity the economy, the Saudi Arabian Ministry of Agriculture and Water embarked during the 1960's on an ambitious reclamation scheme, known as Al-Hasa Irrigation and Drainage Improvement Project. The main objective of the project is to revitalize the once flourishing oasis by improving yields on existing farm lands and extending the total cultivated area to 20,000 hectares (6, p. 7), using water discharged by the springs. To achieve such a goal an intricate irrigation network was constructed consisting of 155 km of main canals, 265 km of sub-canals, 1,100 km of lateral canals, three elevated reserviors and three pumping stations (7, p. 125). The reinforced concrete network combines and redistributes water flowing from the 32 main springs of the oasis. A complementary drainage network incorporating more than 1,300 km of lateral, sub, and main canals was also constructed to lead drainage water to evaporation lakes outside the oasis. The total cost of the project exceeded 500 million Saudi riyals (about 112 million 1965 U. S. dollars).

The project was implemented by the German contractor, Philipp Holzmann over the 1967/1971 five-year period. Implementation followed detailed field investigations and consequent recommendations and designs made by Wakuti, a Swiss consulting firm, which was subsequently contracted to supervise the construction stage. It was anticipated by the project designers and the officials of the Ministry of Agriculture and Water that, once in full operation, the project would make it possible to revive an area of 12,000 hectares in addition to the 8,000 hectares which had already been irrigated, bringing the total area under cultivation to 20,000 hectares (8, p. 5). Although no quantitative targets were suggested, it was further anticipated that the project would bring about a large increase in the quantity and real value of agricultural output of the oasis.

The project has been in full operation since it was completed and officially inaugurated late in 1971. It is operated and managed by Al-Hasa Irrigation and Drainage Authority, whose board of directors is headed by the Minister of Agriculture and Water. The Authority is charged with the operation and maintenance of the project, including water distribution as well as monitoring the discharge of the individual springs feeding the irrigation system and the amount of water discharged by the drainage network. The Authority is also engaged in an active extension program aimed at inducing farmers to use better varieties and adopt more efficient means of production. But water conservation and management practices are not presently part of this program.

No objective assessment has yet been made of the actual impact of the project on the total agricultural output of the oasis. Nevertheless, some tangible results have been accomplished. The malaria-infested saline swamps, which used to blemish the oasis, have vanished, and advancing sand dunes have been partially halted. Water-logging and salt accumulation no longer are considered to be obstacles to crop growth in low-lying areas. And there are claims that many farmers once driven from the land by sand and salt are today moving back (9, p. 22). It is generally an accepted fact that the project has made the oasis a much better place to live and to grow crops. But the project has thus far fallen short of achieving the anticipated goal of putting 20,000 hectares under cultivation. Although there are no official figures on the total area presently cultivated, many knowledgeable people are of the opinion that the project has not yet resulted in a significant increase in the total irrigated area. These people further argue that if the present conditions and practices persist, bringing additional land into cultivation would be highly infeasible. The fact that water shortage exists during the months of peak demand lends support to their argument.

There are two main reasons for the apparent lack of success in accomplishing the desired increase in total irrigated area. The first is that the consulting engineering firm which designed the project, in all probability, over-estimated the amount of water that would flow into the irrigation system from the springs. The consultant had postulated that the total water delivery of the springs feeding the irrigation network would vary between 360 and 400 million cubic meters per year. Actual and potential total flow, as reported by the Authority, could hardly reach 240 million cubic meters per year for the period 1974/1978. The second, and definitely more important, reason stems from the existing water management practices. Available water is distributed free of charge according to traditional water rights and farmers' needs. Since the needs are not clearly defined, there is a general tendency among farmers holding traditional water rights to over-irrigate, leaving little or no water that could be used to open up new lands. The majority of farmers are misguided by the delusion that since some water is good for plants, more of it is better. Lack of understanding of water requirements by both the farmers and the operators in charge of water distribution as well as the absence of water user charges, have enabled this tendency to perpetuate.

Relaxed controls on water delivery and water use have resulted in disproportionate distribution, with much water being intensively applied to a relatively small portion of the oasis. Water is normally allowed to flow into the sub and lateral canals according to a pre-determined time schedule. Flexible hose syphons are used to transfer water to the fields. Within the fields irrigation is normally carried out by flooding with simple traditional technology that has little in common with modern irrigation practices. Several physical factors, such as the sandy texture of the soil, insufficient leveling and the absence of ditch lining inside the farms, usually lead to excessive water use, with much of the valuable irrigation water ending up in the drainage system. This explains the frequently near-capacity flow in some of the drainage canals. Official records for the period 1974/1977 show that the volume of water flowing in the drainage system was, on the average, about 52 percent of the volume of water distributed by the irrigation network. The Authority is now seriously considering recycling of drainage water in an effort to expand the total cultivated area.

Water is a scarce resource and is the main factor limiting the expansion of irrigated area in Al-Hasa oasis. The inadequacy of guidance and restraints in the proper use and conservation of this vital resource has confined the total cropped area to a magnitude much less than the anticipated potential of the project. More land could undoubtedly be brought under cultivation if available water were more efficiently utilized. Higher net returns per unit of water could also be forthcoming from increased irrigation efficiency. But agricultural expansion in the oasis is also constrained by the relatively high cost of labor and the infrequency of using labor-saving techniques. In view of the fact that farming there is still highly labor intensive, a significant portion of the output is determined by the traditional knowledge and skills possessed by farm workers. Since the majority of these workers are functionally illiterate, labor productivity has remained extremely low. Thus, expanding agricultural production in the study area requires raising the productivity of farm workers as well as increasing irrigation efficiency.

The nature of the problem addressed in the previous paragraphs warrants a detailed analysis of how scarce resources in Al-Hasa Irrigation and Drainage Project should be managed and utilized so as to increase the project's contribution to the overall agricultural development goals and enable it to achieve its own specific objectives. Failure of the Al-Hasa Irrigation and Drainage Project to reasonably accomplish the desired goals could have critical policy implications for Saudi Arabian agricultural development. The failure of such a pioneer project could lead to postponment, or even abandonment, of massive public investment in irrigation and land reclamation projects in the future. Top priority should, therefore, be given to developing and implementing policies and management guidelines which would minimize waste and raise agricultural production efficiency in the Al-Hasa oasis.

Objectives of the Analysis

The overall objective of this dissertation is to develop policies and management guidelines which will give resource utilization results near to an economic optimum for Al-Hasa Irrigation and Drainage Project. Such policies and guidelines should be based on the premise that irrigation water from the springs is a scarce resource that should be allocated among crops and cropping patterns so as to maximize long-run net returns for the oasis as a whole, given the prevailing physical and institutional constraints. The specific, or procedural, objectives of the analysis are: (1) to construct cost and return budgets for a number of crop activities selected on the basis of feasibility of production and presence of adequate demand; (2) to develop a regional linear programming model of agriculture in the project area; (3) to determine the optimum pattern of agricultural production in the oasis; and (4) to describe the physical and institutional framework within which optimum resource allocation would be expected to occur.

This study has developed out of the author's firm belief in the existence of a great potential for increasing agricultural output in Saudi Arabia in general, and in Al-Hasa oasis in particular, through improving the utilization of available resources. It is an attempt to apply basic economic principles and empirical techniques in a search for solutions to a set of problems that have resulted from mismanagement of scarce resources in the Al-Hasa Irrigation and Drainage Project. It is hoped that this analysis will enrich knowledge of the scientific community and contribute toward solving the problem of low production efficiency in Al-Hasa and other Saudi oases with similar production patterns and ecological conditions.

Sources of Data

The data used in this analysis were abstracted from the stock of published and unpublished material originating in, or prepared for, the Saudi Arabian Ministry of Agriculture and Water. The stock includes recent agricultural census, periodical crop production estimates, annual price bulletins, cost of production surveys, reports of various consulting firms, groundwater resource studies, and, probably most important of all, research progress reports. Results of research conducted at Hofuf Agricultural Research Center and at Qatif Experimental and Demonstration Farm provided much of the basic data for developing the technical coefficients of the model.

Additional information was provided, through published and unpublished reports, by several other sources, namely, the Saudi Arabian Ministry of Planning, the Central Department of Statistics, Al-Hasa Irrigation and Drainage Authority, Saudi Arabian Agricultural Credit Bank, and the Arabian American Oil Company (ARAMCO). The above data were supplemented by estimates of professional agricultural workers, and by a cost of production survey conducted by the author in early 1978.

Organization of the Analysis

The remainder of this dissertation is organized in the following manner. A brief description of the study area is given in Chapter II to provide the necessary background for succeeding chapters. Chapter III presents the theoretical concepts and empirical procedures appropriate for determining optimum, profit-maximizing, resource allocations. The proposed model for Al-Hasa Irrigation and Drainage Project is delineated in Chapter IV. In Chapter V results of the model are presented and analyzed. In the light of these results, Chapter VI gives a synthesis of policies and management guidelines required for achieving optimum resource utilization at Al-Hasa Irrigation and Drainage Project. Finally, a summary of the analysis and the subsequent conclusions are offered in Chapter VII.

CHAPTER II

EXISTING CONDITIONS IN THE STUDY AREA

Preliminary Background

The oasis of Al-Hasa is probably one of the oldest existing agricultural centers in the world. Nearly twenty centuries ago, both Pliny, in his "Natural History", and Strabo, in his "Geography of the Roman Empire", referred to Al-Hasa as an agricultural production center. Strabo also reported the existence of a permanent river originating in Al-Hasa and flowing to Al-Uqair, an ancient harbor on the Arabian (Persian) Gulf located about 75 km east of Hofuf. At that time, the oasis was a very prized halting place for merchants travelling between India and the Mediterranian (10, p. 1). A number of scholars of various nationalities and backgrounds travelled through Al-Hasa at different times in the past and wrote lively and informative accounts of the area and its people. The list includes such scholarly men as Sadlier (1823), Ibn Battutah (1854), Palgrave (1865), Khosrau (1881), Zwemer (1900), Lorimer (1908), Raunikiaer (1916), Cheesman (1926), Twitchel (1947), and Vidal (1953), to name only a few. All were in agreement on the relative economic importance of Al-Hasa, both as a food producing area and as a trading center.

Al-Hasa oasis, extending approximately from 25° 21' to 25° 37' latitude north and from 49° 33' to 49° 46' longitude east, is located on what ARAMCO geologists have called the Central Plain, a flat area running north to south, fanning out from the north as it proceeds southward (11, p. 16). This Central Plain is bordered on the east and southeast by the shifting Jafurah sand sea, and on the west by the Summan low rocky plateau, which separates it from the Dahana sand belt. The northern boundaries are not well defined, fading into the Bayadh desert expanse.

The landscape of the area is dominated by a mantle of eolian sands occasionally interrupted by low mesas, many of which served as catchment basins for drainage water prior to implementation of Al-Hasa Irrigation and Drainage Project. The sandstone, limestone and shale rocks exposed in and around the oasis are believed to be products of sediments left behind by a sea that receded in the distant past. Organic matter from the plants and animals that lived in the old sea is usually considered to be the source of the enormous accumulations of petroleum underlying most of the eastern part of the country (12, p. 6).

The area occupied by the oasis has roughly the shape of an "L" with the vertical stroke extending about 24 km in a due north-south direction at an average width of 6 km. The horizontal segment protracts eastward for about 17 km, averaging 10 km in width. At the intersection lies the city of Hofuf, the capital of the oasis and one of the main stops on the Dammam-Riyadh railroad. Generally, the surface of the project area slopes gently from west to east at an average elevation of 150 meters above sea level.

A linguistic footnote is befitting here. The name "Al-Hasa" is a slight modification of an Arabic word meaning shallow hand-dug pits leading to sub-surface water. The word "Hofuf" is derived from an

Arabic word stem which means a place where the wind blows. Thus, these two names relate the two main features, namely water and wind, characterizing this oasis which is surrounded by desert and sand dunes.

Natural Resources

The Climate

Saudi Arabia, including Al-Hasa, is located within an arid belt extending from North Africa through the Arabian Peninsula, Iran, and Afghanistan, to Mongolia (12, p. 1). This zone, whose potential evaporation exceeds rainfall, is usually characterized by very hot summers and chilling cold winters. In fact, the intense heat of the summer months is the best known feature of the Arabian climate. But George Rentz (13, p. 9) must have been thinking of Al-Hasa when he wrote: "Although not the happiest on earth, the Arabian climate has often been damned more violently than it deserves. Many days in fall and spring are fresh and mild, and the winters are invigoratingly cool." The climate of Al-Hasa is subtropical, mildly cool in winter, pleasantly warm in fall and spring, but very hot and dry in summer. Some of the relevant meteorological data for the area are presented in Table 1. The data are based on measurements taken at the Hofuf Agricultural Research Center during the 1969/76 eight-year period. The station is located on the western edge of the oasis about 12 km north of Hofuf, at an elevation of 145 meters above sea level.

The data represent a relatively short period and thus may exhibit short-term deviation from the normal pattern. Nevertheless, they point out some predominant climatic features of the area, namely long sunny

Table 1. Meteorological Data for Al-Hasa Oasis During the 1969/1976 Period

Month	1 Mean Air Temperature[a] C°	2 Duration of Sun Shine hrs./day	3 Air Pressure mm Hg	4 Daily Radiation cal/cm^2	5 Relative Humidity %	6 Wind Speed[b] m/sec	7 Evaporation mm/day	8 Rainfall mm
Jan.	14.1	6.73	767.8	332	62.8	2.0	4.0	20.2
Feb.	15.7	7.28	767.0	427	56.8	2.5	5.6	8.7
Mar.	20.6	6.88	765.0	488	49.0	2.1	7.9	18.4
Apr.	25.1	8.00	763.5	528	48.1	1.9	9.7	15.3
May	30.1	9.38	760.7	582	37.1	2.5	12.9	1.4
June	32.8	11.08	756.1	630	27.7	2.5	15.4	0
July	33.9	11.01	753.9	603	29.3	3.1	15.7	0
Aug.	33.5	10.40	755.0	566	36.4	2.7	13.3	0
Sept.	31.0	10.03	759.0	628	42.2	2.0	11.0	0
Oct.	26.4	9.45	764.4	452	44.8	2.1	8.1	1.3
Nov.	20.6	8.90	767.8	375	51.0	1.8	5.7	1.2
Dec.	15.7	6.77	769.1	320	58.9	2.2	4.1	7.1
Average	25.0	8.83	762.5	486	45.3	2.3	9.5	
								Total 73.8

Source: Leichtweiss-Institute Research Team, Publication No. 26, Tables 1, 8, 9, 14, 15, 16, 20, and 22.

[a] Represents the mean of average maximum and minimum daily temperatures recorded two meters above ground level.

[b] Based on 1975 data.

days, high radiation intensity, moderate to high relative humidity, high summer temperatures, very low precipitation, strong frequent winds, and mild winters. As shown by the data, average air temperatures remain at a relatively low level throughout the winter months. However, average minimum temperatures, observed in January and February, did not drop below 8.4 C° (47.1 F°). Average maximum temperatures, on the other hand, exceeded 40 C° (104 F°) during the June-September months, peaking to over 42 C° (107.6 F°) in July and August during the period in question (12, Table 10). The fact that killing frost rarely occurs in Al-Hasa is common knowledge to the farmers there.

Rainfall is scanty and erratic. During the eight-year period the yearly total precipitation varied between 19.4 mm (0.69 inches) in 1970 and 146.3 mm (5.76 inches) in 1976, averaging only 73.8 mm (2.91 inches) (12, Table 1). This total could hardly support plant growth, especially in view of the high evaporation rates observed in the area. As shown by the data, most precipitation occurs during winter and spring, while the summer months are usually rainless.

The annual relative humidity for the study area averaged 45.3 percent during the data period, ranging from a monthly average of 62.8 percent in January to a low 27.7 percent in June. Extreme low values of 10-15 percent were frequently recorded in summer (12, Table 16).

Strong winds, blowing from the north most of the time, are frequent in the oasis, especially during the summer months. These strong winds, intensified by low precipitation and scarce vegetation, sometimes turn into annoying sand storms known as the Shamal winds. The Shamal season, which is common to most of Arabia, is a 28 to 35 day period of high velocity northerly winds of long duration, usually occurring in May, June and July (14, p. 8). The Shamal winds are diurnal, reaching their peak velocity at mid-day and dying out at night. The encroachment of sand transported by these winds has been one of the main obstacles facing agricultural development in Al-Hasa oasis.

The predominance of high mean temperatures, long hours of intense sun light, and the strong advective winds during spring and summer provide conditions conducive to high evaporation rates in the study area. These differing climatic parameters interact in various ways to enhance evaporation from open water surfaces and bare soils as well as transpiration from vegetation. The eight-year data show that average rate of evaporation is relatively high throughout the summer months, peaking to 15.7 mm per day during July, which is about four times the average daily evaporation rate in January (12, Table 22). Such high evaporation rates have some adverse effects on agricultural development as they place a strain on the scarce water resources and contribute to salt accumulation in the soil.

The discussion would be incomplete without some assessment of how the increasingly high air pollution, caused by the oil industry, influences the factors that determine the micro-climate of the oasis. Al-Hasa, it should be pointed out, is located just east of the Ghawar oil field which is by far the largest oil field in the Arabian Peninsula, and probably in the world. Other major oil fields are located within 100 km north and northwest of the study area. Large quantities of natural gas are separated from crude oil and burned on the spot throughout the oil fields. During windless hours, the smoke produced by the burning gas forms dark clouds at low altitudes, covering the sky over large areas of the Eastern Province. If the wind blows from the east, the smoke trails can easily be observed in Riyadh, some 300 km to the west. More often, however, the dark smoke is blown in the direction of Al-Hasa by the prevailing northerly and northwesterly winds, causing a significant reduction in solar radiation (12, p. 23). The effects of this air pollution on plant growth and human health have not yet been determined. Intuitively, nevertheless, polluted rainwater, though scarce, could have some adverse effects on plant growth as a result of possible contamination with soluble toxic acids.

Water Resources

Saudi Arabia has been made and kept a desert wasteland by the scarcity of rainfall. Fortunately, however, much of the barren desert in the central and eastern parts of the country is underlain by vast quantities of water stored in one or more of the major confined aquifers which are presently being tapped for domestic, agricultural, and industrial purposes. Most of the stored water is believed to have entered the aquifers during the last Ice Age, some 15,000 years ago, when Arabia is known to have enjoyed a more temperate climate with greater rainfall than at present (15, p. 195). Precipitation that occasionally falls on the inner highlands continues, nonetheless, to be a vital source of replenishment. Following torrential rainfalls, water that is not used by plants nor lost to evaporation percolates downward to eventually saturate the hydraulic units of the various aquifers.

In spite of the fact that the Eastern Region, which includes Al-Hasa, averages less than 10.2 cm (four inches) of rainfall per year, abundant supplies of water are available from the four main underlying aquifers. These water-bearing formations are, from top to bottom: the Neogene, the Dammam group, the Umm er Radhuma, and the Wasia; the latter is believed to contain more water than there is in the Arabian Gulf (15, p. 187). In general, each of these aquifers has an established hydraulic gradient that decreases, with fair uniformity, to the east and north and a salinity gradient from good quality water in the west to progressively poorer quality to the east and north. The gradients follow the regional gentle dip of the sedimentary rocks off the margin of the Arabian Shield (16, p. 8), an ancient land mass composed of igneous basement rocks rising boldly from the Red Sea coastal plain in the west and sloping gently to the east. These water-bearing zones usually serve as conduits for transmitting water, down dip, from outcrop regions into artesian areas and to natural or artificial pressure release points, such as springs and wells.

Al-Hasa springs derive their water from the Neogene aquifer complex through numerous fractures in the impervious overlying strata. Such fractures allow water confined under hydrostatic pressure to emerge above the ground surface as free flowing artesian springs which are de facto pressure release points from the aquifer. The springs usually reach the ground surface through vertical openings that receive water from several tunnels of various sizes and shapes. Hydrological investigations, though incomplete, indicate that most of the springs are interconnected by a network of tunnels. Moreover, recent studies of a number of major springs along the western border of the oasis have shown their direct intercommunication (17, p. 16). This implies that increased withdrawal from some of the springs would, in all probability, reduce the rate of natural discharge from the others.

The Neogene water-bearing formation is not hydrologically independent of underlying aquifers. Available data, their inconclusiveness notwithstanding, show that the Alat and Khobar aquifers, which are the main members of the Dammam group present in Al-Hasa, have direct connections with both the overlying Neogene and the underlying Umm er Radhuma aquifers. These hydrodynamic relationships indicate that any increased withdrawal from the Neogene or any other aquifer in Al-Hasa oasis could have a more profound effect on the whole hydrological system of the area than mere drawdown or depletion of that aquifer (10, p. 109).

Water salinity in and around the study area varies within each aquifer as well as between the aquifers. It generally increases in the direction of the hydraulic gradient from southwest to northeast, ranging between 2000 and 6000 ppm in the Wasia, between 1000 and 3500 ppm in the Umm er Radhuma, from 1500 to 2500 ppm in the Alat/Khobar, and between 1100 and 2500 ppm in the Neogene (18, p. 12). Chemical analyses show that water discharged by Al-Hasa springs contain, on the average, about 1500 parts per million of total disolved salts. This total includes about 412 parts of chlorine, 323 parts of sulfate, 238 parts of sodium, 198 parts of bicarbonates, 168 parts of calcium, 46 parts of magnesium, and about 40 parts of potassium (19, p. 4). The water temperature is normally within the 35-40° C (95-104° F) range, while its pH is about 7.8. As disclosed by isotope age determination, 80 to 90 percent of the springs outflow is fossil water that is between 13,000 and 17,000 years old. The remaining 10 to 20 percent is fresh water (8, p. 3) that is believed to have penetrated through the outcrop of the Neogene aquifer following relatively recent rainfalls.

Artesian springs are the main source of irrigation water in Al-Hasa oasis. During the late 1960's, 32 springs were integrated into the present Al-Hasa Irrigation and Drainage Project, which was completed in late 1971. The other main springs were closed so that maximum possible discharge from the active ones would be realized. A relatively small amount of additional irrigation water is extracted from private wells and minor springs. In 1967 there were some 330 wells most of which had been hand-dug or drilled near the edges of the oasis to obtain water of better quality or to provide water for agriculture on lands that were not covered by the old irrigation system (18, p. 19). Most of these wells have, however, been closed and water from the project is provided free of charge as a substitute. Furthermore, well drilling within the study area has been prohibited since 1967.

Prior to implementation of the project, the supply of irrigation water in the oasis was governed mainly by the natural flow of the springs. Farmers had no way of modifying the discharge which remained fairly constant throughout the year. Since there were no salient seasonal variations in total irrigated area, climatic factors and plant water requirements determined the extent to which the uncontrolled flow was utilized. Thus, while a large amount of water was wasted as run off in winter, a relatively better utilization was realized during summer. The construction of the modern irrigation network has, however, made it possible to induce some seasonal fluctuations on the discharge, hence modifying the age-long established flow equilibrium. This has been achieved through lowering the weirs of the natural flow basins of the springs and connecting them to concrete irrigation canals by sluice gates which could be manipulated to control the flow. Accordingly, opening the gates during periods of high demand gives greater discharge rates, while closing them, when water requirements are at a minimum, allows water levels in the springs to rise.

The project was designed to put 20,000 hectares of irrigable land under cultivation, based on the assumption that an average annual flow of about 9 m^3/s would be available from the regulated discharge. This average flow estimate was derived from measurements of the average discharge of the individual springs made by the consultant firm during the planning phase of the project. The average discharge was obtained by closing the sluice gates of all the springs, allowing the static equilibrium pressure to be reached, then opening the outlet of each spring and measuring the resultant flow, keeping outlets of all the other springs closed (20, p. 82). Afterwards, the results were summed, with no adjustments made for possible interaction between the springs. No simultaneous tests or observations were made on the surrounding springs to determine their probable contribution to the output of the specific spring being tested. Consequently the cumulative average discharge of the springs was systematically overestimated.

Discharge from the 32 springs has been monitored since 1973 through systematic measurements of the volume of flow in the main canals. According to official records, the average discharge from the springs was 7.2 m^3/s for the 1974/78 period. This average ranged from a low of 5.2 m^3/s, reflecting minimum demand for irrigation water in winter, to a high of 9.2 m^3/s, determined by maximum capacity of the springs in summer when the sluice gates are fully opened. During periods of peak demand, temporary pumps have been used to lift water from a few of the springs and from the drainage system to augment the flow in some irrigation canals. This is probably a manifestation of the fact that the maximum capacity of the springs has been reached.

It seems, therefore, that if the hydrological equilibrium which has prevailed over the years is to be maintained, no further attempts should be made to increase the total annual withdrawal from the springs either through pumping or by lowering the altitudes of the outlets.

Irrigation and Drainage

The project is divided into 10 irrigation districts, each supplied by a main canal fed by separate or grouped springs. Due to differences in elevations and directions of slope, these canals are not interlinked and are, thus, considered to be mutually independent of each other. Their design and construction render interdistrict transfer of irrigation water infeasible. Out of the ten districts, seven, covering a total area of 16,000 hectares, get water by gravity flow. The remaining three, collectively embodying about 4,000 hectares, are supplied from elevated reinforced concrete reservoirs, into which water is elevated, through pumping, from free flowing springs. There are three such reservoirs, two with a capacity of 15,000 m^3 each and a smaller one with a capacity of 8,000 m^3 (8, p. 17).

The irrigation network consists of about 1520 km of open reinforced concrete main, sub-main, and lateral canals. The total length of the main canals is about 155 km of which 40 km are trapezoidal in cross section, with an average depth of 1.5 meters and a bottom width varying between 3 and 11 meters. The other 110 km have a rectangular profile with 1.5 m of clear depth and one to two meters width. The sub-main canals have a total length of 265 km and are mainly constructed with a square cross-section one meter deep and one meter wide. The relatively delicate lateral canals total about 1,100 km in length and are of parabolic profiles. They are laid out, about 150 meters apart, in such a way that irrigation is done only on one side so as to minimize land leveling requirements. Water is conveyed from lateral canals to adjacent farms through flexible hose siphons which can be inserted at any desired spot.

Generally, water is released into the lateral canals twice a week in summer and once a week in winter. As long as there is water in the canal, farmers may obtain their irrigation needs with practically no control on the amounts siphoned. Within the farm the distribution technology is simple, consisting for the most part of small earth and sod dams that are opened or closed to regulate water diversion from unlined earth ditches. Basin flood irrigation is the most commonly used method of water application although some vegetables are furrow irrigated. The basins are generally small because they are prepared in alignment with the topography of the land with minimum leveling efforts.

The inadequacy of land leveling, the lack of proper water management and conservation practices, and the general tendency among farmers to over-irrigate their crops have jointly resulted in the loss of large amounts of water through percolation and subsequent flow into the drainage system. Furthermore, the relatively high salt content in irrigation water, coupled with the commonly high evaporation rates, necessitates continuous application of surplus water to avoid salt accumulation in the top soil. Consequently, irrigation efficiency in the study area has remained very low despite the construction of modern water distribution network. A wide gap still exists between the degree of technical sophistication of the water distribution system and the level of efficiency attained by the existing irrigation practices. The present irrigation practices, which evolved from antiquated traditions, have actually outlived their usefulness. They should be modified so as to fully utilize the potentials and opportunities brought about by the Al-Hasa Irrigation and Drainage Project.

The drainage part of the project includes about 1,320 km of earth ditches consisting of 140 km of main drains, 180 km of subdrains, and 1,000 km of lateral drains. With the exception of concrete tunnels built where the drains cross sand dune areas, the system is constructed as open canals. The lateral drains area laid out about 150 meters apart, parallel to the lateral irrigation canals. They flow into the sub-drains through pipe outlets at depths varying between 1.5 and 2.5 meters. Collected by the sub-drains and subsequently flowing into the three main drainage canals, the drainage water is transported outside the oasis to deep depressions where it either evaporates or infiltrates through the dune chains towards the Gulf. It is estimated that about 600,000 tons of salt, which would otherwise remain in the top soils of the oasis, is transmitted each year, via the drainage water, to the evaporation lakes (8, p. 18).

As interpolated from flow measurements for the period 1974/77 (21, p. 12), the average annual discharge from the main drainage canals is about 3.73 m^3/s, which is slightly more than 50 percent of the rate of total discharge from the springs. This is almost twice the ratio initially perceived by the project designers. Excess winter flows into the drainage system generally indicate insufficient use of irrigation water. However, such flows could have been influenced by drainage from wells and private springs, by infiltration from village seweges, and by immediate or delayed seepages from rains. Regular chemical analyses of drainage water show that its total salt content generally varies between a winter low of 3100 ppm and a summer high of 6700 ppm. A consulting firm has recently been commissioned to study the feasibility of using this drainage water to bring more land into cultivation.

Soils

The soils of Al-Hasa are mostly sandy in texture, with small percentages of silt and clay. Mechanical analyses of samples from top soil layers have shown that the average soil texture in the oasis is made up, weightwise, of 71-79 percent sand, 11-16 percent silt, and 9-13 percent clay. Thus the soils are generally classified as sandy loam, with the exception of the former evaporation swamps, located mainly in the northern parts of the oasis, which have as much as 63 percent silt by weight and are, therefore, classed as silty loam (22, p. 7). The upper soil layers, by virtue of their dominant sandy بفضل structure, possess good natural drainage and aeration properties. تشع However, a nearly impermeable layer of calcium carbonate is known to exist at depths varying between 0.4 meters and 3.0 meters below the soil surface in some parts of the oasis. In areas under irrigation the existence of such a layer prevents downward movement of water and results in the development of a new ground water table the depth of which is determined by the irrigation cycle, the distance to the nearest drainage ditch, and the particle size distribution of the soil

(22, p. 5). As water evaporates, salts usually accumulate in the top soils. Surplus water has to be continuously applied to flush out the salts.

Al-Hasa soils usually lack sufficient organic matter and other nutritive materials necessary for plant growth. The organic matter content in the top soils is usually below 1.3 percent (22, p. 38). While contributing to improving the soil structure, the traditional method of fertilization through application of animal manure has apparently failed to provide enough nutrients to counter the shortages and to restore the amounts of plant food depleted by the intensive cropping. Continuous application of chemical fertilizers, especially nitrogen and phosphorus, is, therefore, a prerequisite for obtaining good crop yields. As might be expected from high evaporation rates, high salt concentration in irrigation water, over-irrigating, and the occasional presence of nearly impervious layers, soil salinity is relatively high. The pH values of the soils in the oasis vary between 7.0 and 8.0. However, chemical analyses have shown that 90 percent of the total soil salt content in unreclaimed soils is sodium chloride which could easily be leached. This means that salinity in the soil could be kept under control if proper irrigation, drainage, and leaching are secured (19, p. 9). The analyses have further indicated that the soils are generally deficient in iron and zinc. Plants grown there would thus benefit from micro-nutrient additions (23, p. 15).

Agricultural Production and Organization

Crop Production

Climatic conditions in the study area allow crops to grow the year around and particularly favor the cultivation of high return specialty crops such as winter vegetables. The generally mild winters and the rapid maturity of many of the relevant crops have resulted in a considerable amount of double-cropping in the oasis. Three crops may occasionally be harvested from the same land within a year. The cropping pattern has traditionally been oriented to the production of food crops, especially dates, vegetables and rice. Forage crops, principally alfalfa, are also grown.

Crop production in the oasis is highly labor-intensive. With the exception of plowing and some rough land leveling, everything is done by hand. The nearly complete dependence on human effort has apparently evolved from farming practices that prevailed in the past, when the dense population of the oasis provided abundant labor which had low opportunity cost. The presently rising labor costs, though sorely felt by farmers, have not yet resulted in adequate use of labor-saving techniques. Thus, production efficiency has remained low, reflecting a significant feature of the oasis agriculture--its subsistence nature.

Reliable, up-to-date statistics on current agricultural production in the study area are not available. A census of agriculture was taken in 1974 covering land tenure, employment, farm population, general transportation facilities, farm size distribution, and fertilizer and farm machinery use. But crop production was not included in the census, an exception being the area occupied by date palms. Assessment of current production is, therefore, a mere guesswork based on sample census estimates.

Estimates of land allocation and total production for the leading crops grown in the oasis are presented in Table 2. These estimates are based on surveys conducted during the 1971/72 crop year for both summer and winter seasons. The figures should be used with caution since they may not necessarily give an accurate picture. They are of value only insofar as they convey the relative importance of the various crops grown within the study area.

Dates by far constitute the largest single crop produced in Al-Hasa. Palm groves, covering over 68 percent of total cultivated area (19, p. 15), are the dominat landscape feature of the oasis. Official estimates indicate the existence there of about 1.5 million palm trees of which about 270,000 (19 percent) are considered to be practically unproductive, mainly because they are in the die-back stage. When properly spaced, the trees are normally intercropped with other more heat and drought sensitive fruit trees, particularly pomegranates, grapes, limes, rough lemons and papayas. Intercropping with rice, alfalfa, and vegetables is common. However, most of Al-Hasa date palms are spaced too close to allow sufficient sunlight to reach the companion crops.

Vidal (11, p. 163) lists 36 varieties of dates which have over the years affirmed themselves in the particularly favorable environment of Al-Hasa oasis. Each variety usually possesses certain characteristics differentiating it from the others in terms of size, color, flavor and digestibility of the fruit; yield capacity; and whether it is an early or a late maturing variety. The fruits of some varieties are of

Table 2. Cropping Pattern in Al-Hasa During the 1971/72 Crop Year

Crop	Area Donums[a]	 % of Total	Production Tons	Yield Tons/Ha
Date Palms	41,210	69.75	46,751	11.35
Pomegranates	1,911	3.23	4,506	23.58
Other Fruits	894	1.51	2,067	23.12
Tomatoes	1,038	1.76	1,937	18.66
Dry Onions	510	0.86	518	10.16
Okra	144	0.24	100	6.94
Watermelons	127	0.21	333	26.22
Egg Plant	122	0.20	265	21.72
Radishes	121	0.20	119	9.83
Squash	115	0.19	147	12.78
Pumpkins	88	0.15	163	18.52
Green Onions	76	0.13	66	8.68
Lettuce	73	0.12	274	37.53
Cucumbers	72	0.12	151	20.97
Other Vegetables	144	0.24	222	15.42
Alfalfa[b]	11,336	19.19	93,593	82.56
Other Fodder Crops	125	0.21	--	--
Rice	498	0.84	72	1.45
Wheat	300	0.51	45	1.50
Barley	174	0.29	29	1.67
Total	59,078	100.00		

Source: Statistics Unit, Ministry of Agriculture and Water.

[a] 10 donums = 1 hectare.

[b] Mostly grown under date palms.

inferior quality and are thus used mainly as animal feed. The finest variety, and the de facto specialty of the oasis, is the Khulas, which accounts for about 15 percent of the total date palms grown. The bulk, about 60 percent, of Al-Hasa dates is, nonetheless, of the high-yielding Ruzaiz variety, which is widely known for its remarkable endurance of the hot desert winds. To perpetuate the varietal characteristics, the date palms are propagated from young offshoots. The trees normally begin bearing about five years after planting, reach their prime when they are ten years old, and continue to be productive for up to 80-100 years.

In the past, the date palm occupied a prominent place in the economic life of Al-Hasa oasis. The tree provided a highly nutritious staple food that could be stored for long periods and transported to distant places. Palm fronds were used for thatching roofs and for making baskets, mats, and numerous other household articles. Wood provided raw material for construction and for industrial purposes, while the sheath was weaved into durable ropes. Any remaining parts that were not utilized in other ways were used as a fuel for cooking and heating. For centuries, the availability of a stable demand for the fruit and the by-products of the date palm, along with the abundance of cheap labor and the lack of sufficiently competitive cash crops, made date palm cultivation a profitable enterprise despite its high labor intensity. The palm understandably became both a source and a measure of wealth. Moreover, as Vidal (11, p. 151) recognizes, the extraordinary attractiveness of such a large area of vegetation with such an abundance of water and cool, shady places in the midst of the bleak surroundings of the desert enabled Al-Hasa gardens to provide equally considerable returns to their owners in terms of acquired prestige in their community.

The importance of dates in the economy of the oasis has diminished significantly during the last two decades owing to a steady decline in per capita consumption of the fruit and to a rapid decrease in demand for the by-products in and outside the oasis. The decline in date consumption has been brought about by a marked growth in consumers incomes and the subsequent shift in preferences towards less traditional commodities. Date prices have, therefore, failed to keep pace with the continuously rising general price level. Furthermore, the increased demand for labor outside agriculture, and the resulting rise in wage levels has escalated production costs of labor-intensive crops such as dates. Increasing production costs and stagnant output prices have greatly depressed net returns from dates. Depressed returns have pressured many small growers to seek full or part-time off-farm employment, thus neglecting, but not necessarily giving up, their farms. The reluctance of such farmers to abandoning their farms has, in effect, induced a decline in the standard of tree husbandry, as fewer efforts are devoted to proper management practices such as timely pollination, pruning, weeding, fertilizing, and replacing old or low-yielding trees.

It seems that present economic circumstances do not favor date palm cultivation in Al-Hasa. The date palms, once valuable economic assets, are apparently shifting to the liability side. They are occupying premium agricultural land and using up much of the limited water supply. Yet, most of these trees are not generating sufficient income to justify their perpetuity. If net returns to limited agricultural resources within Al-Hasa Irrigation and Drainage Project are to be maximized, production patterns should eventually be adjusted so as to incorporate fewer dates and more of the better-earning cash crops.

Although vegetables occupied only about 2630 donums in 1971/72 (Table 2), it is believed that much more land is presently devoted to vegetable production. Two main factors account for this trend: (1) a rapidly growing demand for vegetables within and outside Al-Hasa, coupled with the availability of good roads and adequate transport facilities, has induced farmers to divert more resources into vegetable production; and (2) operation of the irrigation and drainage network has significantly reduced soil salinity, especially in areas further downstream from the springs, to levels that make vegetable cultivation economically feasible.

Vegetables are normally produced in small plots in open fields, or under palm trees when spacing permits. These plots are usually well-managed and, therefore give good yields. However, since almost everything is done manually, the production costs are relatively high. Labban (19, p. 20) identifies two distinctive groups of vegetable growers in the oasis. Members of the first group are conservative farmers who frequently adhere to traditional methods and who, as a rule, market a very small proportion of what they produce. Members of the second group, accounting for the bulk of vegetable production in the oasis, are more or less aggressive, as reflected by their wide use of certified seeds, chemical fertilizers, herbicides and insecticides, as well as proper utilization of their land, water, labor and capital.

Alfalfa is grown perenially throughout the oasis, mostly under date palms. It is cut by hand and fed to confined domesticated animals or sold as a green fodder in the market. The only variety used is the Hasawi, which has experimentally proved its superiority over other alfalfa varieties in terms of yield as well as tolerence to salinity, drought, and wind. Twelve cuttings are usually obtained per year, each cutting yielding about 10 tons per hectare in open fields and about half this quantity when the crop is grown under date palms. Alfalfa stands are retained up to five years. However, the yield is known to start declining in the fourth year (19, p. 25), after which most stands are replaced.

Farm Size Distribution

The bulk of agricultural production in Al-Hasa is carried out on small farms, at or slightly above subsistence size (Table 3). Out of the 8,091 total farms, 4,216, or 52.1 percent, are between zero and five donums and account for 14.1 percent of the total cultivated land. On a wider range, 6,147 farms, or 76.0 percent of total, are within the 10 donum size limit and comprise only 31.2 percent of the entire area under cultivation. In contrast the largest 3.4 percent, or 276 farms, incorporate about 30.3 percent of the total cropped area. The proportion of area in date palms to the total cultivated area is highest in the smallest class farms and decreases with increases in farm size.

Institutional factors are mainly responsible for the fragmentation of farm land in the Kingdom in general, and in Al-Hasa in particular. Land inheritance is regulated by the Islamic religious law, the Sharia, of which primogeniture is not a part. Upon the death of a land owner the land is divided among his heirs, unless the heirs agree to hold the land jointly and delegate its administration to a kinsman or to a hired

Table 3. Farm Size Distribution for Al-Hasa, 1973/74[a]

Farm Size Donums	Farms		Land in Farm		Cultivated Area		Area in Palms	
	Number	% of Total	Donums	% of Total	Donums	% of Total	Donums	% of Cultivated Area
0-2	953	11.78	937	1.15	902	1.35	817	91
2-5	3,263	40.33	9,091	11.10	8,600	12.72	7,556	88
5-10	1,931	23.87	12,581	15.37	11,574	17.12	9,668	84
10-20	1,132	13.99	14,810	18.09	13,703	20.27	11,138	81
20-40	536	6.62	13,965	17.06	12,306	18.21	9,245	75.20
40-60	141	1.74	6,542	7.99	4,999	7.39	3,104	62
60-100	62	0.77	4,302	5.26	3,175	4.69	2,047	62.25
100-200	37	0.46	5,287	6.46	3,746	5.54	1,284	34
200-500	30	0.37	8,254	10.08	4,921	7.28	1,347	47
Over 500	6	0.08	6,097	7.44	2,624	5.43	457	9.5
Total	8,091	100.00	81,866	100.00	67,588	100.00	46,663	69.04

Source: The 1973/74 Agricultural Census, Al-Hasa, Tables 2, 8, 9, and 21.

[a] Includes some farms outside Al-Hasa Irrigation and Drainage Project.

caretaker. While some land is still jointly owned, frequent partitioning at the termination of succeeding generations has caused size of many farms to decrease until they no longer can be operated as viable economic units.

The deep-rooted tradition of income pooling among members of the same family has contributed to the persistence of many small farms by neutralizing the economic forces which might have otherwise made their survival unlikely. Usually some members of the family earn income by persuing non-farming occupations while other members, mostly the elders, operate the farm to supplement the family income through sale or utilization of the produce. The income is then pooled into a joint fund out of which the family financial obligations are met. Drawing on this joint fund, the farm is retained regardless of its net economic contribution to the family income. The profitability of farming activities is frequently of little relevance as a decision criterion for keeping or disposing of the farm. Under such circumstances operators of such farms do not base their decisions on the usual assumptions concerning profit maximization and response to price changes. The small size farms and the traditional inefficient farming practices are thus perpetuated in the oasis in isolation from any possible economic pressure for change.

The custom of placing high premium on individual ownership of date groves as a symbol of social status and a source of prestige in the community has also contributed to the perseverance of the small size farm in Al-Hasa. Many small land owners have been forced by economic pressures to leave their villages to work in one of the larger communities in the oasis or in the nearby oil fields. However, the majority of these people usually retain possession of their small palm groves, working on them whenever time permits or hiring a caretaker. The plots are in fact maintained to maximize their owners' satisfaction rather than to generate income. The absence of land taxes and water charges has made this possible.

Land Tenure

Vidal (11, p. 132) identified four main forms of land ownership in Al-Hasa: (1) individual ownership; (2) multiple ownership, in which individuals own precisely delimited plots in a field which is irrigated in common, but worked and harvested separately; (3) joint ownership, where a group of people own unequal shares of a piece of land which is worked, irrigated and harvested in common and the harvest is normally divided among the owners in proportion to ownership of the land; and (4) government-owned land. A fifth type of land holding is the waqf, which is the endowment of a piece of land to a religious or charitable institution. Once a piece of property is declared a waqf, ownership is inalienable. Eventually, all rights to this land fall to the institution to which it is deeded, but during his lifetime the founder of the waqf has the right to say to whom the usufruct is to fall (24, p. 120). The proportion of cultivated land in each of these forms of property ownership is not precisely known due to the lack of ownership registration.

A significant portion of agricultural land in the study area is operated by tenants and hired operators rather than by owners. Recently, many cultivators with small holdings have entrusted their plots to tenants to seek employment in the oil industry or in large urban centers. The 1974 agricultural census (25, Table 6) indicated that for the oasis as a whole about 55.2 percent of the total agricultural land was operated by owners, 42.3 percent by tenants, and the remaining 2.5 percent by sharecroppers. The corresponding percentages for all the farms within the 10 donum size limit were 61.1, 37.1, and 1.8, respectively. The ratio of owner-operated land to total land is usually higher for smaller size farms.

Labban (19, p. 11) notes that most of the large farms are owned by merchants and businessmen who generally acquire agricultural lands not for income but, rather, for the pride of possession. These farms are usually run by hired workers or by tenants who enter into joint farming ventures with the owners.

Farms are customarily leased for 2-5 years for a fixed annual rent which depends on the location and the types of crops that can be grown. Lease rates for lands under date palms are very low. Relatively higher rents are paid for open lands suitable for alfalfa and vegetable crop production.

Human Resources in Agriculture

The oasis of Al-Hasa has traditionally been a densely populated area that has always provided regional agriculture with an ample supply of labor. In the past, when chances for gainful employment outside agriculture were scarce, the opportunity cost of labor was very low and so were the wages paid to agricultural workers. However, with accelerating economic growth, a sharp rise in the demand for labor has resulted in all sectors of the economy, with the attendant increase in the general wage level. The characteristically low real incomes in agriculture and the increased opportunities for employment in other sectors have resulted in more people seeking employment outside agriculture. Nevertheless, labor is still available in the oasis in appreciable quantities as long as farmers are able and willing to pay its opportunity cost. Some farmers have turned to the relatively cheap imported labor to reduce production costs, not to make up for any existing real labor supply deficiencies.

According to the 1974 agricultural census (25, Table 16), there were about 71,000 agricultural male workers in the study area during the week in which the census was taken. This total included around 61,000 seasonally employed and 1,500 permanently employed workers. The remaining 8,500 men were apparently working on their own farms. These figures may not accurately reflect the total amount of labor devoted to agriculture throughout the year, since it merely represents an inventory of males working during the census week. Furthermore, the census did not account for the people engaged in agricultural-related activities.

Old age and a high rate of illiteracy are among the main features characterizing Al-Hasa farmers in general. As has been indicated by the 1974 agricultural census (25, Table 3), the majority of the oasis farmers seem to have passed prime productive age. Out of a total of 8,089 farmers reported in the census, 708, or 8.8 percent, were under 35 years of age, 1,575, or 19.5 percent, were within the 35-44 age bracket, and 2,316 or 28.6 percent, were between 45-54. The upper (55 and over) age group included 42.6 percent, or 3,449, of the total. The paucity of young farm operators is mainly attributed to higher wages and better working conditions offered outside agriculture.

Illiteracy rate was not incorporated in the agricultural census. However, a survey conducted in early 1975 and involving 256 randomly selected farmers (26, p. 5), disclosed that about 92 percent of the farmers sampled could neither read nor write. This confirms a widely held belief concerning high rates of illiteracy among Al-Hasa farmers.

Aside from its disturbing social implications, the prevailing high illiteracy rate among farmers in the study area is a vexing economic problem. The level of efficiency with which available resources are actually utilized is constrained by the present level of knowledge and skills possessed by these farmers. Illiterate farmers frequently not only exhibit little flexibility in modifying their traditional farming practices but they also demonstrate minimum willingness to accept and apply the more efficient modern farming techniques. This is not a situation unique to Al-Hasa oasis, but neither is it one whose cure will automatically occur in a short period of time.

Water Rights

Water rights in Saudi Arabia are not explicitly defined. Different customs and practices are followed in establishing rights to water in various parts of the country. The ways in which water may be acquired, the basis for determining who has first right, and the limits of these rights are generally on an ad hoc basis and are not defined in a universal water ordinance. A national water code, regulating the development and use of surface and underground water supplies, has initially been scheduled to be drafted by the end of the Second (1975/1980) Development Plan (2, p. 111). But achievement of this objective is not yet in sight and will seemingly be delayed pending the formulation of a national water policy and the subsequent development of a national water plan.

In Al-Hasa, regulations covering the ownership, rotation of use of water, the time for and the duration of irrigation have evolved mostly from old established customs. Prior to implementation of the Al-Hasa Irrigation and Drainage Project, water from each of the main free flowing springs was jointly owned by a group of farmers through their exclusive ancient rights. Water leaving the springs passed through dirt irrigation canals and was distributed among specified farm lands downstream according to a schedule established and affirmed by tradition. The established chain of irrigation worked so admirably that disputes over water distribution seldom arose. When one was buying a farm, the title issued by the local authorities specified the day and time of irrigation as well as the canal to be tapped.

Naturally, some farm operators held no traditional claims on fresh water and, thus, had to rely on the runoff (forfeited water) from other farms for irrigating their palm groves. Normally the surplus and drainage water from fresh-water-irrigated groves would combine into a common channel that served as a source of irrigation water for farms that had no traditional access to fresh water. As might be expected, such farms were less productive, less prestigious to their owners and, consequently, had lower market values. On the other hand, farmers who owned lands that were irrigated with fresh water from spring-fed canals were very proud of this fact, and their prestige in the community was higher relative to what it would be if they were using forfeited water. Hence, spring-fed irrigation canals were constructed and maintained so as to protect their water against being mixed with forfeited water.

While the construction of Al-Hasa Irrigation and Drainage Project has not denied previous fresh water users their traditional rights, it has considerably widened the base of fresh water claimants. Every property owner within the project area now has a claim on fresh spring water in proportion to the size of his holding, regardless of the status of his pre-project water rights. However, water shortages during the peak demand season have forced the project management to give priority, or primary water rights, to lands already under cultivation, particularly date palm groves. New lands brought into cultivation are given secondary water rights and can, accordingly, be irrigated only if there is sufficient water. Water rights are bound to the land and can not, thus, be sold, rented or inherited independently of the land.

Although property owners usually hold the rights to all water sources on their lands, drilling of new wells within the project area has been prohibited. However, there is no limitation on water extraction from existing wells.

Agricultural Services

Extension Services

At least four different institutions are presently involved in providing extension services to farmers in the study area. Although serving a common cause, these institutions work independently of each other, with minimum coordination of efforts. They all provide regular technical advice, and occasionally some inputs, free of charge, with each catering to an exclusive clientele. Their activities center around persuading farmers to adopt new and improved crops, to use more chemical fertilizers, and to apply proper and timely pest control measures. However, water management practices, utilization of the proper size and type of farm machinery, and replacement of old and unproductive date palms are generally not among the topics covered.

The major thrust of efforts devoted to transforming traditional agriculture in the oasis originates from the well-organized extension unit within the Al-Hasa Irrigation and Drainage Authority. The unit maintains direct contacts, through its extension workers, with many farmers in the project area. It makes frequent use of demonstration plots, visual aids, and field days to demonstrate modern farming techniques to interested farmers. As an added incentive to change, the unit periodically offers awards to better-run farms. However, the range of services provided is relatively narrow, limited frequently to crop production and plant protection.

The Directorate of Agriculture and Water at Hofuf, the regional branch of the Ministry of Agriculture and Water, provides limited extension services to some farmers in the project area, mainly along the lines of plant protection, poultry production and bee-keeping. Under-staffing has, however, limited the Directorate's effectiveness as an agent for agricultural transformation in the oasis.

For years, the Agricultural Assistance Division of the Arabian American Oil Company (ARAMCO) has been actively and effectively involved in introducing and diffusing modern farming practices in Al-Hasa. The Division technicians work with a limited number of commercially oriented farmers selected on the basis of willingness and ability to adopt and apply modern farming techniques. Each participant receives the free service for about five years, after which technical supervision is gradually phased out on the premise that sufficient experience in commercial farming has been gained. The services provided normally include extension information on improved crop varieties, fertilizer application, spraying, and poultry production, as well as some supply of seeds and pesticides.

Scientists at the Hofuf Agricultural Research Center provide extension services to a few farmers as a by-product of their research work. The scientists usually conduct some of their experiments on plots loaned to them by farmers throughout the oasis. All inputs used in the experiments, with the exception of land and water, are provided by the research program. As a rule, the farm operator is obliged to work on his plot alongside the research workers through the various phases of the experiment and gets all the produce in return. By watching and doing, the farmer normally becomes better acquainted with new crops and more efficient farming practices.

The total efforts devoted to agricultural extension in the study area are ostensibly impressive. Yet, their actual effectiveness has been minimized by the absence of any comprehensive regional extension program that would coordinate activities of the participants so as to achieve a set of specified objectives. Moreover, the extension services are not presently being addressed to the real problems confronting agriculture in the oasis, namely mismanagement of limited water supplies, high labor intensity in crop production, and predominance of the date palm trees which have lost their economic value. In addition, there seems to be a marked communication gap between most extension agents and the majority of the farmers. This gap is attributable to the prevalence of illiteracy among farmers and to the fact that almost all the extension agents, with the exception of ARAMCO staff, are foreigners whose cultures, attitudes, and perceptions are alien to the farmers.

Research

The Hofuf Agricultural Research Center, occupying some 80 hectares of the project area, is probably the best existing agricultural research facility in the country in terms of physical facilities, technical staff, and volume of research results generated. Established in 1969, the center has produced a substantial amount of research findings, some of which could have a profound long-term impact on agricultural development in and outside the oasis. These findings have resulted from applied and adaptive research carried out by three teams of scientists, each on a separate contract with the Saudi Arabian Ministry of Agriculture and Water.

A British team, representing the University College of North Wales, has been conducting extensive research on livestock and forage crop production since the spring of 1970. The research on animal production, though largely limited to sheep and dairy cattle, has involved a long process of introducing new breeds into the area, making breed comparisons, selecting those with the highest potential, and then proceeding to the multiplication phase through a rigorous breeding and culling program. Research on animal nutrition has received equal emphasis. Pioneering the work on feedstuff evaluation in the Kingdom, the North Wales team has carried out detailed digestibility trials with both sheep and dairy cattle.

A herd of some 250 dairy cows and a flock of about 800 sheep presently comprise the stock of animals bred and maintained in the center. Because of the large number of animals on site, about 80 percent of the station land is now devoted to varietal trials and production of forage crops (27, p. 15). These trials are conducted to assess how sowing dates, seed rates, levels of fertilizer application and other management practices affect the average yields of numerous forage crop varieties.

A West German team from the Leichtweiss Institute, Technical University of Braunschweig, has been conducting research on soil and water management and drainage, as well as the production of selected crops under different levels of salinity. Their research program has included determining the consumptive use and optimum irrigation frequency of representative crops, in addition to the collection and analysis of relevant meteorological data. Supervision on monitoring the flows through both the irrigation and the drainage networks of the project also has been among the team's responsibilities.

The Chinese (Taiwan) Agricultural Technical Mission is the third resident research team at the center. Initially the Mission's task was limited to carrying out research on rice production in the oasis, including varietal trials and hybridization. Recently, however, the scope of the Mission's reseach has been extended to include vegetable production and use of small farm machinery (27, p. 15).

Although working independently of each other without any coordination, these research teams have generated a massive amount of technical information which, if properly utilized, could significantly improve the agricultural situation in the oasis. The abstractness of the research findings and the fact that they are published only in English have undoubtedly limited their immediate use by farmers and the majority of local staff. But this has not minimized their importance for future agricultural development in the study area. The actual impact of the data will be determined largely by the extent to which they are simplified and disseminated in the long run. At the present time, coordination between researchers and extension agents, both in defining the research program and in transmitting research results to the farmers, is almost non-existent.

Agricultural Credit

Farmers in the study area have easy access to interest-free loans from the Saudi Arabian Agricultural Bank, through the Hofuf Field Office. The bank was established in 1964 with the primary objectives of enhancing and facilitating agricultural development in the Kingdom by placing loan funds at the disposal of prospective investors in food production. Starting from a modest base of 10 million riyals, the capital endowment of the bank has surpassed 2.14 billion riyals by the beginning of the 1978/79 fiscal year (28, p. 7), during which 20,298 new loans, amounting to 585.67 million riyals, were granted (29, Table 1). Currently, the bank operates 11 branches supervising a total of 52 field offices.

The bank offers short-, medium-, and long-term loans to individuals, cooperatives, and firms engaged in the production, processing or marketing of agricultural products. Short-term loans, which have to be repaid within a year, are used for meeting the variable costs of procuring seasonal production inputs such as seeds, fertilizers, labor, fuel, custom-hire machinery service, as well as poultry and animal feed. The medium-term loans are intended for meeting the fixed investment costs needed for well drilling, acquisition and installation of irrigation equipment and facilities, purchase of farm machinery, transport vehicles, and fishing gear; starting bee-keeping and livestock production operations; and the construction of durable assets such as poultry houses, dairy farms, feed mills, food processing plants, tanneries, and cold storage facilities. Loans of this type are expected to be repaid within five years. The long-term loans, of which very few have been granted so far, are earmarked for financing large land reclamation projects and are repaid in 25 years.

The number and value of loans that were supplied by the Hofuf Branch of the Saudi Arabian Agricultural Bank during the 1968/69-1977/78 ten year period are presented in Table 4. Although the Branch serves the entire Eastern Region through its Hofuf, Qatif, and Hafr Al-Batin field offices, official records show that most of these loans have been utilized in Al-Hasa oasis, particularly within the project area. The magnitude of these loans could, therefore, be construed as an indicator of the extent to which the bank has contributed to capital formation in the oasis agriculture.

Many progressive vegetable growers and poultry producers have availed themselves of the interest-free credit program. Nonetheless, the author subscribes to the hypothesis that the majority of small farmers in the study area have never applied for loans from the bank. Their abstention is attributed to complacency and fearful attitude towards being in debt, rather than to the complexity of procedures followed by the bank. Since most of these farmers are old and illiterate, they do not aspire to expanding the size of their operations nor to improving their means of production. They simply do not see the need

Table 4. Number and Value of Loans Supplied by the Hofuf Branch of the Saudi Arabian Agricultural Bank During the 1968/69-1977/78 (1388/89-1397/98AH) Period[a]

Fiscal Year	Number of Loans: Short-Term	Number of Loans: Medium-Term	Number of Loans: Total	Value of Loans (1000SR)[b]: Short-Term	Value of Loans (1000SR)[b]: Medium-Term	Value of Loans (1000SR)[b]: Total
1968/69	114	113	227	269	911	1,180
1969/70	167	116	283	638	520	1,158
1970/71	164	142	306	433	1,064	1,497
1971/72	193	174	367	458	1,274	1,732
1972/73	154	155	309	401	1,383	1,784
1973/74	209	270	479	657	3,299	3,956
1974/75	496	1,361	1,857	1,446	17,304	18,750
1975/76	428	917	1,345	2,488	22,961	25,440
1976/77	377	1,236	1,613	2,348	55,331	57,679
1977/78	371	764	1,135	3,205	46,888	50,093
Total	2,673	5,248	7,921	12,343	150,938	163,278

Source: Saudi Arabian Agricultural Bank, Annual Reports 1968/69-1977/78.

[a] Includes loans advanced by the Hofuf, Qatif, and Hafr al-Batin field offices.

[b] 3.37 Saudi Riyals = 1 U. S. dollar.

for credit because they are either not appreciative of the potential benefits from investment in their farms or they are too old and lack successors who are interested in farming.

The Farm Subsidy Program

Saudi Arabia has been a food-deficit country and will, in all probability, continue to be for many years to come. Even though domestic food production has increased in absolute terms over the last 15 years, its annual rate of growth has apparently failed to keep pace with the persistent increase in demand induced by a moderate population growth and a rapid rise in disposable personal incomes. Several factors such as high production costs, easy access to foreign food supplies and high priority attached by the government to the maintenance of a high level of urban consumption at low prices have deterred resources from being committed to agriculture. The chronic low rates of return in agriculture have contributed to its low growth relative to the other sectors of the economy. Because of the widening gap between demand and supply, the Kingdom is becoming more and more dependent upon imports for meeting its food and fiber needs.

A series of recent resource surveys have indicated the potential for increased agricultural production in many parts of the country. Encouraged by these revelations, and motivated by its concern about the falling self-sufficiency in food production, the Government of Saudi Arabia has embarked on an extensive scheme aimed primarily at achieving a gradual but sustained growth in agricultural production. The scheme includes, as one of its major components, a generous subsidy program designed for stimulating private investment in agriculture, raising resource productivity, and emphasizing the production of selected staple food commodities.

Economic as well as equity considerations have played important roles in formulating and instituting the agricultural subsidy program. From the equity perspective, the program is, in fact, a partial fulfillment of the government's pledge to "aim at achieving a reasonable balance between the economic and social rewards available from food production and associated activities in rural communities and those available from other forms of economic endeavors in urban areas" (30, p. 2). In essence, the subsidies are transfer payments disbursed by the government to farmers to elicit a specific response from them, namely increasing the efficiency and size of their operations. Such payments are intended to enable farmers to enjoy the fruits of the economic boom generated by gains in petroleum revenues and government development programs without having to change their occupation.

Economically speaking, the farm subsidy program is aimed at reducing the overall average cost of food production. Such a reduction would not only place domestic producers in a more favorable position to compete with their foreign counterparts for the consumer food budget, but it should also increase the net returns to resources used in agriculture without burdening consumers with higher food prices. This is consistent with the government's commitment to "establish and administer commodity price stabilization or income support programs, where needed and feasible, to prevent undue fluctuations in farm incomes and consumer costs" (30, p. 5).

Current farm subsidies, their rates and dates of introduction are presented in Table 5. As indicated by the data, the government bears part of the cost of certain inputs whose increased use is expected to result in higher productivity and more expanded food production. At the same time the government pays cash grants to producers of a host of farm products which constitute a major portion of the population's diet. These grants are based on the estimated production of certain crops or on the annual ownership of livestock, rather than on what, in fact, reaches the market. However, the program is relatively new, and the procedures applied to implementing its different components are still subject to periodic modifications. Wheat subsidy, for example, is presently being paid on the quantities delivered rather than on estimated production.

The farm subsidy program has not been in existence long enough to objectively evaluate its real impact on the volume and composition of agricultural production in the Kingdom in general and in Al-Hasa in particular. It is believed, nonetheless, that the program is significantly affecting the decisions of many farm operators with respect to input mix and choice of outputs. It is further believed that the program has created an excess productive capacity that is not being put to adequate use. Moreover, the effectiveness of the program has been greatly limited by the shortage of trained agricultural workers who can effectively utilize the new inputs and technologies financed by the program. This shortage has, in fact, prevented efficient utilization of much of the equipment acquired through the program.

Table 5. Type, Rate, and Year of Introduction for Current Agricultural Subsidies, Saudi Arabia

	Year	Rate[a]
Inputs		
Farm Machinery and Equipment	1973	45% of purchase price
Chemical Fertilizers	1973	50% of Total cost[b]
Feed Concentrates (36% protein-minimum)	1973	50% of Total cost[b]
Irrigation Engines and Pumps	1974	50% of purchase price
Poultry Farms--Equipment	1974	30% of purchase price[b,c]
Dairy Farms--Equipment	1974	30% of purchase price[b]
Feed Grain for Drought Relief (sorghum and barley)	1974	At nominal prices (about SR 100/ton)
Air Freight Transportation for Dairy Cattle (200 minimum)	1975	Total cost of transportation
Date Palm (specified varieties and 30 trees minimum)	1976	SR 50/newly planted tree
Outputs		
Wheat	1973	SR 0.25/kg.
Sorghum and Maize	1973	SR 0.25/kg.
Rice	1973	SR 0.30/kg.
Sheep (minimum: 40 heads)	1974	SR 20.00/head
Camels (minimum: 5 heads)	1974	SR 60.00/head
Millet and Barley	1975	SR .15/kg.
Dates	1976	SR 0.25/kg.

Source: Department of Research and Development, Ministry of Agriculture and Water.

[a] 3.37 Saudi riyal = 1 U. S. dollar.

[b] Based on C. I. F. port of entry if imported or factory price cost if locally produced.

[c] 20% if financed by the Saudi Arabian Agricultural Bank.

Marketing Services and Infrastructure

Despite the government's heavy involvement in providing incentives for increased agricultural production, the pressing need for reorganization and development of the marketing system seems to have so far been overlooked. Up to now, the market in which Al-Hasa farmers buy and sell has remained both informal and unsystematic, critically lacking the capability to effectively accommodate the expanding production. In addition to the absence of any established standards, there are no facilities for receiving, sorting, packaging, and distributing incoming farm produce. An exception is the Hofuf Egg Marketing Cooperative, which offers grading, cold storage, and wholesaling services to its members.

Commercial vegetable growers ship large portions of their produce to the Dammam-Dhahran consumption area or export to neighboring Gulf states, particularly Kuwait and Qatar. Small farmers, meanwhile, rely on the local Hofuf, and to a lesser extent on the Mubarraz, central markets for disposing of their surpluses. They usually bring small lots of several types of fresh produce to the market in crates and boxes of varying shapes and sizes. Each lot is sold separately through auctioning by the farmer himself or by a middleman. Buyers, who are usually wholesalers, exporters or retailers, pay cash on the spot, with no records made of the transactions. In general, the produce is marketed unsorted, varying considerably in quality. Prices are subject to significant flucuations due to the irregular arrival of produce consignments, related speculations and changes in weather. The lack of timely collection and dissemination of information on prices, supply and demand in local and alternative markets has undoubtedly contributed to the price instability for most farm products in the study area.

The Hofuf Date Packing Plant is the only agricultural processing plant in Al-Hasa. Established by the Ministry of Agriculture and Water in 1962 and subsequently sold to a local businessman, the plant has the capacity to fumigate, grade, and pack 1000 tons of mature dates per year. However, the plant has been under utilized, with the actual output seldom exceeding 250 tons per annum (31, p. 21), which is insignificant relative to the oasis total production. The bulk of dates produced in the study area is still marketed in a primitive way with minimum hygienic care, a fact which has greatly contributed to the declining date consumption and the resultant low rate of returns to date production.

The present marketing system in the study area is inefficient, wasteful, and not condusive to investment in increased agricultural production. Lack of investment in facilities for storage, cooling, and packing causes higher spoilage rates, particularly in view of the high perishability of the products and the predominance of high temperatures. Uncertainty about quality, induced by the absence of established standards, depresses prices received by farmers, lowering net returns from farming activities and consequently discouraging further investment in farming operations. The development of the agricultural marketing system should, therefore, be given top priority if the objective is to transform subsistence agriculture in the oasis into a commercial sector.

Sand Stabilization Project

Al-Hasa oasis is bordered on the east and northeast by the Jafurah sand dunes, which, for hundreds of year's, have been driven southward by the prevailing northerly winds at an average rate of 10 meters per year. While the northern portion of the oasis has been provided with some protection by the rocky ridge of Jabal Buraiqa, the eastern part has been exposed to continuous encroachment by the advancing sand dunes. Over the years, the southbound sand dunes, rising to over 25 meters, have caused a direct loss of some good agricultural fields (32, p. 130), forcing inhabitants to move south, usually to less productive lands. The dunes, advancing along a 12 km front, gradually buried villages, palm groves, and springs, as well as main irrigation and drainage canals, causing the oasis to shrink inward. The ancient town of Juwatha, believed to have been the capital of Al-Hasa and the center of cultivated area in the days long past, has only recently been uncovered from beneath the sand mass. A survey made in 1960 indicated that 14 villages and large tracts of cultivated land would eventually be inundated by the migrating sand field if no timely preventive measures were taken (19, p. 38).

In 1962, the Ministry of Agriculture and Water initiated the Al-Hasa Sand Stabilization Project to protect the oasis against the invading sands. During the early stages of the project, efforts were concentrated on experimenting with various mechanical, physical, and agronomic techniques of settling the restless sands. Afforestation was subsequently found to be the most effective technique in the long run. Though slow and expensive, this method has since been widely and successfully used for sand stabilization.

In the early years of the project, a number of nurseries were established for providing young stock, as well as for conducting trials to determine the suitability of different tree species for the prevailing environmental conditions. The tree selection was eventually narrowed to three species: *Tamarix aphylla*, *Prosopis juliflora*, and *Eucalyptus camaldulensis*, all of which are well-known for their tolerance to drought and salinity in addition to their capability to withstand the strong winds and the wide temperature extremes that often occur. The *Tamarix aphylla* is considered to be the most effective since it requires no irrigation after three years due to its very extensive and deep rooting system that can tap the water table underlying the dune. It can also be successfully propagated with cuttings from growing trees, thus eliminating the need for nurseries (32, p. 130).

Sand stabilization has been carried out by establishing a belt of woodland along those borders of the oasis lying within the sand migration path. Prior to the spring of 1975, establishment of such trees was accomplished through a costly and lengthy procedure of preparing the land, laying out the irrigation system and providing irrigation water. Sand dunes were leveled by bulldozer and then covered with a layer, 15-20 centimeters thick, of top clay soil scraped from the nearby saline flats. The leveled land was subsequently divided into small basins traversed by cement-lined irrigation canals. After the seedlings or the cuttings were planted, water from artesian or surface wells was applied the year around at a rate of about 10 centimeters every seven days in summer and every 15 days in winter. To provide initial protection for the establishment of the trees, a series of palm frond fences were constructed on the windward side. By the end of 1974 there were about 50 km of these fences providing adequate protection to some 650 hectares of afforested land (7, p. 129).

A new method of afforestation without irrigation was started in the project in early 1975. This simple and inexpensive method is nothing more than planting long Tamarix cuttings in depressions between the small crescental dunes, where the sand cover is shallow enough to allow the developing root system to tap moisture available in the original soil beneath the sand. The cuttings are planted between October and April, when temperatures and wind velocities are relatively low, and when rainfall and relative humidity are comparatively high. The rate of survival and growth among planted cuttings has been encouragingly high. It is anticipated that this new method, by providing a cheaper and more practical alternative to irrigated afforestation, will make it possible to extend sand stabilization services to new areas around the oasis.

Its slow progress notwithstanding, Al-Hasa Sand Stabilization Project has been a success. The project has provided effective protection to the eastern part of the oasis against sand dune incursions. In addition, the established tree plantings are serving as windbreaks, thus improving the microclimate and reducing crop damages that might be caused by the hot summer northerly winds. Furthermore, by being turned into a national park, the project has become an important recreational attraction for the oasis inhabitants.

CHAPTER III

THEORETICAL FRAMEWORK AND EMPIRICAL TECHNIQUES FOR DETERMINING OPTIMUM RESOURCE ALLOCATION

The objectives of this chapter are to: (1) present the basic theoretical framework relevant for determining the optimum allocation of scarce resources among alternative uses; (2) relate some of the theoretical profit-maximizing models to Al-Hasa; (3) describe some of the empirical methods used in making the theory operational; and (4) review some regional linear programming studies concerned with optimum use of limited resources.

Theoretical Framework

Economics may be defined as the study of the use of limited resources for the achievement of alternative ends (33, p. 1). The basic tenet of economics is that in any society, be it a nation, a community, of a family living on a farm in a desert oasis, some of the needed resources are limited in quantity. An economic problem arises because some factors of production are scarce relative to the demand for the goods they are capable of producing. Over the years, economists have used basic economic principles and analytical tools to deal with the resource scarcity problem, i.e., increased efficiency in the use of limited resources. That branch of economics focusing on the efficient use of scarce productive resources is commonly referred to as production economics. Its role is to facilitate choice in production patterns and resource use so that objectives of producers and consumers can be achieved to the greatest degree. When applied to agriculture, production economics has the two-fold role of providing guidance to individual farmers in using their resources most efficiently and facilitating the most efficient use of resources from the standpoint of the consuming economy (34, p. 3).

The analysis of resource use at the farm level is generally carried out within the framework of the neoclassical or marginal theory of production. The conventional approach to production economics has been succinctly summarized by Carlson (35). The task of marginal analysis is to determine the optimum input-output mix using established physical relationships as well as prevailing input and output prices. When applying the marginal approach to real world resource allocation problems, economists usually base their analysis on a number of a priori simplifying assumptions. Basic among these assumptions is the postulate that economic units will allocate resources in such a manner as to maximize net returns within the existing legal, social, and economic framework in which they operate. The other assumptions include pure competition in both factor and product markets; full knowledge of input-output relationships and prices; timelessness; and constant tastes, preferences and states of technology. All these assumptions are retained throughout the following analysis.

Since resources are relatively scarce, they must be rationed among alternative uses. Therefore, a farmer seeking to maximize profits must make three fundamental and interdependent economic decisions: (1) What should be produced? That is, how much and which of alternative feasible crops are to be grown? (2) How should these crops be produced? That is, with what resources and in what technologies are they to be produced? (3) How much to produce, or how far to go on the total product curve? In other words, how intensively should variable factors be applied to a set of fixed factors in producing a given output? In economic parlance, these decisions are normally referred to as product-product, factor-factor, and factor-product decisions, respectively. Their simultaneous solution provides the farmer with his profit maximizing position.

Factor-Product Decisions

The solution to the factor-product problem for a specific product on a given farm will determine the quantity of a variable input, such as irrigation water or chemical fertilizer, that a farmer should use in combination with a fixed input, such as a hectare of land, so as to achieve his predetermined objective of profit maximization. The solution is dependent upon the production function, the prices of variable inputs, and the prices of a unit of output. A full understanding of the production function concept must be established prior to determining the optimum input-output solution.

Production, in the economic sense, is the attempt to create a product which is more valuable than the original input elements. The technical relationship specifying the amount of output capable of being produced by each set of inputs for a given state of technology is called the production function. In order to simplify the analysis we assume a production function using only one variable input that, in combination with a set of fixed inputs, produces only one output. The effect of a single input on a given output may conceptually be determined by varying that particular input while holding all other inputs constant. A production function representing the output resulting from one variable input may be expressed in general mathematical terms as:

$$Y = f(X_1 | X_2, X_3, \ldots, X_n) \qquad (1)$$

which states that output Y is a function of amount of the variable input X_1 used in combination with a fixed quantity of other factors of production, X_2, X_3, ..., X_n. The total amount of output produced as a result of the variable input and the fixed inputs is represented in Figure 2 by the total physical product (TPP) curve.

The concept of a production function is based on the fact that total output varies with the quantities of inputs used in the production process. The typical behavior of total output as increasing amounts of a single input are applied to a set of fixed inputs is described by the law of diminishing returns. The law states that if increasing amounts of one input are added to a production process while all other inputs are held constant, the amount of output added per unit of variable input (conventionally called the marginal physical product) will eventually decrease (36, p. 23). Furthermore, if the increases in the variable resource are carried far enough, the total product will reach a maximum and may then decrease (37, p. 150). The law of diminishing returns is illustrated by the shape of the marginal physical product (MPP) curve in Figure 2. The changing profile of physical productivity indicates that there is a certain proportion in which variable and fixed inputs combine most efficiently in the production process. Deviation from this proportion will impair the efficiency with which either the variable or the fixed inputs are utilized. This is one of

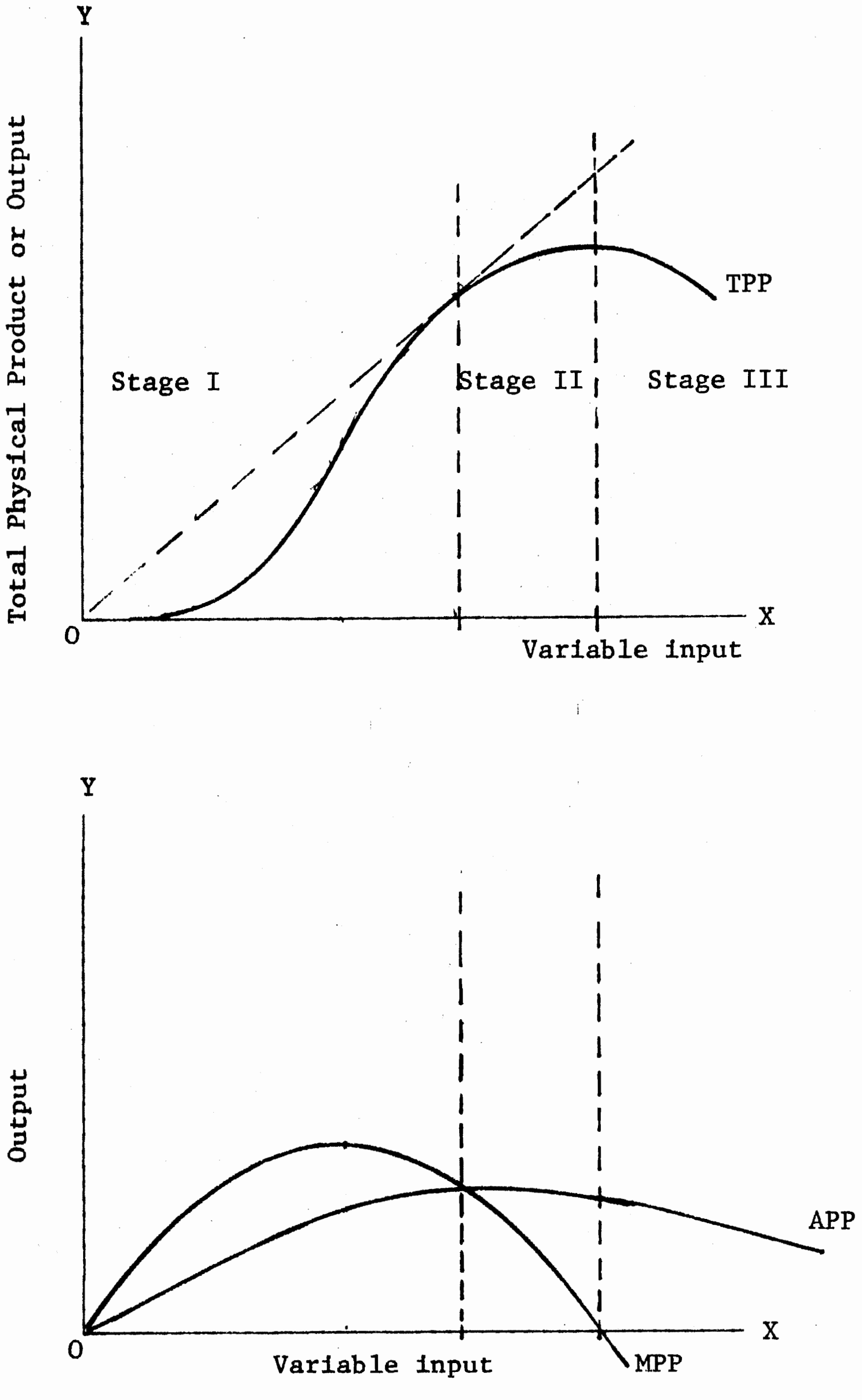

Figure 2. The Classical Production Function and the Three Stages of Production

the key insights that a study of production economics gives us into the workings of the real world and is certainly of great relevance to optimizing resource use in Al-Hasa oasis.

Economists usually divide the classical production function into three regions or stages, each important from the view point of efficient resource use. A graphic representation of these stages is shown in Figure 2. Stage I is the region of increasing returns, extending from the origin to the point of maximum average product. Throughout this region the average productivity of both the variable and the fixed factors is rising because each unit of added input produces more output than the average product. This increase in productivity may be attributed to the scarcity of the variable input relative to the fixed inputs. In other words, the number of variable units is not adequate to effectively utilize the fixed factor units. Thus adding more units of the variable factor will result in more efficient use of the fixed factors. As production per unit of fixed factor is pushed toward the limit of this stage, greater output is forthcoming from the fixed factors as well as from each additional unit of the variable factor. Rational producers seeking to maximize profits in purely competitive environment should not produce in this stage, since producing in this stage entails under-utilization of the fixed factors in addition to ceasing to apply an input whose efficiency in use is increasing.

Throughout stage II each additional unit of input yields a relatively smaller amount of additional output. The marginal physical product decreases because each successive unit of the variable factor has a smaller quantity of fixed factor units with which to work. The total physical product continues to increase at a decreasing rate and eventually reaches a maximum when the marginal productivity of the variable factor drops to zero. Application of additional units of the variable factor beyond this point will actually reduce total output, ushering in a new production region. This is stage III or the region of negative return, where too many units of the variable factor are used relative to the amount of the fixed inputs. Clearly a farmer should never produce in this region since he can obtain more output by reducing the intensity at which he applies his variable input in the production process.

Knowledge of the production function and input and output prices may be utilized to determine the most profitable amount of each variable input used in the production process. In the case of a single variable input utilized in the production of one output, the profit function may be stated algebraically as (36, p. 55):

$$\text{Profit} = P_y f(X) - P_x X - TFC \tag{2}$$

where

X = units of the variable factor utilized in the production process,

$f(X)$ = units of output expressed as a function of the level of the variable input,

P_y = price per unit of output,

P_x = price per unit of variable input, and

TFC = total fixed costs.

Total profit with respect to the variable input may be maximized by setting the first derivative of the above function to zero:

$$\frac{d\ \text{Profit}}{dX} = P_y\ MPP_x - P_x = 0$$

or

$$P_y\ MPP_x = P_x$$

that is

$$MVP_x = P_x \tag{3}$$

This means that the optimum use of a variable input occurs when the revenue obtained from the extra output produced (MVP) is equal to the cost of the additional unit of that input.

When a scarce resource such as water is used in the production of two or more crops, the final allocation of the resource is optimum when the marginal value products of the use of water on all crops are equal. Equilibrium is attained when (38, p. 13):

$$MVP_{w1} = MVP_{w2} = \ldots. = MVP_{wn} \geq MC_w \tag{4}$$

where MVP_{w1}, ..., MVP_{wn} represents the marginal value product of water used in the production of n alternative crops and MC_w represents the marginal cost of another unit of water.

Factor-Factor Decisions

One of the main features of agricultural production is that various combinations of two or more inputs can be used to produce a given level of output. In other words, one input may be substituted for another in such a way as to maintain a constant level of output. Typical factor-factor substitutions in agriculture occur between labor and machinery (capital); land and fertilizer; or water and land. The locus of points representing all possible combinations of two inputs capable of producing the same level of output is called an isoquant curve. Figure 3 illustrates the isoquants for two inputs, labor and machinery, used to produce three levels of an output. The locus of all combinations of the two inputs that can be purchased for a stipulated amount of expenditure, given input prices, is termed an isocost. The optimum input mix for any given level of output is the point of tangency of the isoquant curve and the isocost line. This point gives the highest level of output achievable for a given cost outlay. At this point the slope of the isoquant or the marginal rate of technical substitution of labor for machinery is equal to the slope of the isocost line. That is:

$$\frac{MPP_{x_1}}{MPP_{x_2}} = \frac{P_{x_1}}{P_{x_2}} ,$$

or

$$\frac{MPP_{x_1}}{P_{x_1}} = \frac{MPP_{x_2}}{P_{x_2}} \qquad (5)$$

which states that when two variable inputs are combined with some fixed inputs in producing a given level of output, profit is maximized (cost is minimized) when the ratio of the marginal product to the price is equal for both inputs.

The line joining all points of least cost resource combination for each possible cost outlay is called the expansion path. Profit is maximized along this line as the scale of operations is increased, ceteris paribus.

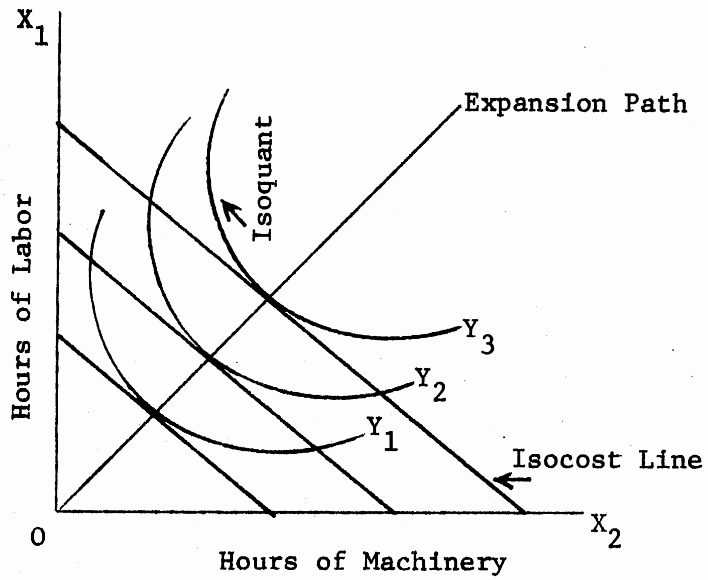

Figure 3. Solution to the Factor-Factor Decisions

Equation (5) can be expanded for any number of variable inputs utilized in the production of a given output (36, p. 122):

$$\frac{MPP_{x_1}}{P_{x_1}} = \frac{MPP_{x_2}}{P_{x_2}} = \frac{MPP_{x_3}}{P_{x_3}} = \ldots = \frac{MPP_{x_n}}{P_{x_n}} \tag{6}$$

In other words, the ratio of the marginal product to the price must be equal for all variable inputs.

Farm resources are often used in the production of more than one output. When two variable inputs, such as water and fertilizer, are used in the production of two crops, such as alfalfa and dates, the profit maximizing conditions may be stated as:

$$\frac{MVP_{x_1y_1}}{P_{x_1}} = \frac{MVP_{x_2y_1}}{P_{x_2}} = \frac{MVP_{x_1y_2}}{P_{x_1}} = \frac{MVP_{x_2y_2}}{P_{x_2}} = 1 \qquad (7)$$

where $MVP_{x_1y_1}$ is the marginal value product of the first resource (x_1) used in the production of the first output (y_1) and P_{x_1} is the unit price of the first resource. The other MVP's have similar meanings. These equilibrium conditions assert that the marginal returns per monetary unit spent on inputs must be the same for both inputs in both enterprises.

Equation (7) can be expanded to include the use of n inputs in the production of m outputs (36, p. 167):

$$\frac{MVP_{x_1y_1}}{P_{x_1}} = \frac{MVP_{x_2y_1}}{P_{x_2}} = \ldots = \frac{MVP_{x_ny_1}}{P_{x_n}} = \frac{MVP_{x_1y_2}}{P_{x_1}} = \frac{MVP_{x_2y_2}}{P_{x_2}} = \ldots =$$

$$\frac{MVP_{x_ny_2}}{P_{x_n}} = \ldots = \frac{MVP_{x_ny_m}}{P_{x_n}} = 1 \qquad (8)$$

where $MVP_{x_ny_m}$ is the marginal value product of the n^{th} resource used in the production of the m^{th} output and P_{x_n} is the unit price of the n^{th} resource. As stipulated by these conditions, profit is maximized when the ratio of the marginal value product to the price of an input is equal for all inputs in all uses.

The allocation of scarce inputs among different users is also of interest. To maximize profits from a fixed stock of resources, the resources should be allocated so that the marginal physical product of any resource in the production of a particular good is the same no matter which firm produces that good. In other words, profit maximization requires that the marginal value productivity of each input be equated for all users. For purposes of illustration, consider the simple case of two farmers producing a certain crop (Y_1) from the use of water and other inputs. If water is in short supply, it should be allocated between the two farms such that:

$$MVP_{w_{11}y_1} = MVP_{w_{12}y_1} \tag{9}$$

where the left hand term refers to the marginal value productivity of water in producing y_1 on the first farm and the right hand side represents the marginal value productivity of water used by the second farm to produce y_1. The equation could be generalized to include other inputs, crops, or producers.

Intuitively, resources should be transferred to those farms where they can be most efficiently utilized if the objective of profit maximization is to be achieved. Maximum profits can only be attained when the transfers are carried to the point where the marginal value product for each resource is the same for all users.

Product-Product Decisions

The product-product decision involves the allocation of a given bundle of fixed and variable inputs among competing crops. Farm managers must decide what combination of enterprises should be produced from a given bundle of fixed and variable inputs so that maximum revenue may be attained from a specified cost outlay. When only two competing products result from the production process, a production-possibility frontier or transformation curve can be developed to show the maximum attainable amount of one commodity for every possible volume of output of the other commodity, given the fixed resource base. Given the price of each commodity, it is possible to construct the isorevenue line showing all product combinations that will generate the same revenue. As shown in Figure 4, the tangency point of the product transformation curve and the isorevenue line determines the optimum combination of the two products. It is at this point that the highest net revenue is achieved from the given bundle of resources. This is the equilibrium point of the physical rate of substitution between the two products and the rate at which they may be exchanged in the market place. Equation (10) defines the equilibrium product-product solution:

$$\frac{dY_1}{dY_2} = - \frac{P_{y_2}}{P_{y_1}} \tag{10}$$

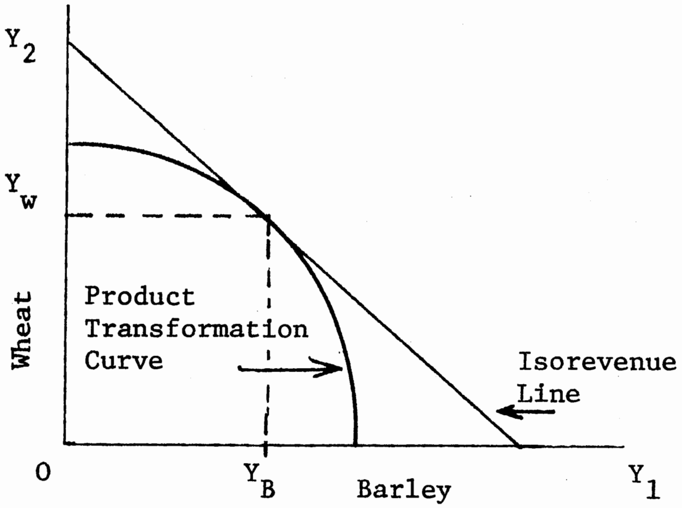

Figure 4. Solution to the Product-Product Decisions

The left-hand side is the marginal rate of product substitution or the slope of the production-possibility curve while the right side is the inverse ratio of the product prices or the slope of the isorevenue line.

Implications of Marginal Analysis for Al-Hasa

According to marginal economic analysis, the rate at which variable factors are applied to fixed factors must fall within stage II if net returns from the production process are to be maximized. Combining fixed and variable resources in a manner that falls in either of the two other stages would, therefore, be considered irrational from the vantage point of profit maximization. Irrational or technically inefficient production exists if resources can be rearranged in any way to either (a) give a greater product from the same bundle of resources or (b) give the same product with a smaller aggregate outlay of fixed and variable resources (33, p. 92). Applying this definitional framework, one can find reasons to believe that the present cropping pattern and resource use in the study area is irrational from the view point of efficient economic utilization of scarce resources.

There are several examples which indicate that crop production in Al-Hasa is carried out in stage III, the range of negative marginal productivity illustrated in Figure 2. One example is the common practice of too-close spacing of date palms, resulting in larger than optimum number of trees per hectare. The tree density problem is sometimes aggravated by intercropping date palms with other, less heat-tolerant, fruit trees, particularly pomagranates and rough lemons. Although the exact effect of this practice on total yield is yet to be experimentally determined, the consensus among the experts is that wider spacing, thus fewer trees per unit area, would result in higher total yield per hectare. Another example is the tendency among many farmers to over-irrigate. While some water in excess of the amount consumed by plants is needed to leach salts from the crop root zone, use of excessive amount of water could limit crop production by removing valuable nutrients from the soil. Reducing the depth of water applied per unit of time could intuitively increase total yield per hectare.

Some variable inputs are so inadequately used by the Hasawi farmers that crop production actually takes place in stage I, where the percentage response of the output to additional units of the variable factors exceeds the percent change of each variable factor. Modern capital inputs, such as chemical fertilizers, farm machinery, and pesticides, are not applied at rates great enough to allow full utilization of the services of such fixed factors as land, management, and family labor. Since average productivity of a variable factor is rising throughout this stage, expanding input use will increase net returns to the fixed factors. Farmers can augment their profits by using increasing amounts of these capital inputs as long as the value of the extra yield exceeds the cost of the extra inputs.

Irrational or technically inefficient production may exist not only because resources are combined in a specific proportion, but because an inefficient technique is employed (33, p. 93). This is particularly true in Al-Hasa, where crop production is generally carried out according to a traditional, highly labor-intensive technology which is characterized by low efficiency in the use of scarce resources. Replacing this outmoded technology with a newer, more effective one is, therefore, a prerequisite for improving resource utilization in the oasis. The prime purpose of such a technological change is to create more output from a given set of production inputs. The adoption of modern farming practices is likely to shift the production function upward, thereby shifting the TPP, MPP, and APP curves (Figure 2), and consequently lowering the per unit production costs and increasing net income from farming.

Marginal analysis stipulates that, to maximize profits, a given bundle of productive resources should be allocated among competing enterprises so that marginal returns (MVP's) are equal in each enterprise. This principle seems to be totally violated by the majority of Hasawi farmers when deciding what to produce. The product mix is determined mainly by traditions rather than by potential profitability of each crop. While almost all farmers constantly complain about the relatively low profits forthcoming from date production, dates continue to be the dominant agricultural crop in the oasis. Since most of the crops grown in the oasis are competitive in the use of the limited productive resources, the present level of date production can only be maintained by limiting or even forgoing the production of other, probably more profitable, crops such as rice and vegetables. Date production should, therefore, be viewed in terms of its opportunity cost or the value of the alternative crops that are sacrificed. Net returns from a given set of inputs can be maximized when the marginal return from dates is equal to the potential marginal return from the crop that is sacrificed. As long as the marginal return from dates is below its opportunity cost, net returns will remain below the maximum;

productive resources should be diverted away from dates to the production of other, more profitable crops.

Empirical Techniques

Several quantitative techniques have been effectively used by agricultural production and farm management economists to determine optimum cropping patterns and input mixes under particular resource limitation conditions. Important among these optimizing analytical tools are budgeting, functional analysis, and linear programming, all of which aid the decision-making process by projecting the economic results of a particular set of actions. While these alternative techniques serve as supplements and complements rather than rivals, each is intuitively more helpful than the other two in analyzing specific problematic situations. The choice as to the most efficient tool to be applied to a certain farm management problem is generally determined by the nature of the problem at hand, the specific objective function to be optimized as well as the magnitude and structure of available data. A brief discussion of each of the three empirical techniques is presented below.

Budgeting

Budgeting is a technique that utilizes economic theory, farm records, and price expectations to synthesize an optimum physical and financial plan for the operation of a given farm for some future period of time. The technique is, in fact, a trial and error process through which the farm planner strives to find an optimum allocation of available resources. It includes statements of physical inputs, volume of outputs, expected expenses, and the variation in income that would result from the use of alternative resource combinations.

Two broad categories of budgets are commonly used in farm management studies: complete budgets and partial budgets. A complete budget is normally concerned with the organization of the entire farming business and is, thus, associated with total (including fixed) costs and total returns. It involves a listing of all physical inputs and their cost as well as a listing of all outputs and the expected income (39, p. 388). A partial budget, on the other hand, is usually concerned with the effect of a change in farm organization on net receipts. It is often used to evaluate the economic consequences of a change in farm operations that does not call for a complete farm reorganization. A partial budget may be subdivided into enterprise budgets, each estimating the net return forthcoming from producing a given quantity of a specific enterprise.

A principal difficulty often encountered in using the budgeting analytical technique is the limitation imposed by data management. Typically the farm manager goes through the process of budgeting either by hand, or using a desk calculator. Consequently, the amount of detail that he is able to include in his budgeting model represents only a small part of what might reasonably be included (40, p. 3). Increased use of high speed computers to analyze alternative farm management plans has, however, minimized this difficulty.

Functional Analysis

This technique utilizes the production function concept along with some established functional relationships between a product and a set of factor inputs in providing a framework for adjusting production patterns and resource allocation to prevailing economic conditions. Even though the production function is technically concerned with the reactions of total output to changes in inputs of various factors, it is capable of relating total revenues to the amounts of inputs and total costs to the amount of output. Therefore, the production function technique is conceptually useful in estimating the most profitable point of operation for an enterprise in the short run under certain simplifying assumptions. This can be done by determining either the optimum amount of input to be utilized or the optimum amount of output to be produced.

Several types of functional forms have been applied to farm management research studies including the linear, quadratic, power or Cobb-Douglas, Spillman, and the square root. The concepts and methods relating to the prediction and use of these agricultural production functions have been delineated by Heady and Dillon (41). The algebraic form of each function and the magnitudes of its coefficients will generally be influenced by ecological conditions, type and variety of crop, resource being varied, state of technology, and quantity of fixed inputs. While no single form can be used to characterize agricultural production under all environmental conditions, some forms are intuitively more flexible than others.

A major limitation of the functional analysis technique is the narrowness of its range of application. Typically, the production function model focusses upon a relatively small part of the total range of farm activities, such as determining the optimum fertilization level for a given crop on a particular type of soil. In this respect, the technique is almost always partial. Attempts made to characterize a farm business with a global production function have not been at all encouraging (40, p. 5).

Linear Programming

Linear programming is an analytical tool that is often helpful in arriving at decisions requiring a choice among a large number of alternatives. The technique is commonly used to maximize (or minimize) a linear objective function subject to a set of linear constraints. When applied to farm management problems, the model is capable of choosing a combination of enterprises that yields maximum net returns to a given bundle of productive factors when prices, costs, and production coefficients are specified. The technique is particularly useful in determining optimal distribution of several crops over a given cultivated area. A more complete discussion of the theory of linear programming and its application to agriculture may be found in Heady and Candler (42), Agrawal and Heady (43), or Beneke and Winterboer (44), among others.

The profit-maximizing linear programming model may be presented, in a matrix form, as follows:

$$\begin{array}{ll} \text{Maximize} & Z = C'X \\ \text{Subject to} & AX \leq B \\ \text{and} & X \geq 0 \end{array}$$

where

Z represents the value of the objective function to be maximized,

C' is a transposed column vector of weights (prices or net returns) assigned to each structural activity of the problem,

X is a vector of activity levels obtained in the optimum solution,

A is a matrix of input-output coefficients, and

B is a vector of resource supply and other restrictions given in the formulated problem.

Three conditions must exist if the standard linear programming technique is to be effectively used in solving an economic problem: (1) there must be an objective function (such as profits or costs) which the model attempts to maximize or minimize; (2) at least one resource must be restricted; and (3) there must be several, preferably many, alternative ways of achieving the objective function. In addition to these conditions, the following basic assumptions are usually made (43, p. 31): (1) The objective function is linear, indicating that the quantities of inputs used and outputs produced are not affected by their prices, and that the input-output ratios remain constant at all levels of production. (2) Resources are additive, or the sum of resources used individually by each activity must equal the total quantity of resources used collectively by all activities. This implies absence of any interaction among the different activities. (3) Resources and activities are divisible. In other words, factors can be used and commodities can be produced in fractional units. (4) Alternative activities and resource restrictions which need to be considered are finite. (5) Expectations are single-valued. This means that resource supplies, input-output coefficient, and prices are known with certainty.

Broadly speaking, linear programming is more versatile and more efficient than competing techniques. It allows farm management workers to test a wide range of alternative decisions and to analyze their consequences with relatively small input of managerial time. It further permits a more complete analysis than either functional or budgeting techniques. Thus the whole farm business can be thoroughly and conveniently analyzed. The depth of analysis realized with this technique can considerably be greater than that attempted with budgeting, in particular, because the data management problem is not so burdensome. Thus more levels of input application and more land use alternatives can be simultaneously considered.

Some Previous Linear Programming Applications

The static linear programming technique has been extensively used in agricultural economic research during the past two decades. Much of its use has been in the determination of profit-maximizing farm plans for resource situations typical of those found on individual farms. Some use has, moreover, been made of the technique to find optimal allocation of resources in agriculture at the sub-regional and regional levels. A few previous studies relevant to the current analysis are briefly reviewed. In selecting the studies, emphasis has been placed on those dealing with optimum allocation of irrigation water, which is the main limiting agricultural input in Al-Hasa oasis.

Pomareda (45) developed a linear programming model at the farm level for analyzing optimal level of water application among various crops with different water response functions and a limited water supply. This method provides advantages over the partial one-crop type of analyses because it captures intercrop trade-offs in water and land use in response to farm management decisions or to changes in water supply.

Anderson (38) used the static linear programming technique to appraise the potential of irrigation water in that portion of the Washita River Basin located within Roger Mills County in Western Oklahoma. The specific objectives of his analysis included estimating the value of water used to irrigate alternative crops under varying levels of water availability and farm resource situations as well as determining the optimum allocation of alternative levels of available water among crops and farms in the study area. Parks and Hansen (46) utilized static linear programming models of representative farms to estimate farm incomes under alternative water allocation patterns in the Pirque Valley in central Chile. Their principal objective was the determination of the optimum economic allocation of available irrigation water among the different farm-size classes in the study area.

A number of applications have been made of single-period linear programming models to estimate the demand function for irrigation water. Gisser (47) employed the technique to derive the agricultural demand function for imported water in the Pecos basin in New Mexico. The derived demand function indicated the expected quantities of imported irrigation water that would be demanded at different prices and under a variety of constraints. A similar approach was employed by Flinn (48) to determine optimal seasonal demand schedules for water in the Yanco irrigation area in New South Wales, Australia.

The linear programming techniques have also been applied to the planning and management of specific watersheds with the overall objective of maximizing social net returns over time from the use of these watersheds subject to a set of financial, institutional and physical constraints. Pavelis and Timmons (49) used linear programming to develop an optimum management program for the Nepper Watershed, located in Western Iowa. They incorporated 50 land uses and 31 resource restrictions to derive alternative optimal management programs that would maximize net benefits from the watershed for any amount of expenditure that might be available.

A comprehensive linear programming model was developed by Andrews and Weyrick (50) for evaluating water resources and cost and benefit allocation of surface water uses in a small southern New Hampshire river basin. To include as many interfaces of water resource use as possible, the authors employed the basin-wide firm concept which is essentially combining all firms into one decision-making unit that would allocate all resources in the basin. Lokshminarayana and Rajagopalan (51) constructed a similar model for the Bari Doab water basin in the Indian state of Punjab. The central objective of the model was to determine the optimum allocation of available water among alternative irrigated crops such that benefits from the system would be maximized.

The linear programming technique has also been used as a tool for selecting the least-cost types and quantities of specific inputs that are consistent with a given total cropping plan. Danok, McCarl, and White (52) employed the technique to determine the kinds and sizes of machinery needed on a state farm in the central part of Iraq. The model was intended to serve as an integrated planning process that can evaluate simultaneously the effects of machinery purchase and crop production alternatives within the resource constraints imposed upon the farm.

CHAPTER IV

ANALYTICAL MODEL FOR AL-HASA IRRIGATION AND DRAINAGE PROJECT

This chapter presents the details associated with the construction of a proposed empirical model for Al-Hasa Irrigation and Drainage Project. The general features of the model are first identified and the basic assumptions are then stated. Limitations of the model are subsequently outlined. Finally, the various components of the model are delineated. The technique discussed here is rather simplistic although valid for use in building more complicated linear programming models for other irrigated areas.

General Features of the Model

The analytical model used in this study is a static linear programming model which incorporates numerous activities and resource restrictions to represent Al-Hasa agriculture. The objective of the model is to determine the pattern of resource allocation and management that would maximize total net returns to a set of fixed factors, namely irrigable land, water, irrigation facilities, and management resources in the oasis as a whole. Obtaining all the results in one package is consistent with the general objectives of this study. The optimum solution that the model chooses is not necessarily one that yields the highest net return to any one factor, but one that makes the most efficient use of all available fixed resources.

A macro programming approach is employed to identify the potential optimum levels and patterns of regional output and the corresponding resource combination. This approach considers the entire project area a decision-making unit or a profit-maximizing entity that accepts exogenously determined input and product prices. Since the project is operated by a central authority seeking to increase regional food production without much concern about the micro configuration within the oasis, such simplification is reasonable. While this macro-oriented technique bypasses the problems of resource allocation within and among individual farms, its main advantage lies in the fact that it is less demanding, in terms of data requirements, time and cost of the analysis, than the micro programming approach. As a practical matter, it is impossible to analyze the behavior of every farming unit within the study area. Therefore, aggregation is necessary if empirical analysis of the problem at hand is to be reduced to a manageable size.

The model seeks to fulfill the profit maximizing conditions specified in the previous chapter. These conditions stipulate that available resources in the study area be allocated in such a manner that the marginal value product of any single resource is equated for all competing uses and users. For the oasis as a whole, this essentially requires diverting some resources, particularly water, from uses associated with low marginal value productivity, such as date cultivation, to other uses, such as vegetable production, that can bring forth higher net returns per unit of water. It may also entail diverting water from farms where it has low marginal productivity in the production of a given crop to other farms where it can be used more efficiently in producing the same crop.

Accordingly, the plan suggested by the model represents a socially optimum solution which may not necessarily be optimum for individual farms. Such a solution should not, nonetheless, be taken to denote an equilibrium which will rigidly shape future resource allocation decisions in the oasis; rather it might serve as a guide for public policy actions which would, in addition to market forces, encourage reallocation of available resources to meet a socially optimum economic efficiency criterion. It is earnestly hoped that the plan outlined by the model would be useful for Al-Hasa Irrigation and Drainage Authority which operates the project.

The model is basically deterministic; that is it assumes that all relevant physical and economic data are known with certainty. All economic interpretations relate to a predetermined set of price and cost conditions calculated and estimated from official sources and sample data to represent the 1977/78 crop year. The validity of the solution determined by the model should, therefore, be confined to this framework. Furthermore, the model is generally normative, indicating what farmers should (rather than what they actually would) do to achieve the profit-maximizing objective.

The Mathematical Programming System--Extended (MPSX), a modified simplex algorithm, is used to facilitate the analysis of this linear programming problem (53). The MPSX System is an efficient tool for evaluating the profitability of alternative crop enterprises and assigning shadow prices to resources. It is capable of monitoring the sensitivity of the optimal plan to changes in the basic data.

Basic Assumptions for Model Application

The development of a model for analyzing a specific problem requires a set of simplifying assumptions about physical, economic, and institutional variables relevant to the problem at hand. In addition to assumptions for the general linear programming model outlined in the previous chapter, several specific assumptions are made for this analysis. The first is that profit maximization is the major goal toward which the production decisions of individual farm operators within the project area are directed. While some farmers may respond to stimuli other than profit maximization in their economic decisions, the behavior of the majority is taken to be consistent with this assumption. The second assumption is that individual farmers within the study area face a perfectly elastic demand curve for products sold as well as a perfectly elastic resource supply curve, except for land and water. Obviously, this may not be precisely true for any specific farm. Farmers do sometimes face scarcity of some production inputs, particularly labor and machinery. Nevertheless, these resources are relatively mobile in the oasis and are supplied at no increase in price over the range of any individual farm's demand.

Another assumption which should be made is that the study area is homogeneous with respect to production costs as well as critical producing characteristics such as soil type and fertility, water quality, irrigation efficiency, production technology, and climate. In other words, the study area is assumed to depict homogeniety of yields, production techniques, and factors of production. It is further assumed that knowledge and management capabilities among farmers are equal throughout the project area.

It is also assumed that there is a fixed area of potentially irrigable land and a maximum amount of water that would flow into the irrigation system per unit of time. Rainfall is so scarce and so eratic that it is ignored. In addition, it is assumed that farmers in the study area fully realize the profitability of using modern farming inputs and practices and are able and willing to utilize such innovations to increase their net returns per unit of irrigated land.

Finally, it is assumed that the major institutional parameters which affect agriculture in the oasis will remain constant over the period of analysis. These include property and water rights as well as government programs designed to support prices and incomes or to stimulate production of specific crops.

Components of the Model

The major building blocks of this multi-product multi-factor linear programming model may be identified as: the objective function, alternative activities, production coefficients, and resource and other restrictions. Using these components, the model may be expressed mathematically as:

$$\text{Maximize} \quad P = C_1X_1 + C_2X_2 + \ldots + C_nX_n \qquad (1)$$

$$\text{Subject to} \quad \begin{aligned} a_{11}X_1 + a_{12}X_2 + \ldots + a_{1n}X_n &\leq b_1 \\ a_{21}X_1 + a_{22}X_2 + \ldots + a_{2n}X_n &\leq b_2 \\ \vdots \qquad \vdots \qquad\qquad &\vdots \\ a_{m1}X_1 + a_{m2}X_2 + \ldots + a_{mn}X_n &\leq b_m \end{aligned} \tag{2}$$

$$\text{and} \quad X_1 \geq 0,\ X_2 \geq 0,\ \ldots,\ X_n \geq 0$$

where

P represents the total profit (net return) above variable production costs from n crops grown in the project area,

$C_1, C_2, \ldots, C_n$ is defined as net revenue (in Saudi Riyals) forthcoming from growing one hectare (10 donums) of a given crop,

$X_1, X_2, \ldots, X_n$ denotes the level of a specific crop (in hectares) obtained in the optimum solution,

$a_1, a_2, \ldots, a_n$ specifies the amount of a particular resource (water) required per unit (hectare) of a given crop, and

$b_1, b_2, \ldots, b_n$ indicates the maximum quantity of a given resource (water, land) which is available for use in the production process per unit of time.

The remainder of this chapter is devoted to delineating the major components of the model.

Alternative Crop Production Activities

Crops considered in this analysis are presented in Table 6 along with their anticipated yields under optimum management conditions. These crops are chosen on the bases of technical feasibility of production and presence of adequate demand. The table is somewhat selective, rather than being inclusive; other, and probably more profitable crops such as pomagranates, grapes, green onions, pumpkins, and sunflowers could have been incorporated into the model to present

Table 6. Alternative Crop Enterprises for Al-Hasa Irrigation and Drainage Project

Crop	Variety	Anticipated Yield (ton/ha)[a]	Optimum Date for Transplanting or Direct Sowing	Growing Period (Days)
Alfalfa	Hasawi	30 d.M/Yr.	Oct. and Feb.	Perennial
Dates	Many	11.35		Perennial
Rice (summer)	Hasawi	3.4	Late July-Early Aug.	110
Oats (forage)	Astor	13 (d.m.)	Oct.-Nov.	115
Millet (forage)	Pankum Milaceum	10 (d.m.)	April-Sept.	90
Rice (spring)	NTU	5.5	Early March	120
Rice (summer)	NTU	4.8	Late July	110
Barley (grain)	Australian	3.8	Late Nov.	120
Wheat (grain)	Super-X	5.5	Late Nov.	130
Sweet Corn (spring)	Golden Cross Bantam	15	Late Feb.-Early March	90
Sweet Corn (fall)	Corn Belt X Carribean Comp.	15	Late August	90
Sorghum (grain)	Australian	6.2	Late March-Early April	120
Sugar Beets	Trirave E	79	Early November	195
Cabbage	Brunswich	40	Sept.-Dec.	120
Cantaloupe	Farmer's Friend 57	15	Early March	120
Carrots	Scarlet Nantes	22	Oct.-Dec.	120
Cauliflower	Farmer's Friend Early Mature No. 2	31	Aug.-Nov.	105
Cucumber (spring)	Swallow	24	Late Feb.-Early March	120
Cucumber (fall)	Beta Alpha	25	September	120
Eggplant	Florida Market	40	July and Feb.	150
Okra	Local	15	July-Aug.	90
Lettuce (fall)	Great Lakes-Standard	35	Late Sept.-Dec.	83
Lettuce (winter)	Great Lakes Mesa-659	35	Dec.-Jan.	90
Radish	Southern Market Globe	20	Sept.-Oct.	60
Onions	Granex Yellow	40	Oct.-Nov.	200
Potatoes	Patrones	20	January	140

Table 6. Continued

Crop	Variety	Anticipated Yield (ton/ha)[a]	Optimum Date for Transplanting or Direct Sowing	Growing Period (Days)
Tomatoes (spring)	Pearson A-1	54	Jan.-Feb.	150
Squash (fall)	Zucchini	22	September	90
Squash (spring)	Zucchini	22	Jan.-Feb.	90
Tomatoes (fall)	Pearson A-1	54	Aug.-Oct.	150
Watermelon (spring)	Charleston Gray	20	Late Feb.-March	140
Watermelon (fall)	Charleston Gray	20	August	140

Source: Hofuf Agricultural Research Center and ARAMCO's Agricultural Assistance Division.

[a] Under optimum management conditions.

a greater choice of alternatives from which farm operators may choose. However, the scarcity of reliable data on the yields and input requirements of these and other crops has led to their exclusion from the model. Moreover, those included in the model represent an adequately varied array of the choice possibilities available to farm operators in the project area and are sufficiently similar to act as substitutes for other possible alternative crop activities.

Although sugar beets are not commonly grown in Al-Hasa, they are included in this model because of the interest shown by farmers, extension workers, and research personnel. They have also been included in the model in response to expressed keen interest by government officials and community leaders in promoting the introduction of some basic industrial crops into the region.

Data on crop variety choice, anticipated yield, recommended date of planting, duration of growing period, and input requirements were extracted mainly from research progress reports prepared at Hofuf Agricultural Research Center. Additional technical information was also obtained from ARAMCO's Agricultural Assistance Division (54) and from Qatif Experimental Farm (55).

The Objective Function

As specified by the above assumptions, the objective of the model is the maximization of net revenues over operating costs for the entire project area. The elements of the objective function are taken from the per hectare unit budgets developed in Appendix A for each of the crop enterprise activities identified in Table 6. The budgets were developed for each crop by determining the per hectare input requirements and specifying their unit costs. Per hectare gross returns were also computed using the average yields listed in Table 6 and the official wholesale product prices (56). The operating costs were then subtracted from gross returns to obtain net returns, which make up the coefficients of the objective function of the model. The gross returns, operating costs, and net returns abstracted from each of the unit budgets developed for the various crop enterprises are presented in Table 7.

Each element of the objective function represents the net revenue anticipated from growing one hectare of a given crop and is actually the residual return to land, water, irrigation facilities, and management. All product and factor prices utilized in deriving these elements reflect the economic conditions that prevailed in the study area during the 1977/78 crop year.

A major problem encountered in estimating net revenues is the scarcity of reliable data on the costs of production. While wholesale and retail output prices are monitored and reported by a government agency, systematic information relating to input prices, labor wages, and machinery costs is lacking. In assessing production costs, the author relied mainly on interviews and personal communication with a number of knowledgeable farmers, extension workers, and input suppliers in the study area. The cost figures used in the calculations reflect the author's perception of what seemed to be the most realistic and do not necessarily represent a consensus among those interviewed.

The accuracy of the solution produced by the model depends, among other things, on the exactness of the input and product prices used in computing the coefficients of the objective function. These prices, it should be pointed out, could be either under or over stated due to

Table 7. Estimated Per Hectare Net Returns for Selected Crops Grown in Al-Hasa Oasis

Crop	Yield (Ton/Ha)	Price SR/Ton	Total Receipts (Riyals)	Variable Cost (Riyals)	Net Return (Riyals)
Alfalfa	32 (DM)	1,500	48,000	9,064	39,382
Dates	11.35	2,110	23,949	8,726	15,223
Rice (Hasawi)	3.4	9,030	30,702	6,595	24,107
Rice (NTU-Spring)	5.5	3,000	16,500	6,765	9,735
Rice (NTU-Summer)	4.8	3,000	14,400	6,660	7,740
Barley	3.8	2,490	14,362[a]	3,574	10,788
Wheat	5.5	3,250	22,075[b]	3,694	18,381
Sweet Corn	15	2,750	44,050[c]	3,608	40,442
Grain Sorghum	6.2	2,100	16,620[d]	3,877	12,743
Sugar Beets	79	275	32,525[e]	4,032	28,493
Dry Onions	40	2,750	110,000	9,125	100,875
Potatoes	20	3,000	60,000	12,290	47,710
Cabbage	40	2,500	100,000	7,524	92,476
Cantaloupe	15	2,500	37,500	5,866	31,634
Carrots	22	2,250	55,000	6,154	48,846
Cauliflower	31	3,500	108,500	8,761	99,379
Cucumber (Spring)	24	3,500	84,000	6,030	77,970
Cucumber (Fall)	25	3,500	87,500	6,030	81,470
Eggplant	40	3,250	130,000	11,719	118,281
Lettuce	35	3,250	113,750	8,997	104,753
Squash	22	4,750	104,500	8,929	95,571
Tomatoes	59	3,250	191,750	13,804	161,696
Watermelon	20	2,250	45,000	7,841	37,841
Okra	15	9,000	135,000	10,640	124,360
Radish	20	2,250	45,000	4,491	40,509
Millet (forage)	10 (DM)	1,300	13,000	2,897	10,103
Oats (forage)	13 (DM)	1,200	15,600	2,314	13,286

[a] Includes 4,900 riyals for straw.

[b] Includes 4,200 riyals for straw.

[c] Includes 2,800 riyals for stalks.

[d] Includes 3,600 riyals for straw.

[e] Includes 10,800 riyals for tops.

random factors or errors in judgement. Furthermore, the mounting general inflation may raise skepticism about the validity of any given set of prices. However, relative prices are of more concern than absolute prices for determining the optimum crop mix. Normally, across the board under- or over-stating of input and product prices would not affect the relative profitability differences among crops.

Water Requirements

Production coefficients are normally stated in terms of the amounts of inputs required per unit of the activity. The programming model requires an estimate of the amount of each of the scarce resources needed per unit of crop production activity, arbitrarily defined as one hectare. In this analysis water is considered the major constraining resource. While other inputs such as labor, machinery, fertilizers, and chemical pesticides are as equally important for crop production, they are assumed to be available in ample quantities at constant costs and are, thus, not limiting to crop production activities. Discussion of the model production coefficients is, therefore, focused on water requirements.

The rate at which water is extracted from the soil by evaporation and plant use is interchangeably referred to in the literature as water consumptive use or evapotranspiration by a crop. This rate is determined by the interaction among climatic factors, soil conditions, and the specific characteristics of the crop under consideration. It varies with the stage of maturity of the crop and the changing climatic factors during the growing season. Agronomists refer to the quantity of water needed per unit of time to compensate for losses through evapotranspiration as the crop water requirement, usually expressing it in depth or in volume per unit area for a given time period. One of several techniques, particularly the Blaney-Criddle, the Radiation, the Penman, and the Pan Evaporation, can be used to estimate the seasonal water requirements for any given crop in any specific area (57).

When estimating total water requirements for a crop, allowance must be made for the economically unavoidable losses normally incurred during conveyance and application of water. This is usually expressed in terms of project irrigation efficiency, which is generally defined as the ratio between the quantity of water used in evapotranspiration and the total quantity entering the irrigation system. It is the product of the distribution and the field application efficiencies, each of which is affected by a different set of conditions (57, p. 79).

On lands under gravity irrigation, from one to three times the amount of water actually used to satisfy consumptive use may be lost in the process of delivering water and applying it to the field. Seepage from canals, laterals, and farm ditches as well as evaporation, administrative waste, surface runoff, and deep percolation on farm fields all deplete the water supply initially diverted (58, p. 6). Although the project irrigation efficiency is affected by a number of factors, particularly climatic conditions, field leveling, soil type, and method of irrigation, it generally does not exceed 60 percent. As has been indicated by Bas and Nugeren (59), it normally ranges between 32 and 58 percent for projects using good layout design, adequate land leveling and optimum irrigation practices.

Gross monthly water requirements for crops grown in Al-Hasa and incorporated into the model are presented in Table 8. The figures represent the amount of water, in cubic meters, that the irrigation system must provide each month to meet the water requirements of the various crops. This estimated amount is believed to be essential for attaining the crop yields specified. Contribution from precipitation is neglected because of its scarcity and erratic nature. Also, use of the present (largely basin) irrigation method is assumed to continue throughout the project area. Transformation to other (and probably more efficient) techniques such as sprinkler and drip irrigation is considered economically infeasible at this time.

The gross water requirements were calculated using crop consumptive use or crop water requirement data developed by agronomists at Hofuf Agricultural Research Center (60, Table 8) and an assumed 53 percent project irrigation efficiency. Implicit in this conjectured efficiency is the hypothesis that 47 percent of the overall water supply disappears in conveyance losses in canals and field ditches and in deep percolation and field runoff. The total water requirement figures were obtained for each crop by dividing the estimated consumptive use figures of the respective crop by the assumed project irrigation efficiency. Generally, the percolation losses occurring in the project area can adequately meet the leaching requirement needed for maintaining a tolerable salinity level in the soil.

Although the crop consumptive use estimates were based on ten-year meteorological data, the actual crop evapotranspiration rates may not be equal to the predicted values for all parts of the project area. The discontinuity of cultivation within the oasis makes many irrigated

Table 8. Estimated Gross Water Requirements for Crops Grown in Al-Hasa Oasis--M^3 per Month per Hectare[a]

Crop	Planting Time	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Alfalfa		2281	2589	3860	4358	6083	6566	7194	5966	4302	3626	2377	2281
Date Palms		1053	1321	1872	1981	3451	3283	3802	3919	3000	1696	1132	1579
Wheat (g)	Nov. 1	2106	1532	--	--	--	--	--	--	--	--	1472	2106
Barley (g)	Nov.	2106	1532	--	--	--	--	--	--	--	--	1472	2106
Rice (s)[b],	Jul. 25	--	--	--	--	--	--	1928	7311	6849	3860	849	--
Rice (sp)[b],	Mar. 1	--	--	4158	5321	8072	7415	--	--	--	--	--	--
Sorghum (g)	Apr. 1	--	--	--	2604	5791	7755	6083	--	--	--	--	--
Sweet Corn (sp)	Jan. 1	811	1724	3580	--	--	--	--	--	--	--	--	--
Sweet Corn (f)	Sept. 1	--	--	--	--	--	--	--	--	2393	2616	2994	--
Sugar Beets	Nov. 1	2220	2789	4092	3249	1472	--	--	--	--	--	1406	1432
Common Cabbage	Sept. 1	--	--	--	--	--	--	--	--	2547	3316	2864	2088
Millet (fr)	June 1	--	--	--	--	--	3962	7205	5656	--	--	--	--
Oats (fr)	Oct. 1	--	--	--	--	--	--	--	--	--	1842	2734	2187
Cantaloupe	Mar. 1	--	--	1930	3170	5674	7075	--	--	--	--	--	--
Carrots	Aug. 21	--	--	--	--	--	--	--	1162	4132	3685	2604	962
Cauliflower	Nov. 1	2123	1902	--	--	--	--	--	--	--	--	1302	1790
Cucumber (sp)	Mar. 1	--	--	1930	3170	5674	5896	--	--	--	--	--	--
Cucumber (f)	Sept. 1	--	--	--	--	--	--	--	--	2547	2506	2474	1283
Eggplant (sp)	Mar. 1	--	--	1814	3852	7159	8491	5511	--	--	--	--	--
Eggplant (f)	Jul. 1	--	--	--	--	--	--	3743	5147	6113	4445	2377	--
Okra	June 1	--	--	--	--	--	4245	6314	6375	--	--	--	--
Lettuce (f)	Oct. 1	--	--	--	--	--	--	--	--	--	1151	1536	1506
Lettuce (w)	Dec. 1	1169	2324	--	--	--	--	--	--	--	--	--	819
Radish	Oct. 1	--	--	--	--	--	--	--	--	--	2579	2863	--
Onions	Sept. 1	1930	2536	2166	--	--	--	--	--	2598	2985	2166	1989
Potatoes	Jan. 1	1042	1826	4053	4920	1925	--	--	--	--	--	--	--
Tomatoes (sp)	Jan. 1	907	2105	4632	5570	5489	--	--	--	--	--	--	--
Squash (sp)	Jan. 1	965	1724	3113	--	--	--	--	--	--	--	--	--
Squash (f)	Oct. 1	--	--	--	--	--	--	--	--	--	2211	2213	1283

Table 8. Continued

Crop	Planting Time	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Tomatoes (f)	Aug. 1	--	--	--	--	--	--	--	2678	4126	4422	3125	1830
Watermelon (sp)	Mar. 1	--	--	1930	3170	5674	7075	3311	--	--	--	--	--
Watermelon (f)	Aug. 1	--	--	--	--	--	--	--	3042	3396	3509	2604	962

Sources: 1) Leichtweiss-Institute Research Team Publication No. 17: Irrigation Handbook, Tables 3-8.
2) FAO Irrigation and Drainage Paper No. 24-1977 Revised Edition, Tables 21 and 22.

[a] Calculations based on 53 percent project irrigation efficiency.

[b] Transplanted.

[c] Abbreviations are the following: sp = spring; s = summer; f = fall; w = winter; g = grain; and fr = forage.

fields surrounded by extensive dry fallow areas subject to advection. With winds as dry and as warm as they are in Al-Hasa, appreciably higher crop evapotranspiration rates, hence higher total water requirements, can be expected at the windward edges of the oasis.

Program Constraints

Most, but not all, linear programming restrictions are defined in terms of fixed quantities of certain resources per unit of time. For the Al-Hasa Irrigation and Drainage Project, the major binding resource constraints are land and water. Once a farm's labor and machinery resources are exhausted, for example, additional resources can be hired at the market price without limit. Therefore, two groups of constraints, representing limitations on the availability of land and water throughout the year, are specified in the model. The year is divided into 12 monthly periods, during which crops may be planted or harvested, and the amounts of arable land and irrigation water available to the program in each period are indicated.

Land Availability Restrictions. Because climatic conditions within the study area often permit the production of two or more different crops from the same land in one year, a land availability constraint has been specified for 12 time periods corresponding to the calendar months of the year. Barley, for example, may be planted in November and harvested in March, thus requiring land during the November-March periods. The same land may then be used for growing grain sorghum during the April-July periods. Or, as another possibility, fall lettuce may be planted in October, harvested in December, then followed by spring eggplant in

February. Other complementary combinations could also be suggested. Since these combinations do not always occur in a prescribed or set rotation, the division of land according to time periods is an appropriate method for handling the double cropping situation.

The land availability constraint requires that the total area under cultivation in any given period does not exceed the net cultivable area covered by the irrigation network. The maximum area that may be brought into crop production during any monthly period must, therefore, be equal to or less than 16,400 hectares. This maximum represents the total project area minus the area occupied by villages, roads, irrigation and drainage canals, pumping stations, reservoirs, and springs.

Water Availability Restrictions. The water availability restrictions are used to limit the quantity of irrigation water available to the program over the 12 monthly periods. These restrictions necessitate that the quantity of water used in each period be equal to or less than the maximum total discharge from the individual springs feeding the irrigation system. In other words, the maximum volume of irrigation water that could be made available to the program during any single month is determined by the discharge capacity of the feeder springs.

As has been established by official measurements of the actual flow in the main canals during the 1974/78 period, the maximum total discharge from the springs is around 23.468 million cubic meters per month (see Appendix B). This figure represents the full discharge capacity of the springs during periods of peak demand for irrigation water. It is assumed that this quantity will be available to the program throughout the 12 monthly periods, and that its use during a given period will not affect its availability in any of the other periods.

Date Palm Activity Restriction. Even though their economic significance may be declining, date palms are still given priority over other crops grown in the project area, and there are no reasons to believe that their number would be reduced by uprooting or by abandonment in the near future. The trees will in all probability continue to occupy the land and utilize available productive resources, particularly water, even at the expense of other, and possibly more profitable, crops.

To account for the inflexibility in the total area devoted to date production in the short run, a date palm activity restriction is specified in the model. This restriction sets the minimum number of hectares that must be set aside for date cultivation each period. It requires that total area under date palms in any period be equal to or greater than the total area presently utilized for date palm cultivation. As was earlier indicated, (Table 2), this area is about 4,100 hectares. This minimum constraint is specified lest the date enterprise activity be forced out of the solution by other crops with considerably higher per hectare net returns.

Vegetable Activities Restrictions. The net returns from all the crop enterprises included in the model are based on the assumption that the demand for these crops is perfectly elastic with respect to price. In other words, the individual product prices which underlie the profit coefficients given in the objective function are assumed to prevail regardless of the quantity produced of each commodity. However, such assumption can not realistically be applied to most fresh vegetables produced in the study area, particularly in view of the limited absorptive capacity of the marketing system and the great potential for increased production. It is, therefore, essential to indicate the range within which total production should fall in order for the profit coefficients to be relevant.

Since vegetables are close substitutes both in consumption and in resource use during a given season, they should be collectively considered when deriving a cropping plan that is consistent with the objective of maximizing net returns to limited resources in the oasis. Thus, an upper limit is imposed on the total area devoted annually to the production of vegetables as a group. This limit is determined mainly by what the market will bear at the assumed product prices. Assuming a per capita consumption of 150 kilograms per year, it is estimated that about 48,000 tons of fresh vegetables would be consumed annually by inhabitants of the oasis and the neighboring communities. It is further estimated that an equal amount of produce would be shipped to major consumption centers in and outside the Eastern Region. Considering the fact that all vegetables produced in the study area are presently sold for fresh consumption and assuming an overall yield of 24 tons per hectare, the total area devoted to vegetable production each year should not exceed 4000 hectares. In the absence of any processing facilities, increasing total production through yield improvement or area extension could result in depressed farm prices. Onions and potatoes are excluded from this limitation because the country is a net importer of both, and because they lend themselves to storage and long distance hauling without appreciable loss in quality or value.

Because some vegetables, such as lettuce, cauliflower, squash and cucumbers, usually generate considerably higher per hectare net returns than most other vegetables, they might be expected to enter the solution at their maximum levels. Therefore, upper limits must be imposed on these high valued crops in order to maintain the solution within the realm of realism. So, in addition to restricting the total area under vegetable production, the model limits the area utilized by any particular vegetable crop activity (excluding onions and potatoes) to a maximum of 400 hectares. This maximum, it should be pointed out, is rather arbitrary, as no clear-cut guideline exists for setting the constraint limits on the various vegetable crop activities included in the model. A detailed study is needed to objectively determine the potential demand for each crop activity.

Other Considerations. While the above described model is necessarily simplified, mention should be made of some of the other factors which were considered in its development but have not been incorporated into the analysis, since they were not viewed as being restrictive on the model. Among such factors were labor, machinery, credit and other capital inputs, all of which do enter into the farm decision-making process. However, since these factors have been assumed to be mobile and in elastic supply, they were not believed to be restrictive.

Consideration was also given to rotational restrictions or diversity requirements for the cropping programs. Farmers have many reasons for following crop rotation programs: improving soil conditions, disease and insect control, risk aversion, and making better use of resources in the short run. There is no consensus, however, among plant and soil scientists that rotational requirements are necessary for maintaining crop yields at the specified levels. Therefore, it was assumed that rotational requirements are not restrictive and that price-quantity relationships will determine the optimal solution.

CHAPTER V

RESULTS OF THE LINEAR PROGRAMMING ANALYSIS

This chapter presents the results of the linear programming analysis for Al-Hasa Irrigation and Drainage Project. Results of the basic linear programming model described in the preceding chapter are given first. Then, the impact of the size of total area devoted to date production on total net return is assessed by considering several computer runs with varying date palm area restrictions. Finally, the project's demand for additional irrigation water is estimated by altering the restrictions on the total amount of water made available to the program each month.

Results of the Basic Model

Cropping Pattern

A summary of the optimal crop production plan for Al-Hasa Irrigation and Drainage Project is presented in Table 9. Among the elements of this table are the specified total area, the estimated gross water requirement, and the expected net revenue for each of the crops incorporated into the final plan. The plan is the result of repeating computer runs of the linear programming model delineated in the previous chapter, with minor adjustments in planting dates of some crops and subsequent modifications in total monthly water requirements. It

Table 9. Optimal Production Plan for Al-Hasa Irrigation and Drainage Project

Crop	Planting Date	Growing Period (Days)	Area (Hectares)	Net Revenue (1000 SR)	Water Use (1000 M^3)	Average Net Return Per M^3 of Water (Riyals)
Dates[a]	Perennial	---	4,100	62,414	115,162	0.54
Oats	Oct. 1	90	559	6,700	3,781	1.77
Millet	June 1	90	396	4,001	6,665	0.60
Wheat	Nov. 1	130	2,656	48,820	19,166	2.55
Sorghum	Apr. 1	120	76	969	1,526	0.63
Cauliflower	Nov. 1	120	400	39,891	2,847	14.01
Spring Cucumber	Mar. 1	120	400	31,188	6,671	4.68
Spring Eggplant	Mar. 1	150	400	47,312	10,731	4.41
Fall Lettuce	Oct. 1	90	400	41,901	1,677	24.98
Winter Lettuce	Dec. 1	80	400	41,901	1,725	24.29
Okra	June 1	90	400	49,744	6,774	7.34
Onions	Sept. 1	200	3,663	369,505	59,963	6.16
Potatoes	Jan. 1	140	805	38,407	11,082	3.47
Spring Squash	Jan. 1	90	400	38,228	2,321	16.47
Fall Squash	Oct. 1	90	400	38,228	2,283	16.75
Spring Tomatoes	Jan. 1	150	400	64,678	7,481	8.65
Fall Tomatoes	Aug. 1	150	400	64,678	6,472	9.99
Annual Total			16,255	988,571	266,325	

[a] The date palm activity is forced into the solution at a minimum area of 4,100 hectares.

represents the most efficient overall use of water, land, management, and irrigation and drainage facilities within the project area under the specified assumptions and conditions. Although resources, activities, and net returns may slightly vary without affecting the optimum crop mix, marked deviations from this plan without corresponding changes in the underlying set of conditions and assumptions would result in less than maximum net revenue forthcoming from the use of the limited resources in the oasis.

As would be expected, high-return crops entered the solution at their maximum allowable levels. Sufficient land and water resources are available to permit cauliflower, cucumber, eggplant, lettuce, okra, squash, and tomatoes to be grown in areas up to the constraint level. Dates, on the other hand, came into the solution only at the minimum required level. In fact, the computer output specifies that increasing the area under date palms by one hectare, ceteris paribus, would reduce the objective function by 92,450 riyals. This could be construed as a manifestation of the relative low profitability of date cultivation in the study area.

Onions and wheat entered the final solution as the dominant non-constrained crops, with 3,663 and 2,656 hectares respectively. The dominating position of these two crops indicates an economically sound development target which is consistent with both objectives of maximizing net returns from Al-Hasa Irrigation and Drainage Project and minimizing the country's dependence on outside sources for basic foodstuffs. Other crops, particularly potatoes, oats and millet, came into the solution in areas greatly exceeding their present levels but were limited at the margin by the water constraint.

Crops that were included in the model but have been left out of the optimal plan because of their relatively low profitability are presented in Table 10. A comparison between the Assumed Net Return and the Required Net Return columns provides explanation for excluding these crops from the final solution. While the former merely repeats the programmed per hectare net return for each crop, the latter states the minimum net revenue that a hectare of a given crop must be able to generate in order for it to come into the solution without reducing the value of the objective function. The difference between corresponding elements of the two columns indicates the magnitude of income penalty for (income foregone by) forcing one hectare of the prospective crop into the final plan. The range within which these stipulated differences are valid is defined in the last column. The implicit product price converts the required per hectare net return to product prices using the yield and variable cost figures specified in Table 7. This is the required price of the product in order for it to come into the optimal solution.

As indicated by the optimal plan, production and sale of alfalfa in the project area is not among the most profitable enterprises. For alfalfa to compete for land and water resources against the high-return crops, it must be capable of generating a per hectare net revenue of 171,828 riyals, or 132,446 riyals over its programmed annual net return (Table 10). It should be pointed out, however, that alfalfa's possible contribution to soil fertility was not accounted for in assessing its income-generating potential. Its long term profitability may, therefore, have been underestimated.

Table 10. Programmed Crops Excluded from the Optimal Production Plan for Al-Hasa Irrigation and Drainage Project

Crop	Planting Date	Growing Period (Days)	Assumed Net Return (Rls/ha)	Required Net Return (Rls/ha)	Implicit Product Price Rls/ton	Valid Range (Ha)
Alfalfa	Perennial	---	39,382	171,828	5,086[a]	0-74
Barley (grain)	Nov. 1	120	10,788	18,381	2,607	0-2656
Hasawi Rice	July 1	110	24,107	156,683	44,144	0-162
NTU Rice (Spring)	Mar. 1	120	9,735	46,494	7,223	0-72
NTU Rice (Summer)	July 25	110	7,740	156,683	31,255	0-162
Sweet Corn (Spring)	Jan.	90	34,942	95,510	5,887	0-400
Sweet Corn (Fall)	Sept. 1	90	40,442	108,414	6,747	0-400
Sugar Beets	Nov. 1	195	28,493	59,781	569[b]	0-797
Cabbage	Sept. 1	120	92,476	123,325	2,895	0-400
Cantaloupe	Mar. 1	120	31,634	77,970	4,807	0-337
Carrots	Aug. 21	120	48,946	152,850	6,668	0-400
Cucumber (Fall)	Sept. 1	120	81,470	118,913	4,515	0-400
Eggplant (Fall)	July 1	150	118,281	196,921	4,630	0-400
Radish (Fall)	Oct. 1	60	40,509	54,521	2,502	0-400
Radish (Winter)	Jan. 1	60	40,509	66,408	3,096	0-351
Watermelon (Spring)	Mar. 1	140	37,841	82,153	3,870	0-400
Watermelon (Fall)	Aug. 1	140	37,841	136,274	6,422	0-400

[a] Riyals per ton of dry matter.

[b] Riyals per ton of fresh roots.

Increased investments in dairying and sheep fattening farms in and around the oasis are expected to increase the demand for, thus the net returns from, forage crops grown in the project area. However, seasonal fodder crops, such as millet, sorghum, maize, oats, wheat, and barley seem to be more profitable than alfalfa. Adaptability of these seasonal fodder crops to existing conditions in the oasis has already been demonstrated by agronomists at the Hofuf Agricultural Research Center.

Land and Water Use

Land and water utilization by the optimized production plan during the 12 monthly periods is outlined in Table 11. As may be noted from the table, the total area utilized by the plan in any single month falls short of the land area limitation imposed on the model. Thus, the constraint placed on the total cultivable land available to the program does not seem to be limiting under the present water supply conditions. More land could conceivably be brought into cultivation, hence more income generated, if additional water would be made available to the program during the water-deficit months.

The table shows that all available water is used up by the program during February, March, May, July, September, and December, while varying amounts of water are left unused during the other six months. According to the table, the peak demand for irrigation water occurs in September when a shadow price of 22.5 riyals per cubic meter is indicated. The Shadow Price column denotes the marginal value product or reduction in total net returns associated with reducing the amount of irrigation water available to the program by one cubic meter. When available irrigation water is not fully utilized, it has a zero shadow price.

Table 11. Monthly Land and Water Use by the Optimal Production Plan for Al-Hasa Irrigation and Drainage Project

	Land Use		Irrigation Water		
Monthly Period	Cropped Land (Ha)	Fallow Land (Ha)	Plan Requirement (1000 M^3)	Surplus (1000 M^3)	Shadow Price Rls/M^3
January	13,383	3,017	20,847.5	2,620.5	---
February	12,825	3,575	23,468	---	4.46
March	12,825	3,575	23,468	---	9.30
April	6,181	10,219	17,317.1	6,150.9	---
May	6,181	10,219	23,468	---	0.97
June	5,712	10,628	23,071.1	396.9	---
July	5,372	11,028	23,468	---	1.26
August	5,296	11,104	21,927.2	1,540.8	---
September	8,163	8,237	23,468	---	22.52
October	9,522	6,878	22,031.6	1,436.4	---
November	12,579	3,821	21,843.3	2,183.7	---
December	12,979	3,421	23,468	---	5.48

The above pattern of land and water use pertains to the optimum production plan outlined in Table 9. As has already been pointed out, the plan is synthesized from the various ingredients specified in Tables 6, 7, and 8. Changes in those ingredients are likely to bring about corresponding changes in the plan with the attendant modifications in the pattern of land and water use in the project area.

Effect of Traditional Date Palms on Net Returns and Crop Mix

Parametric programming was used to estimate the effect of date palm restriction on total net returns and optimum crop mix. This was done by reducing the area devoted to date cultivation by increments of

200 hectares to a minimum of 1,500 hectares and optimizing the model after each increment. The response of total net return to successive reductions in date palm restriction is traced in Table 12, along with the resulting major changes in the optimum crop mix. As indicated in the table, there is an inverse relationship between the area under date palms and the value of the objective function. Total net returns continue to increase, though at a declining rate, with successive reductions in date hectareage throughout the specified range. There seems to be a trade-off between the total area devoted to date production and the feasible total net returns. This apparent relationship is illustrated in Figure 5. It should be emphasized, however, that this inverse relationship is associated with the traditional date cultivation practices currently prevailing in the project area. Improved cultivation practices, including wider spacing and varietal selection, could raise the profitability of the date enterprise, thus enabling it to positively influence the magnitude of total net returns.

It should be pointed out, nevertheless, that the accounting cost of reducing the date palm population in the project area has not been accounted for in the present analysis. Ideally, the cost of uprooting the palm trees and removing them from the field as well as the cost of land preparation should be calculated and charged (on an annual basis) to the alternative crop enterprises if net returns in the project area are to be maximized. But this has not been attempted in the analysis, owing mainly to lack of reliable estimates. It is very likely, however, that the net revenue increase resulting from the corresponding decrease in total area devoted to date production will exceed the total cost outlays required for tree uprooting and hauling and for the subsequent land preparation.

Table 12. Effect of Reducing the Area Under Date Cultivation on Total Net Returns and Optimum Crop Mix for Al-Hasa Irrigation and Drainage Project

Area Under Date Palms (Ha)	Total Net Returns (1,000 Rls)	Total Net Return Increase[a] (1,000 Rls)	Area Under Millet (Ha)	Area Under Wheat (Ha)	Area Under Sorghum (Ha)	Area Under Onions (Ha)
4,100	988,613	--	396	2,656	76	3,663
3,900	1,007,303	18,690	439	2,483	190	2,894
3,700	1,025,480	18,171	522	2,311	232	4,125
3,500	1,042,543	17,063	604	2,138	275	4,356
3,300	1,057,233	14,690	686	1,965	317	4,587
3,100	1,071,923	14,690	769	1,792	360	4,818
2,900	1,086,613	14,690	851	1,619	403	5,049
2,700	1,101,303	14,690	933	1,447	445	5,280
2,500	1,111,808	10,505	1,016	1,388	488	5,398
2,300	1,122,124	10,316	1,098	1,335	530	5,512
2,100	1,132,446	10,322	1,180	1,282	573	5,626
1,900	1,142,768	10,322	1,263	1,228	616	5,739
1,700	1,153,090	10,322	1,345	1,175	658	5,853
1,500	1,163,412	10,322	1,427	1,122	701	5,967

[a] Attributed to the last 200-hectare decrement in area under date palms.

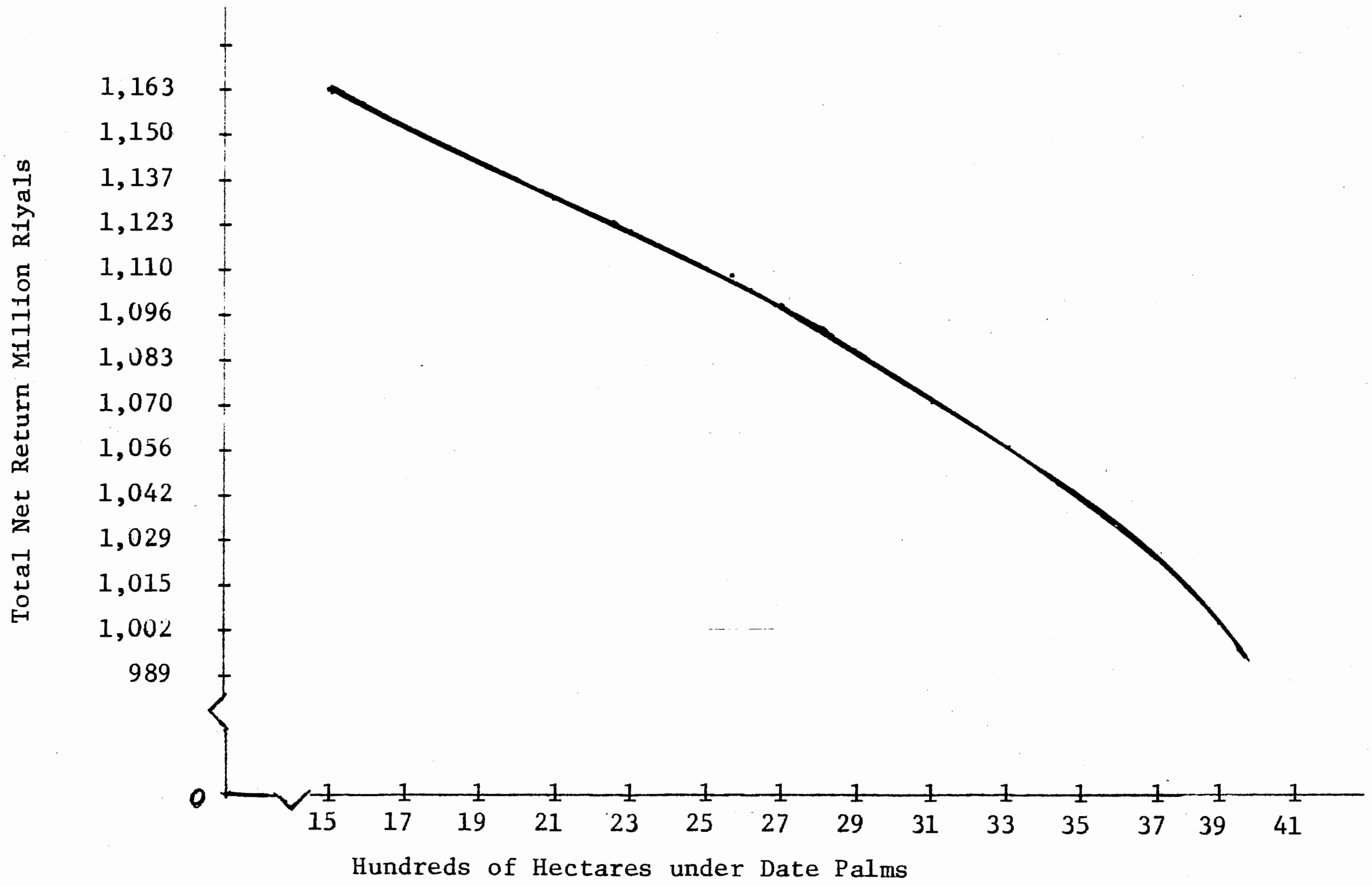

Figure 5. Effect of Area Devoted to Traditional Date Production on Feasible Total Net Revenue, Al-Hasa Irrigation and Drainage Project

The land and water released by dates are used by three main crops: millet (forage), sorghum (grain), and onions. Successive reductions in date planting result in corresponding increments in the levels at which these crops enter the solution. This indicates that there is a competitive relationship between the traditional date enterprise and each of the three crops. On the other hand, the area devoted to wheat production decreases with subsequent reductions in the area under date palms, implying a complementary relationship between the two crops.

Demand Function for Additional Water

When presenting the optimized solution for the model, it was pointed out that water shortage during six months of the year was responsible for limiting the total irrigated land within the project area. Hence, it was intuitively assumed that availability of additional water during those critical months would make it possible to bring more land into cultivation, thus increasing total net returns to land, management, and irrigation and drainage facilities. The sensitivity of the model to possible additional water supplies is tested here with the use of parametric or variable resource programming. The test involves extending the water constraints by increments of 5, 10, 15, and 20 percent, subsequently optimizing the model at each increment. Gross water requirements are held at their original levels, indicating that no changes along the production functions for the various crop activities or in the project irrigation efficiency were contemplated. To keep the solution within the sphere of realism, the area devoted to onions was limited to 3670 hectares.

Table 13, derived from data given in the programming output, shows the shadow prices or marginal value products for additional water and

Table 13. Marginal Value Product of Additional Water and Resulting Total Net Returns for Al-Hasa Irrigation and Drainage Project[a]

	Initial Water Supply (23,468,000 M^3 per Month)	5% Increase In Water Supply (24,641,400 M^3 per Month)	10% Increase In Water Supply (25,814,800 M^3 per Month)	15% Increase In Water Supply (26,988,200 M^3 per Month)	20% Increase In Water Supply (28,161,600 M^3 per Month)
Critical Month	MVP of Water (Rls/M^3)	MVP of Water (Rls/M^3)	MVP of Water (Rls/M^3)	MVP of Water (Rls/M^3)	MVP of Water (Rls/M^3)
February	4.46	4.46	4.46	4.46	4.17
March	9.30	9.17	9.17	9.17	6.34
May	0.97	1.25	1.25	1.25	1.25
July	1.26	1.40	1.40	1.40	1.40
September	22.52	8.97	8.97	3.13	3.13
December	5.48	5.48	5.48	5.48	--
Average	7.33	5.12	5.12	4.15	3.26
Total Net Revenue[b]	988,052	1,026,909	1,062,976	1,098,349	1,126,866
% Increase in Net Revenue	--	3.93	7.58	11.16	14.05

[a] The effect of additional increments of water beyond the 20 percent level was not analyzed.

[b] Thousand riyals.

the proportional increases in net revenue under the several incremental changes assumed. Each shadow price figure represents the maximum price a farmer can afford to pay per cubic meter of additional water at each water supply level. As can be observed from the table, response of marginal value product of water to changes in water supply level is different for the different months. On the average, however, the marginal value product of additional water declines but remains positive throughout the specified range. No sensitivity analysis was carried out beyond the 20 percent incremental level. Nevertheless, the different marginal value product levels shown in the table provide the basis for developing a short run demand function for additional water up to this point.

The derived demand function for additional water supply for Al-Hasa Irrigation and Drainage Project is graphically depicted in Figure 6. In general, the linear segments of the function provide an empirical approximation to a continuous curve sloping downward and to the right. When water supply is relatively limited, priority is normally given to those crops yielding the highest marginal net returns per unit of water added. As water availability increases, the more water intensive, lower return crops enter the solution, thus bringing about the decreased marginal value product of water.

In considering alternatives for expanding the total cultivated land within the project area, an important economic criterion should be kept in sight. Before it would be profitable to tap any of the new sources, the unit cost of developing and delivering additional water to farmers in the study area has to be less than its marginal value product. In

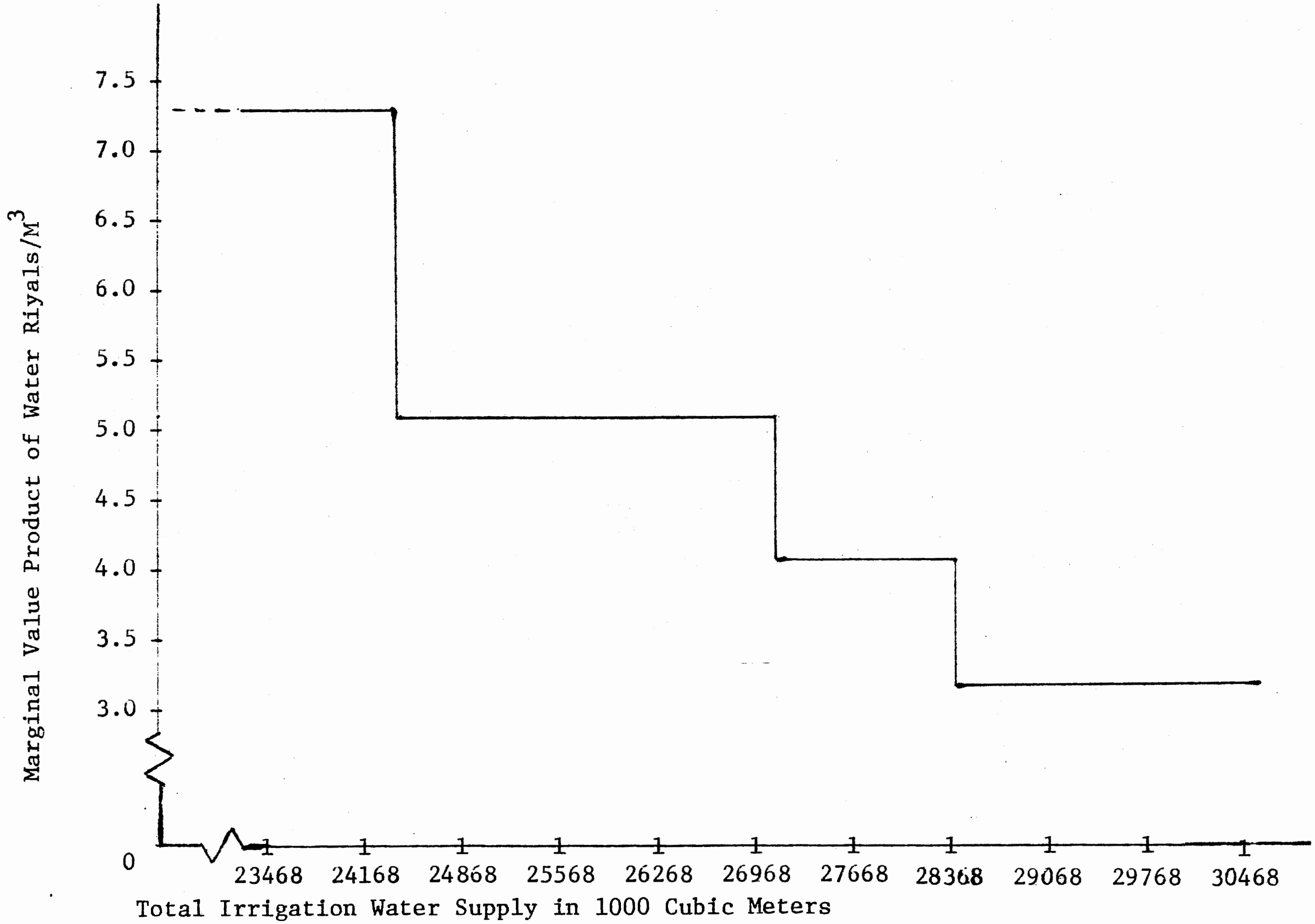

Figure 6. Short Run Demand Function for Additional Irrigation Water, Al-Hasa Irrigation and Drainage Project

other words, the income-generating potential of the additional water should exceed its average total cost.

CHAPTER VI

SYNTHESIS OF POLICIES AND MANAGEMENT GUIDELINES FOR AL-HASA IRRIGATION AND DRAINAGE PROJECT

The overall objective of this chapter is to synthesize long term policies and management guidelines needed for optimal utilization of scarce resources in Al-Hasa Irrigation and Drainage Project. These policies and guidelines should be actively pursued and gradually implemented if the goal of maximizing net returns to agricultural resources in the project area is to be attained. The material in the chapter essentially relates to modifying the present cropping pattern and enhancing the efficiency with which production inputs, particularly water, are utilized. It also pertains to diffusing modern farming techniques, making more effective use of financial production incentives, and improving factor and product markets. The material is also related to promoting the introduction of some basic institutional changes that would facilitate the application of more economically oriented criteria to allocating and managing productive resources in the project area.

The policies and guidelines recommendations outlined here have resulted from a thorough analysis of circumstances existing in the study area and conditions that should exist if net returns are to be maximized. They are geared mainly to realizing some of the long term objectives specified for the agricultural sector in both the Saudi Arabian Agricultural Policy and the Third Development Plan. Furthermore, these policies and guidelines are more or less indicative of the potential for transforming agriculture in the oasis through finding imaginative but practical ways of dealing with the prevailing problems.

Policies on Cropping Patterns

To improve resource utilization in the project area, emphasis should generally be placed on crop selection, application of proper farm management practices, efficient use of scarce inputs, increasing crop yields, and reducing unit production costs. Since the scope for agricultural development in the project area is particularly determined by the availability of irrigation water, optimum use should be made of the limited water supplies. This calls for a cropping pattern that would maximize net returns per unit of irrigation water, so far as technical, institutional, and economic conditions permit. While ultimately the decision as to what cropping pattern should be promoted in the oasis may be based on criteria other than that of economic efficiency, the opportunity cost of water as measured by its potential value in alternative crops must enter any rational decision regarding the use of the limited water supplies.

The crop production plan suggested by the linear programming model (Table 9) for Al-Hasa Irrigation and Drainage Project is capable of maximizing net returns per unit of water under the specified set of assumptions and conditions. It is in sharp contrast to the actual cropping pattern outlined in Table 2. Comparison between the two tables underlines the need for inducing marked changes in the present cropping pattern to make it compatible with the objective of maximizing total net returns to scarce resources in the project area. Policies for bringing about such changes need to be strong enough to overcome the centuries-old inertia of continuing to grow traditional crops using traditional methods.

As indicated by the results of the linear programming model, maximizing net farm returns in the project area requires making several adjustments in the existing agricultural production pattern. Such adjustments should include, but are not necessarily limited to: (1) reducing the total area under traditional date palms; (2) abandoning rice cultivation; (3) increasing the production of both summer and winter vegetables; (4) incorporating some strategic field crops especially wheat, onions, and potatoes into the production plan; and (5) replacing the perennial alfalfa crop with seasonal, fast growing forage crops such as millet, maize, oats, wheat, and barley. Since such changes are not likely to occur voluntarily in the short run, some government initiative is needed to evoke them. Such initiative may be pursued along the following policy guidelines.

Reducing Date Palm Population

As had already been pointed out, date palms occupy over 68 percent of the total irrigated land in the study area. Official estimates indicate the existence of about 1.5 million date palm trees of which no less than 18 percent are considered practically unproductive, mainly because they are in the die-back stage. When properly spaced, the trees may be profitably intercropped with other perennial or seasonal crops. However, most of the date palms in the project area are spaced too close to allow sufficient sun light to reach potential companion crops. Therefore, it is recommended that a practical program be implemented for uprooting all date palms that have outlived their economic usefulness. This should include date palms that, due to old age or varietal inferiority, are not capable of generating sufficient revenue to cover the cost of their upkeep. If adequately carried out, such a thinning process would make it economically feasible to intercrop the remaining palms with high return crops, particularly vegetables, consequently increasing net returns to water, land and management resources in the study area.

To gain support for the uprooting program, farmers should be compensated for income losses, actual or imaginary, that could result from date palm removal. Therefore, it is strongly recommended that an uprooting premium be established and that payment procedures be clearly defined and made known to potential participants. The amount to be paid per uprooted tree should be based on the economic as well as the esthetic value of the tree as viewed from the farmer's vantage point. As an added incentive for participation in the program, the project management should provide free uprooting service.

The cost of date palm uprooting program should be paid from public funds as it constitutes an integral part of the total public investment in the project. As was indicated by the results of the parametric programming (Table 12), the cost will be compensated, at the macro level, by the expected increase in total net returns resulting from reducing the date palms' share of the total cultivated area.

Increasing Vegetable Production

Climatic conditions in the study area allow growing of crops the year around and particularly favor the cultivation of high return specialty crops such as winter vegetables. In addition, the oasis is conveniently located with respect to four major consumption centers: Riyadh, Dammam, Jubail, and Doha, where there is a perennial shortage of, and where premium prices are paid for, fresh vegetables. But despite this advantageous position, the volume of vegetable production is still relatively insignificant, as is apparent from Table 2.

The detailed crop budgets (Appendix A) indicate that vegetables generally generate higher per hectare net returns than the other crop categories. Also, as a group, vegetables enter the linear programming solution at the maximum level allowed, a reinforcement of their relatively high profitability. This means that if total net farm returns in the project area are to be maximized, more vegetables should be incorporated into the production plan. Therefore, it is recommended that a vegetable production program be implemented in the project area. Such a program should be aimed at making better utilization of available research results, intensifying extension efforts, and improving the marketing system.

While the data in Table 9 specify some vegetables that can be produced profitably in the project area, the final decision on crop selection and volume of production should be based on a more refined assessment of potential demand and Al-Hasa share of the fresh vegetable market in the main consumption centers. The feasibility of establishing a vegetable processing industry in the study area should also be considered. Emphasis in crop selection must ultimately be based on the relative advantage enjoyed by the study area in the production of certain vegetables during specific seasons.

Since vegetable production in the study area during the summer months is constrained by the prevailing high temperatures, emphasis should be placed on introducing more heat-tolerant vegetable varieties into the project area. This will not only increase the range of choices available to the project farmers but will also relieve the frequent shortage of fresh vegetables in the local markets during the hot summer months. In selecting such varieties, use could be made of the experiences of other arid countries as well as the results of research conducted by resident research teams, international institutions, and major seed companies.

Expansion of vegetable production in Al-Hasa should, nevertheless, be promoted with extreme care, as the Hasawi farmers must compete with producers from other regions. The comparatively favorable position of the Hasawi vegetable producers is likely to be endangered in the long run by optimizing the use of the various irrigation projects in and outside the Eastern Province, such as Haradh and Wadi Dawasir projects, and by the rapid improvement of the Kingdom's transportation and marketing systems.

It should be pointed out, however, that vegetable production in Al-Hasa can not be realistically determined in isolation from vegetable production in other regions. The subject of regional specialization of agricultural production in the Kingdom should be extensively studied to find adequate guidelines for optimized regional agricultural development programs. Future industrialization, which can already be seen within the proposed establishment of new basic industries in various parts of the country, will undoubtedly alter the traditional production pattern and marketing channels. The study may also reveal specific insights into the comparative advantage of Al-Hasa oasis. It is conceivable that in the future the oasis might concentrate on the production of high-return vegetables and thus gradually phase out date and forage production.

Seasonal Forage Crops

Alfalfa is the dominant forage crop grown in the study area at the present time. Its dominance has apparently been perpetuated by tradition rather than by economic forces. The crop is, indeed, well suited for ecological conditions in the oasis, but its profitability relative to other forage crops is still questionable. Agronomists at Hofuf Agricultural Research Center have clearly demonstrated the adaptability of a number of forage crops to existing conditions in the study area. Furthermore, results of the linear programming model indicate that seasonal forage crops are more profitable than alfalfa. It is, therefore, recommended that the production of seasonal forage crops be promoted and expanded in the project area. The expansion should be gradual, depending largely on the experience gained and the ability of the extension officers to convince reluctant and tradition-bound farmers to try new crops.

Promoting the production of seasonal forage crops in Al-Hasa is actually consistent with the policy actively pursued by the Government for increasing domestic dairy and meat production. It is also in accordance with the objective of maximizing total net farm return in the project area. Thus, diverting some of the generous subsidies currently being paid on imported animal feed to enhancing forage production in the study area is fully justified.

It is believed that feed and forage crops which may be produced in the project area in the immediate future can be profitably marketed to nomadic stockmen and to dairy and confined sheep-growing enterprises in and outside the oasis. However, this will require a modification of the methods of harvesting and marketing the fodder crops. The crops should be cut, cured, and stored or marketed in pelleted or baled form to be used when needed. But achieving such adjustments will entail some action on the part of the Government, possibly in the form of guaranteed prices and an organized marketing system. It would be advisable to make a careful analysis of the fodder hay market, including the feasibility of cooperative processing and marketing by producers.

Strategic Field Crops

Climatic and economic conditions in the project area favor increased production of a few strategic field crops which are heavily imported into the country, especially wheat, onions, and potatoes. These particular crops lend themselves to mechanized production and to storage and long distance hauling with minimum loss in quality or value. In addition, they are highly profitable, as indicated by the optimized linear programming solution (Table 9). A special program is needed to foster the production of these crops in the project area. Such a program is consistent with both long term objectives of reducing the country's dependence on foreign food sources and maximizing total net farm revenue in the project area. The program should initially provide proper incentives and adequate extension service for participating farmers. Potential participants should also be made fully aware of the profitability and the proper cultivation methods of these crops.

Industrial Crops

The above conclusions dealing with the profitability of some vegetable, field, and forage crops should not be taken as a final judgement on the economics of industrial crops. Some industrial crops such as safflower and sunflower are adaptable to growing conditions in the study area and may prove to be highly profitable under the presence of adequate processing facilities. At the present time, the Kingdom is a heavy importer of edible fats and oils which receive an import subsidy from the government. A careful review of the market may reveal an economically attractive opportunity to construct the necessary processing plant and to encourage Hasawi farmers to grow sufficient quantities of such crops to make the entire operation practical. Hence, it is recommended that the economic feasibility of growing specific industrial crops in the project area be evaluated.

Policies on Water Management

Although water is only one of several production factors, it is the major limiting resource for expanding agricultural production in the study area. As the demand for water in agricultural, industrial, and municipal uses continues to grow in the oasis, the efficient use of scarce water resources becomes more imperative. More concern should thus be devoted to measures aimed at improving the efficiency with which available water supplies are used. Even though the management of water resources in the study area includes a range of problems far too broad to be treated comprehensively in the present analysis, some water management policy guidelines are outlined below.

Improved Irrigation Efficiency

Irrigation efficiency may be enhanced by reducing evaporative and deep percolation losses which occur normally in the process of water conveyance and application. Due to the predominance of high temperatures, dry winds, and low relative humidity, a considerable amount of irrigation water is lost through evaporation from open canals and irrigated fields, particularly during the summer months. To minimize such losses, the project management should emphasize evaporation-reducing practices such as irrigating at night or during the late afternoon hours, using mulches on irrigated soils, and establishing wind breaks. The economic feasibility of controlling evaporation losses by covering irrigation canals should also be considered.

Three main factors contribute to percolation losses: excessive irrigation, inadequate land leveling, and unlined irrigation ditches within the fields. Increasing the irrigation efficiency requires minimizing the adverse effects of each of these factors.

To overcome the tendency among the majority of farmers to over irrigate, specific measures must be taken by the project management. One recommendation is to establish an official set of gross water requirements per hectare for the various crops grown in the project area. These figures should then serve as upper limits on the quantities of water made available to farmers. Monitoring and controlling water deliveries should eventually discourage excessive application of irrigation water.

The flood irrigation method presently used in the project area requires adequate land leveling. Land leveling is an important water management practice that must be encouraged and promoted if water use efficiency is to be increased. Hence, the project management should persuade farmers to invest in leveling their fields. In the extreme case, availability of water could be tied to implementing adequate land leveling.

Due to the predominantly sandy texture of the soil, much water is lost to percolation during conveyance through unlined earth ditches within the fields. To minimize this loss, farmers should be encouraged to line their field irrigation canals with concrete, plastic foil or other recommended materials. Such lining should gradually be mandated, as it is the least that the project farmers would be expected to do to share the cost of water distribution. Their peers in other locations already bear a major share of the cost of drilling, pumping, and distribution of irrigation water.

Since reducing percolation losses from field distribution ditches could have a marked impact on the overall water use efficiency, the project management should become actively involved in improvising ways to control these losses. The management is indeed capable of doing so, as it owns the plant which was used to cast the pre-fabricated, reinforced concrete sections for the irrigation network during the construction phase of the project. The plant, which is currently idle, could be used to make small canal sections that would be sold to farmers at nominal prices. The cost of the operation should be considered part of the overall public investment in the project. This is consistent with the government's present policy of subsidizing well drilling, land leveling, and construction of modern irrigation systems on newly reclaimed agricultural lands.

Water use efficiency may also be influenced by the type of irrigation method employed. The basin flood irrigation, which is widely used in the study area, is generally less efficient than some other surface irrigation techniques, particularly border-strip and furrow irrigation. Results of water management research at Hofuf Agricultural Research Center have indicated the suitability of both the border-strip and the furrow irrigation methods to soil and water conditions in Al-Hasa. Besides water conservation, the advantages of these two irrigation techniques include low labor requirements, efficient use of machinery, and suitability to a wide range of crops (61, p. 3). Therefore, the project management should encourage farmers to replace basin irrigation by furrow and border-strip methods.

Water User Charges

Individual exercise of traditional water rights in the project area is limited only by the vague rule of reasonably beneficial use and is often contingent on customary levels of water application. Generally, farmers holding traditional water rights tend to over-irrigate. The absence of any charges for the amount of water used encourages them to use irrigation water in quantities that may reduce its marginal value product to zero. Their collective actions are likely to exhaust the limited water supply, leaving little or no water that may be used more profitably on other farms, and consequently reducing the average net returns from water in the oasis.

Since the marginal productivity of water on over-irrigated farms is lower than on farms facing water shortages, the overall economic efficiency of the project will be enhanced by curtailment of excessive use of water. Institutional arrangements should, therefore, be made to provide farmers with a real incentive to avoid wasteful use of water. This may be achieved by imposing a unit price on irrigation water delivered to individual farms. Farmers, acting in their self interest in an effort to maximize net returns, should react to such a price by economizing on water use. They ultimately could be discouraged from using water on their fields that would produce more in terms of additional output on other fields.

Water pricing may also stimulate changes in cropping patterns. In arid environs the situation is such that when the cost of irrigation water increases, ceteris paribus, farmers would eventually adjust their cropping patterns by decreasing areas of the crops that demand more water and emphasizing crops with relatively low total water requirements. Also, creating a water market is likely to facilitate water transfers from uses of low value productivity to uses of higher value productivity.

Water pricing in the study area entails modifying some cultural attitudes toward the sale of public water for agricultural purposes. Philosophical and social concepts and viewpoints, as well as economics, are involved in the overall question of water pricing. This study does not undertake to deal with these issues. It must be pointed out, nonetheless, that Islamic law, which regulates public and private actions in Saudi Arabia, clearly recognizes that water resources which have not been privately acquired through inheritance, purchase, or investment in the networks and facilities are public property. This applies to the springs feeding Al-Hasa Irrigation and Drainage Project. Thus, the government--acting on behalf of the community--is fully responsible for allocating the water from these springs among potential users so that the community welfare will be maximized. Imposing a water user charge as a means of discouraging misuse and raising funds for the operation and maintenance of the facilities is, indeed, consistent with, and may even be obliged by, the intent of the Islamic law.

It would be naive to recommend outright that a specific irrigation fee per unit of water be collected. On purely theoretical grounds, the fee should be sufficient to cover both the outlay required for operation and maintenance of the project and the imputed cost of depreciation and interest on the capital investment. However, charging such a high price is neither realistic nor in accordance with the government's policy of minimizing domestic farm production costs. To be practical and equitable, water charges should be based on the payment capacity or the shadow price of water and related to the annual cost of operation and maintenance of the project. The cost of obtaining water from an alternative source is also helpful in determining water charges. For instance, some farmers within the project area obtain irrigation water from their private wells using their own pumps. The average cost incurred by these farmers, including the cost of well drilling and of acquisition, installation, operation, and maintenance of the pump, could serve as a guideline for setting the unit price that users of the project water must pay.

Policies on the Use of Modern Inputs

Improvements in water management are necessary but not sufficient for optimum use of resources in the study area. These improvements can be beneficial only if introduced as part of a package of improved high-yielding technology that would increase total output per unit of water. Equal emphasis must, therefore, be placed on achieving adequate and effective use of modern farm inputs, particularly chemical fertilizers, pesticides, machinery, and improved seeds. Such emphasis is imperative for realizing the optimal production plan discussed earlier. Accordingly, the following policy guidelines are offered.

Chemical Fertilizers

Reliable data on fertilizer application at the regional level are not available at the present time. However, there seems to be a general agreement among knowledgeable people that the current use of chemical fertilizers in the study area is simply inadequate. Moreover, there are strong indications that the majority of the project farmers have very little knowledge of the various types of fertilizers available and the proper methods, rates and timing of their application to the different crops (26, p. 12). Thus, while some cultivators may be using too much fertilizer others may be using too little, and the majority could be applying the least effective type or using improper timing of applications.

Because Al-Hasa soils generally lack sufficient organic matter and other nutritive materials needed for plant growth, timely application of proper types and quantities of chemical fertilizers is essential for obtaining good crop yields in the project area. Consequently, the project management should make serious efforts to remove major impediments to increased and more efficient application of chemical fertilizers. The management should also promote the adoption of certain farm management practices aimed at improving the fertility and organic matter content of the soil in the long run. Typical among such practices are the use of green-manures and rotations with leguminous forage crops.

The use of a chemical fertilizer is usually influenced by its availability and cost in addition to the farmers' awareness of its potential profitability and their willingness and ability to invest in its use. It is doubtful that the cost, availability and farmers' financial capability considerations constitute real obstacles to increased use of chemical fertilizers. The fertilizers are heavily subsidized by the government and are, by and large, available at several retail outlets which are easily accessible to farm operators. Moreover, their purchase may be financed with interest-free, short-term loans from the Saudi Arabian Agricultural Development Bank. To make the fertilizers more readily available to the project farmers at reduced costs, the project management should, nevertheless, encourage and assist farm cooperatives to get more involved in the procurement and distribution of the proper types and quantities of chemical fertilizers.

Perhaps the main obstacle to a wider application of chemical fertilizers in the project area is the low utility attached to their use by most farmers. Chemical fertilizers are a relatively new innovation that is still viewed with considerable apprehension by the majority of farmers who generally lack adequate knowledge concerning its optimal use and potential benefits. The project management is thus faced with the difficult task of making farmers more willing to avail themselves of the profit opportunities offered by the use of this vital input. This requires: (1) determining, in cooperation with research workers, the types of chemical fertilizers most suitable for the various crop categories under existing conditions in the oasis, along with the optimal quantities and times of applications; and (2) expanding the extension services to teach farmers, through demonstration, the optimal use of fertilizers in accordance with their cropping patterns.

Plant Protection

Al-Hasa irrigated crops, because of their spatially intensive production patterns, are highly susceptible to insect and disease infestation. Serious outbreaks of plant pests and diseases are common in the study area, and their quick multiplication and spreading, due to favorable physical conditions, make them more devastating. Since most farmers generally lack both the knowledge to detect and the means to prevent these pests and diseases, their regular incidence often clouds agricultural production in the oasis with discouraging uncertainty.

The project area is also infested with a host of weeds that strongly compete with cultivated plants for land, water, and nutrients. Control of weeds is essential for obtaining acceptable crop yields. At the present time, farmers totally rely on human labor for weed control. But hand weeding is a time consuming operation that usually inflates production cost and depletes the farm labor supply.

Significant research efforts have been devoted to plant protection in the study area over the last five years. Consequently, the major crop diseases and pests have been clearly identified and measures for their control have been prescribed. If properly implemented, such measures would be instrumental in minimizing crop damages, reducing production costs, and ultimately increasing net farm revenues. However, it is generally recognized that many farmers in the study area still lack the necessary know-how regarding the use of chemical pesticides, unnecessarily increasing the production cost or even creating potential health hazards to consumers through improper doses, methods, and timing of application (62, p. 21). Meanwhile many others seem to be unaware of the potential gains that could be reaped from the use of these modern innovations.

Use of basic production inputs, such as water, fertilizers, and improved seeds, would be more financially rewarding if supplemented with adequate crop protection measures. Although conclusive economic data are not available, it is widely believed that returns from the use of chemical pesticides in the study area are high and that expanded use of pesticides could result in increased net farm returns. Therefore, the project management should develop and implement an integrated pest control program that would translate research results and subsequent recommendations into a practical plan of action. The program should be educational in nature and should promote use of chemical pesticides. It should particularly emphasize the use of chemical herbicides and mechanical power as means of controlling weeds at reduced costs.

In preparing and implementing the pest control program, potential adverse effects of chemical pesticides should be noted. Precautions must be taken to protect human and animal health and to minimize harmful ecological effects associated with repeated use of chemical pesticides.

Farm Machinery

Farm machinery has not found wide use in the study area. The existence of government subsidies and the availability of interest-free financing by the Agricultural Bank have enabled some farmers to purchase tractors which they occasionally use to work their own lands or to provide custom service to other farmers. These tractors are large (60-80 HP), generally having much more capacity than can be efficiently utilized by the average size farm. Although the tractors are capable of performing numerous tasks around the farm if proper attachments are available, their present use is practically limited to rough land leveling, plowing, ridging, and disking. Their utilization hours per year are, thus, quite limited (63, p. 18).

Labban (19, p. 12) has outlined the main problems that have deterred introduction and widespread use of mechanical technology in the study area. These problems include the following: (1) most farms in the oasis are too small to justify ownership of relatively large tractors and farm equipment; (2) irrigation and drainage layouts break farms into many small individual fields for which a large tractor is completely unsuited; (3) small tractors, which may easily be adaptable to farm shapes and sizes, are not among those imported and promoted by local suppliers; and (4) there is an acute shortage of technicians who can teach farmers how to use, maintain, and service farm machinery and equipment.

Intuitively, the above obstacles could be alleviated if the size and type of equipment were adjusted to suit the limited sizes and the irregular shapes of small farms. This could probably be achieved by promoting the use of small tractors which are especially designed to serve small plots. When provided with the proper attachments and accessories, such tractors can supply small farmers with sufficient power for land preparation, seeding, fertilizer application, pest control, and even harvesting the crop. Researchers at the Hofuf Agricultural Research Center have adequately demonstrated the adaptability, effectiveness, and economic viability of these tractors. In addition the actual cost of such tractors is in line with the level of income attainable by small farms.

The importance of the role of mechanization in the process of transforming Al-Hasa agriculture cannot be overstated. Adequate substitution of mechanical power for the generally less productive human labor is basic to raising farm productivity and net revenue in the project area. Proper use of machinery will normally reduce production cost and allow timely execution of the various complementary farm operations with minimum labor requirements, making it possible to expand cultivated area using only available farm labor. The project management should, therefore, give top priority to promoting and facilitating a more widespread use of agricultural machinery in the project area.

Since small machines have a good potential for mitigating the problem of inadequate use of mechanical technology in the oasis, the project management should make strong efforts to expand the demand for, and insure the availability of small tractors and their complementary attachments. As an initial step, the management should arrange for the purchase of small tractors recommended by research workers, along with the essential attachments and spare parts. Then the services of research, extension, and training personnel should be mobilized in a project-wide campaign to demonstrate what these tractors can do and to motivate farmers to purchase them. Short courses should, subsequently, be organized to teach prospective owners the proper operation and maintenance procedures. A special section must also be set up within the project's machine shop unit to provide timely repair service at reasonable cost.

Improved Seeds

At the present time, there are no facilities or provisions for the production of certified seeds in the study area. Some farmers use imported certified seeds which are usually available from local suppliers. But imported seeds, though of unquestionably good quality, do not always perform up to the expectations under the specific soil and water conditions prevailing in the project area. In addition, high prices and the uncertainty associated with germination rate (which is normally a function of their age) have discouraged many farmers from their use. Accordingly, the majority of farmers usually rely on seeds produced on their own or their friends' farms during previous seasons.

The use of viable seeds is fundamental to obtaining good crop yields. Hence, a program should be initiated for the production, certification and distribution of quality seeds in the study area. The program should initially be implemented as a joint effort by the project management and the Hofuf Agricultural Research Center. Future participation by the College of Agriculture, King Faisal University, should be encouraged. To insure a wider use of the desired crop varieties, raising of seedlings should be integrated into the program.

Policies on Agricultural Services and Institutions

Farm Size and Economic Efficiency

The phenomenon of small land holdings is a recognized feature of the study area. As was indicated in Table 3, about 70 percent of agricultural production in the Al-Hasa is carried out on plots falling within the 4 hectare (10 acres) size class. The division of agricultural land into extremely small operational units has apparently constrained the majority of farm operators from using more mechanization in farming operations. Consequently, agricultural production in the oasis has remained highly dependent on human effort, with the resulting high costs of production and low marginal value product of labor.

In a recent study purporting to relate farm size to economic efficiency in the project area, Abu-Bakr (64) estimated the benefit-to-cost ratios for 12 farm-size classes ranging from 0.1 to 10 hectares. Using the estimated benefit-to-cost ratios as a proxy for economic efficiency, he found a general positive relationship between farm size and economic efficiency. But he more specifically concluded that farms falling within the two-hectare limit, and constituting over half of the total cultivated land in the project area, were inefficiently operated. This has serious implications for agricultural development in the oasis.

The problem of small farm size in the oasis is indeed acute, and its persistence will undoubtedly minimize the effectiveness of efforts aimed at maximizing net farm returns in the project area. Accordingly, it is recommended that the Ministry of Agriculture and Water take appropriate long-term measures which would lead to consolidation of very small farms into larger, more efficient units. This is likely to increase net farm revenues for the project as a whole by making it feasible for farmers to mechanize and benefit from economies of larger operations. Regulations must also be initiated to prevent further fragmentation of farm land. Admittedly, such measures are perhaps difficult to prescribe and may even prove to be more difficult to implement, as they may run counter to religious beliefs, cultural traditions, and social characteristics of the population. However, legislating and enacting such measures are necessary for transforming agricultural production and achieving reasonable economic efficiency in the oasis.

From a point of view of maximizing returns and production, a deliberate policy to encourage commercial farming in the study area would undoubtedly be recommended. Since the government owns a significant portion of the total cultivable land within the project area, the criteria, methods, and time-schedule adopted in allocating this land will have a marked impact on the manner and efficiency with which the project resources are utilized. To encourage commercial farming within the existing institutional framework, two recommendations are offered with respect to public lands: (1) medium size tracts of irrigable lands should be made available for long-term lease by farmers who have appropriate technical knowledge and who possess, or are willing to borrow, adequate capital; (2) temporary concessions could be given to commercial farming enterprises for the production of basic industrial crops with possible processing facilities on the site. The crop choice should be based not only on economic reasons assessed at the local level, but also on trends of agricultural policy at the national level.

The conditions set and enforced by the project management for the use of government lands should clearly define the rights and duties of those to whom the land is assigned. The contract terms should adequately safeguard the interests of the land users but must, at the same time, aspire to achieve optimum use of agricultural resources in the project area. If successful, such arrangements could set a precedent for optimum utilization of other irrigation projects in the country.

Marketing of Farm Products

The present marketing system in the study area is inefficient, wasteful, and not conducive to investment in increased agricultural production. It can neither cope with the requirements of modern production technology nor accommodate the consumption needs of the growing urban centers. Hence, any significant output expansion is likely to create serious marketing problems particularly in the case of fresh vegetables. This, of course, has undesirable implications for the efficiency of resource utilization, regional specialization, farm income, and diffusion of modern technology in the project area. It is essential that the marketing system undergo considerable improvements to become an effective instrument in the transformation of Al-Hasa traditional agriculture into an economically viable sector.

It must be pointed out, however, that the major obstacles inhibiting efficient marketing of farm products are not unique to Al-Hasa. Agricultural marketing throughout the Kingdom is generally hampered by lack of standards and grades, limited storage, processing and refrigeration facilities, deficiency of marketing information, high retailer markups, and unethical market conduct. Basic recommendations for improving the agricultural marketing system at the national level have been made during the last 15 years by a number of highly qualified market consultants and specialized agencies. However, two main reasons have, more or less, impeded their implementation (65, p. 1): (1) the importance of market development is not fully realized by the public, and the role of the Ministry of Agriculture and Water in leading the government efforts for agricultural marketing development has not yet been clearly determined; and (2) the required resources of people and funds within the Ministry of Agriculture and Water have not yet been directed toward solution of the most vital problems of marketing, or to the development of basic standards, institutions, and infrastructure upon which improved systems of marketing individual commodities would be developed.

Although the overall problem of agricultural marketing is too complicated and too perplexing to be adequately dealt with at the local or even the regional level, some improvements in the marketing system in the study area should be attempted. Ideally, such improvements should stem from the private initiative of producers and traders acting cooperatively. However, since there is little evidence to suggest that this is likely to occur spontaneously in the near future, the situation calls for more intensive efforts and deeper involvement by the project management. The management should, therefore, lead, stimulate, and coordinate efforts directed to preserving product quality, broadening the geographical breadth of the market, increasing the farmer's share of the retail price, and equalizing the supply and demand over time. The following recommendations are offered:

(1) To reduce the post-harvest costs and to facilitate a faster and more even flow of commodities into the market, the project farmers should be encouraged to cooperate in the collection, hauling, and marketing of their produce. The project management should seek practical ways to initiate and organize such cooperative action.

(2) To minimize the uncertainty normally associated with the quality of the produce, a pilot grading and standards program should be developed for the project area. The program should primarily aim at achieving a widespread use of standardized containers in conjunction

with a simplified grading system. The project management should play a leading role in developing and implementing the program. However, adequate participation by farmers as well as full understanding and acceptance by market intermediaries are indeed essential for the program success.

(3) To stimulate the demand for dates, top priority must be given to modernizing their marketing system. The commodity should be made available to consumers in sanitary and convenient containers and should be attractively presented and reasonably priced so as to suit tastes and budgets of the majority of consumers. The project management should, therefore, take appropriate measures to bring the production level at Al-Hasa Date Packing Plant to full capacity. Considerations should also be given to expanding the present plant or establishing new facilities.

(4) The project management is urged to sponsor two economic feasibility studies aimed at broadening the scope of marketing Al-Hasa farm products. One of these studies would be concerned with the production, processing, and marketing of feeding pellets, whose principal ingredients might include alfalfa and other green roughage, as well as low quality dates. The other study should deal with the potential for growing and processing specific industrial crops in the study area.

(5) It is recommended that a functionally self-contained marketing unit be established within the administrative organization of the project management. The functions of the unit should include the collection and dissemination of market information, conducting market research, and developing crop budgets, as well as planning, implementation, and enforcement of grades and standards.

Extension and Training

Agricultural output in the study area is mostly the product of efforts and decisions made by many independent farmers who are functionally illiterate and who have had very limited exposure to modern farming practices. The knowledge, skills, and attitudes of these farmers ultimately determine the types of inputs to be used and the manner in which they are combined, as well as the specific crops to be grown. Improving the knowledge of these farmers and modifying their attitudes are, thus, deemed essential for maximizing total net farm revenues in the project area. This calls for a comprehensive extension program that would include a number of fundamental aspects of modern farming such as crop protection, improved water management practices, use of fertilizers, machinery, and quality seeds, as well as diffusion of market information and preparation of production plans. Accordingly, the following guidelines are recommended:

(1) One of the major difficulties facing extension workers in the study area is the lack of specified objectives to be pursued. Because extension efforts would be more meaningful and more effective when directed toward achieving certain targets, the project management should periodically define some regional objectives and provide guidelines for their pursuance. Such objectives could deal with production targets, resource management, promoting the use of a given technology, or emphasizing the production of a specific commodity. They must be addressed to the real problems facing agricultural development in the oasis, particularly mismanagement of irrigation water, high labor intensity in crop production, and the predominance of low-return date palm trees.

(2) Although the total extension efforts in the study area are ostensibly impressive, their effectiveness has perhaps been minimized by lack of coordination among the different institutions presently involved in providing extension services to the project farmers. To obtain results commensurate with total efforts, the project management should develop a comprehensive regional extension program that coordinates activities of the participants so as to achieve a set of specified objectives.

(3) A fund of technical data on input-output relationship has been generated by researchers at the Hofuf Agricultural Research Center. Though extremely useful, much of this data is virtually unknown to the project farmers. The abstractness of the research findings and the fact that they are published only in English have greatly limited their use by farmers and the majority of local staff. It is recommended, therefore, that the project management initiate measures to translate these data into a language and a form that are comprehensible and usable by farmers.

(4) The effectiveness of extension efforts has been attenuated by the existence of a market communication gap between most extension agents and the majority of the project farmers. This gap is largely attributed to prevalence of illiteracy among the farmers and to the fact that almost all of the extension agents are foreigners whose cultures, attitudes and perceptions are alien to the farmers; farmers tend to believe that foreigners are not sincerely and genuinely interested in helping them. Because the success of the extension program depends to a great extent on the farmers' voluntary response and cooperation, the project management should seek ways for reducing the communication gap and enhancing farmers' receptiveness to modern farming technology. A

practical approach would be to gradually replace foreigners with Saudi extension workers. Admittedly, qualified Saudis are in short supply. However, by providing adequate incentives and improving employment procedures, the project management can undoubtedly fulfill all its needs of adequately trained Saudis.

(5) Since it is almost impossible to recruit sufficient extension agents in the short run, it is suggested that each extension worker be encouraged to concentrate on a few farm operators who are selected on the basis of willingness to adopt modern techniques and potential influence on other farmers. Basically, this method of extension involves the development of model farms that, in effect, serve as demonstration plots for other farmers in the project area. Extension workers should arrange regular visits to selected demonstration farms for farmers in the neighborhood.

(6) Improved agricultural practices can be well understood by the farmers only if presented in a way that considers their level of education, beliefs, and traditions and that approaches the problem on "as-is" principle. This calls for the development of an adult farmers' training program which must be tailored to fit the specific needs and cultural conditions of the study area. It is therefore recommended that a farmer training center be established within the functional organization of the project management. Since farmers are unable, and probably unwilling, to spend long periods away from their holdings, the courses should be limited to one week's duration. The information imparted at each course must be easily understood by the farmers and limited to a few ideas, otherwise there is a risk of confusion in the farmers' minds which could result in their adopting none. Details of all points covered in each

course should be passed to the extension officers so they can amplify them.

(7) Extension workers must be kept aware of modern developments and new research findings so as to maximize the effectiveness of their efforts. Accordingly, it is recommended that a regular in-service training be provided for extension workers. A one week course every six months for each worker should be adequate, particularly if supported by frequent publications explaining research findings. In addition to the in-service training, the workers should be provided with extension aids in the form of posters, pamphlets, or flipcards, all of which must be regularly updated in the light of new research findings.

Farm Cooperatives

Organization of local farm cooperatives is a useful instrument for fostering agricultural development in the study area. Properly managed farm cooperatives usually offer many advantages as a vehicle for procuring inputs, marketing outputs, disseminating information, as well as encouraging the use of new and improved production inputs and techniques. They could also provide opportunities for acquiring and operating farm machinery sized to suit farming operations.

At the present time, essential inputs are relatively expensive and sometimes difficult to obtain, very little machinery is used, and practically no marketing structure exists in the oasis. This underlines the need for cooperation at all levels of small-scale production and marketing. Consequently, it is recommended that the project management become more actively involved in organizing and strengthening farm cooperatives in the study area. This is in line with the Kingdom's dual objective of achieving active participation of the population in economic and social development and increasing farm efficiency and food production.

Applied and Adaptive Research

A substantial amount of research has been carried out over the last decade and a half at the Hofuf Agricultural Research Center. However, the subject matter of this research has not been adequately oriented toward seeking practical solutions to the major problems facing agricultural development in the region. Also, the bulk of the research results has not yet been transmitted to the project farmers because coordination between researchers and extension officers is practically non-existent at the present time.

For the research efforts to be more relevant to the overall objective of maximizing net returns to agricultural resources in the study area, they must be directed to increasing water-use efficiency, improving date culture, reducing dependence on human labor, as well as identifying the optimum levels and modes of input use. High priority must also be given to assessing the economic implications of the research results. The following are specific recommendations:

(1) Since water is the most limiting factor of production in the oasis, research efforts should be directed to economizing on its use and to reducing the evaporative and percolation losses normally incurred during its conveyance and distribution. Research should also be directed at determining yield response to varying rates of water application. Such response normally influences the magnitude and frequency of irrigation as well as the cropping pattern at the farm level. Research on

the selection of salt-tolerant crops should be emphasized to make better use of drainage water with high levels of salinity.

(2) The date palm, despite its predominance, has until now been excluded from the research program. However, due to the special position occupied by date palms, improving their management is fundamental to increasing net farm revenues in the project area. Accordingly, the crop production research program should include studies relating to date varietal selection, proper spacing, fertility and irrigation practices, along with the use of appropriate machinery. Research into the economics of date production is also needed to determine their long range profitability under monoculture and when grown in companion with other crops.

(3) Adaptive and applied research studies should be carried out for selected varieties of fruits such as citrus, grapes, and pomegranates under monoculture and intercropping with date palms.

(4) To help in reducing production costs and minimizing dependence on manual labor, priority should be given to research on the introduction and development of appropriate machinery adapted to the soil and farming conditions of the study area.

(5) The project farmers and the extension agents generally lack sufficient knowledge concerning soil fertility requirements and the types and quantities of chemical fertilizers that could be used to meet these requirements. Research efforts should, therefore, be directed to determining the optimal types, quantities, and methods of application of the different fertilizers available.

(6) The farmer himself seems to have been the forgotten element in the whole research process in the study area. While soil, water, and

climate have been examined by specialists, no socio-economic studies of the farmers have been attempted. The human element is a key factor whose influence on the pace of agricultural development in the oasis can not be overlooked. Socio-economic research should, therefore, be conducted to discover what decisions farmers make, what determines their decisions, and how could they be motivated to alter their behavioral pattern so as to improve the efficiency of their operations.

(7) To timely evaluate the economic implications of the research results, the research team at the Hofuf Agricultural Research Center should include an agricultural economist with broad experience and sufficient technical and professional capabilities.

(8) Coordination and communication between the Hofuf Agricultural Research Center and the College of Agriculture, King Faisal University, Hofuf, are practically non-existent at the present time. Because the College has the potential for making significant contributions to total agricultural research efforts in the oasis, steps should be taken to bring about its active involvement in the planning and implementation of the research program and in evaluating the research results.

Policies on Financial Incentives

At the present time, the project farmers are beneficiaries of a generous financial incentives program which includes interest-free loans, subsidies on major inputs, and cash grants on a number of farm products. The program is intended to stimulate domestic food production and also to improve farm income in the Kingdom as a whole and is not designed to meet the specific needs of any particular region. The rules, regulations, and administrative procedures for implementing the various components of the program are determined at the national level and are uniformly applied to all farming communities regardless of their geographic location.

Due to the fact that the determination of the directions, policies, and implementation procedures for the financial incentives program is beyond the field of influence of the project management, the scope for increasing the effectiveness of the program in Al-Hasa alone is rather limited. Nevertheless, two recommendations are offered, both calling for some involvement by the project management in improving the effectiveness of the subsidies and credit programs in the study area within the existing general policies, rules, and regulations.

The first recommendation relates to the potential role that could be played by the project management in administering the commodity subsidies in the study area. Ideally, the subsidies should be based on quantities produced and brought to the market. However, the underdeveloped nature of the marketing system has rendered this ideal approach almost impossible. Instead, output subsidies are presently based on estimated production of standing crops, wheat subsidy being an exception. The estimates are crude, usually made before the crop reaches maturity stage by a team of assessors with minimum agricultural background. The team visits each farm and grants the operator a certificate estimating the expected yield from the standing crop. Payment is made upon presentation of the certificate at the end of the growing season with no requirement for verification of the quantity actually produced.

More accurate estimates of production are essential for achieving the dual objectives of the commodity subsidy program. Hence, it is recommended that the task of determining and certifying the quantities produced by each project farmer be delegated to specially trained project management personnel. However, this regulatory task should not be charged to the project extension agents lest their educational and advisory functions be impaired.

The second recommendation is concerned with improving credit management so that the investment will be more productive for the individual farmer and the Kingdom. Presently, loan applications are processed by the staff of the Agricultural Bank with no consultation or coordination with the extension service. In approving each loan, the Bank personnel usually emphasize the provision of a real guarantee for repayment rather than the payoff potential of the loan. Although applicants are normally obliged to submit proposed plans for the use of individual loans, critical evaluation and timely follow-up of the loans are hampered by the Bank's lack of sufficiently trained personnel. Consequently, many loans are often diverted to uses other than those for which they were originally intended. Others are used in a manner that may not be condusive to increased farm productivity.

Agricultural development in the study area could be greatly enhanced by linking the extension services with the credit requirements of the project farmers. While the project management exercises no control over credit, its extension officers can provide valuable services in determining input requirements and providing guidance for their proper use. Hence, it is recommended that a pilot program of cooperation and coordination between the project management and the Hofuf Branch of the Agricultural Bank be initiated that would integrate the use of recommended technologies and inputs with the availability of the needed capital. In implementing this program, extension officers should work with each farmer to develop an annual operating plan that would specify the types and quantities of crops to be produced, along with the required inputs. Based on this plan, the production input needs and timing would then be recommended by the extension agent. This recommendation should serve as a basis for processing short-term loans. Once the loans are granted, the follow-up on their use should become the joint responsibility of the extension agents and the loan officers.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary

The three main objectives for agricultural development in Saudi Arabia are to raise per capita income and improve the welfare of rural people, minimize dependence on imported food, and release surplus labor for employment in other fields. These objectives are being pursued through raising the level of productivity and bringing more land into production where water resources permit. It is in keeping with these objectives that Al-Hasa Irrigation and Drainage Project was implemented during the 1960's. The primary objective of the project is to increase agricultural output in Al-Hasa oasis through improving yields on existing farm lands and extending the total irrigated area to 20,000 hectares.

Although in full operation for almost a decade, the project has thus far fallen short of achieving the anticipated vertical and horizontal expansion in agricultural production in the area. This apparent lack of success may be attributed mainly to mismanagement of scarce resources, particularly water. Other factors such as reliance on traditional production methods, low labor productivity, infrequent use of labor-saving techniques, and inefficient marketing system also may have impeded agricultural development in the oasis. Hence, the situation calls for detailed analysis of how scarce resources in the project area should be managed and utilized so as to increase the project's contribution to the overall agricultural development goals and to enable the project to achieve its own specific objectives.

The overall objective of this dissertation is to develop policies and management guidelines which will give resource utilization results near to an economic optimum for Al-Hasa Irrigation and Drainage Project. In pursuing this overall objective, a static linear programming model is developed using available technical and economic data. The purpose of the model is to determine pattern of resource allocation and management that would maximize total net farm revenues within the project area. The model assumes the whole project area is a profit-maximizing entity which accepts exogenously determined input and product prices. It seeks to fulfill the profit maximizing conditions usually specified by marginal economic analysis for the use of a given bundle of resources. These conditions stipulate that available resources in the project area should be allocated in such a manner that the marginal value product of any single resource is equated for all competing uses and users. For the oasis as a whole, this essentially requires diverting some resources, particularly water, from uses associated with low marginal value productivity to uses that can generate higher net returns per unit of input. It also may entail diverting water from farms where it has low marginal productivity in the production of a given crop to other farms where it may be used more efficiently in producing the same crop.

In constructing the linear programming model for Al-Hasa Irrigation and Drainage Project, a set of simplifying assumptions about the physical, economic, and institutional conditions in the study area are specified. One of these assumptions stipulates that the objective of the model is the maximization of net revenues over variable costs for the entire project area. The coefficients of the objective function are abstracted from the per hectare unit budgets developed in Appendix A for each of the crop enterprises incorporated into the model. The crops considered in this analysis are chosen on the bases of technical feasibility of production and presence of adequate demand.

Discussion of production coefficients of the model has been focused on water requirements because water is considered the major constraining resource. While other inputs such as labor, machinery, fertilizers and chemical pesticides are as equally important for crop production, they are assumed to be available in ample quantities at constant costs and are, thus, not limiting to crop production activities. Gross monthly water requirements for crops incorporated into the model are calculated using crop water requirement data developed by agronomists at Hofuf Agricultural Research Center and an assumed 53 percent project irrigation efficiency.

To make the analysis more realistic, two groups of constraints are imposed on the model. The first group represents limitations on the availability of land and water throughout the year. The land availability constraint requires that the total area under cultivation during any monthly period does not exceed the net cultivable area covered by the irrigation network. Similarly, the water availability constraint necessitates that the quantity of water used in each of the 12 monthly periods be equal to or less than the maximum total discharge from the individual springs feeding the irrigation system.

The second group of constraints is concerned with placing lower or upper bounds on the total area that may be devoted to date or vegetable production in any given period. To account for the short run inflexibility in total area under date palms, a minimum constraint is specified for the total area that should be set aside for date production in any given period. This minimum is specified so that the date palm enterprise activity not be forced out of the solution by other crops with considerably higher per hectare net returns. In view of the great potential for increased production and the limited absorptive capacity of the marketing system, an upper limit is imposed on the total area that may be devoted to the production of vegetables as a group. This limit is determined mainly by what the market will bear at the assumed product prices. To prevent the high-return crops from dominating the solution, the model also imposes a limit on the maximum area that may be utilized for producing any particular vegetable crop each year.

The optimal crop production plan produced by the linear programming model for Al-Hasa Irrigation and Drainage Project is presented in Table 9. The plan represents the most efficient overall use of water, land, management, and irrigation and drainage facilities within the project area under the specified assumptions and conditions. As would be expected, high-return vegetable crops, such as cauliflower, eggplant, lettuce, okra, squash, and tomatoes enter the solution at their maximum allowable levels. Dates, on the other hand, come into the solution at the minimum required level, a manifestation of their relative low profitability. Onions and wheat enter the final solution as the dominant non-constrained crops. Their dominating position indicates a sound development target which is consistent with both objectives of maximizing net returns from Al-Hasa Irrigation and Drainage Project and minimizing the country's dependence on imported food. Other crops, particularly potatoes, oats, and millet, come into the solution in areas greatly exceeding their present levels but are limited at the margin by the water constraint.

Crops that are incorporated into the model but have been excluded from the optimal plan because of their relatively low profitability are presented in Table 10. As indicated by the data, production of alfalfa and rice, the two main traditional crops in the oasis, is not profitable under the specified assumptions. It should be pointed out, nonetheless, that the possible contribution of these two crops to soil fertility has not been accounted for in assessing their income-generating potentials. Although the demand for forage may be stimulated by increased investment in dairying and sheep fattening farms in and around the oasis, seasonal fodder crops such as millet, sorghum, maize, oats, barley, and wheat seem to be more profitable than alfalfa.

Land and water utilization by the optimized production plan during the 12 monthly periods is outlined in Table 11. As may be noted from the table, the total area utilized by the plan in any single month falls short of the land area limitation imposed on the model. Hence, more land could conceivably be brought into cultivation if additional water would be made available to the program during the water-deficit months.

Parametric programming is used to estimate the effect of date palm restriction on total net returns and optimum crop mix. This is done by reducing the area devoted to traditional date cultivation by increments of 200 hectares to a minimum of 1,500 hectares and optimizing the model at each increment. The response of total net return to the successive reductions in traditional date palm restriction is traced in Table 12, along with the resulting major changes in the optimum crop mix. As indicated by the data, there is an inverse relationship between the area under date palms and the value of the objective function. The data also show a competitive relationship between traditional dates and each of forage millet, grain sorghum, and onions as well as a complementary relationship between traditional dates and wheat.

Parametric programming is also used to estimate the demand function for possible additional water supplies. This involves extending the water constraints by increments of 5, 10, 15, and 20 percent, subsequently optimizing the model at each increment. Gross water requirements are held at their original levels, as no changes in net water requirements or in irrigation efficiency were contemplated. The results generated by the model indicate that the marginal value product of additional water declines but remains positive throughout the specified range. However, this should not be construed as a recommendation for augmenting the present water supplies. Before it would be profitable to tap any of the alternative sources, the unit cost of developing and delivering additional water to farms in the study area has to be less than its marginal value product. In other words, the income-generating potential of additional water should exceed its average total cost.

Conclusions

A number of policy and management guideline recommendations are outlined in this study for maximizing net returns to scarce agricultural resources in the project area. These recommendations have resulted from a thorough analysis of circumstances existing in the study area and conditions that should exist if net returns are to be maximized. The recommendations essentially relate to modifying the present cropping pattern and enhancing the efficiency with which production inputs, particularly water, are utilized. They also pertain to diffusing modern farming techniques, making more effective use of financial production incentives, and improving the marketing system. In addition, the recommendations purport to promote the introduction of some basic institutional changes that would facilitate the application of more economically oriented criteria to allocating and managing productive resources in the study area.

Several policy recommendations are offered for changing the present agricultural production pattern in the project area to make it more compatible with the objective of maximizing total net returns. These recommendations include: (1) reducing the total area under date palms; (2) increasing the production of both summer and winter vegetable crops; (3) incorporating some strategic field crops especially wheat, onions, and potatoes into the production plan; and (4) replacing alfalfa with seasonal forage crops such as millet, maize, oats, wheat, and barley.

Some policy guidelines are also suggested for improving the efficiency with which the limited water supplies are used. These include measures for reducing evaporative and percolation losses, discouraging excessive application of water, and using more efficient irrigation methods. Imposing water user charges is also suggested as a means of restraining misuse and raising funds for the operation and maintenance of the facilities. Since improvements in water management can be beneficial only if introduced as part of a package of high-yielding technology, recommendations are offered for promoting increased use of modern farm inputs, particularly chemical fertilizers, pesticides, machinery, and improved seeds.

Although the overall problem of agricultural marketing is too complicated and too perplexing to be effectively dealt with at the local level, some improvements in the marketing system in the study area should be attempted. Hence, measures are suggested for more involvement by the project management in leading, stimulating, and coordinating efforts directed to preserving product quality, broadening the geographical breadth of the market, increasing farmer's share of the retail price, and equalizing the supply and demand over time.

Some guidelines have been recommended for developing a comprehensive extension program that would encompass a number of fundamental aspects of modern farming such as land consolidation, on-farm investment, crop protection, improved water management practices, use of fertilizers, machinery, and quality seeds, as well as diffusion of market information and preparation of production plans.

The need for more cooperation at all levels of small-scale production and marketing in the oasis has been stressed in this study. Consequently, it is recommended that the project management become more actively involved in organizing and strengthening farmer cooperatives in the project area. This is in line with the Kingdom's dual objective of achieving active participation of the population in economic and social development and increasing farm efficiency and food production.

A substantial amount of research has been undertaken over the last 15 years at Hofuf Agricultural Research Center. However, the subject matter of this research has not been adequately oriented toward seeking practical solutions to the major problems facing agricultural development in the region. Also, most of the research results have not yet been transmitted to the project farmers because coordination between researchers and extension personnel is practically non-existent at the present time. Some recommendations have, therefore, been offered for directing research efforts to increasing water use efficiency, improving date culture, reducing dependence on human labor, identifying the optimum levels and modes of input use, and to assessing the economic implications of the research results.

Since the determination of the directions, policies, and implementation procedures for the subsidy and credit programs is beyond the field of influence of the project management, the scope for increasing the effectiveness of these two programs in Al-Haṣa alone is rather limited. Nevertheless, two recommendations are offered both calling for some involvement by the project management in improving the effectiveness of the programs within the existing general policies, rules, and regulations. The first recommendation suggests that the task of determining and certifying the quantities of subsidized commodities produced by each project farmer be delegated to specially trained project management personnel. However, this regulatory task should not be charged to the project extension officers if it will impair their educational and advisory functions. The other recommendation calls for more cooperation and coordination between the project management and the Hofuf Branch of the Agricultural Bank for linking the extension services with the credit requirements of the project farmers.

Limitations of Study and Need for Future Research

While the present study has outlined a number of policies and management guidelines that should be pursued if total net farm revenue in the study area is to be maximized, it is readily apparent that additional policy problems remain to be faced. It is appropriate, then, to point out some of the more obvious shortcomings of this study and to indicate possible areas where additional research efforts may prove fruitful.

This analysis is the first attempt at applying an empirical optimizing technique to a farm management problem in Saudi Arabia. Like many pioneering endeavors, the analysis has some shortcomings which could intuitively reduce its effectiveness in solving the problems associated with resource management in the project area.

A major shortcoming of the study is the questionable reliability of the data used to construct the linear programming model for Al-Hasa Irrigation and Drainage Project. Since prices and input-output coefficients incorporated into the model are exogenous variables, both the expected net returns and the production possibilities could either be under or over estimated due to random factors or to errors in judgement. The production coefficients used in the model represent point estimates which have not been subjected to adequate verification. Hence, they may not reflect the economically optimum factor-product relationships. Also, the estimated net returns could be distorted by scarcity of reliable data on the costs of inputs. Thus, the results produced by the model can only be as accurate and as reliable as the input data used in the analysis. The model should be employed with prudence, common sense, and full realization of its limitations.

The applicability of the solutions generated by the model is largely determined by the realism of the underlying assumptions. The importance of the simplifying assumptions specified for Al-Hasa Irrigation and Drainage Project should, therefore, be emphasized. No relevance of the findings of the model can be claimed beyond the conditions specified by these assumptions. Caution must be exercised in drawing implications about the desirability of changes in cropping patterns in the oasis, particularly when some of these assumptions are violated.

The aggregate nature of the model used in the analysis does not allow detailed scrutiny of agricultural activity within the study area under alternative premises. Nor does its static nature provide for changes in the technology and price expectations. Thus, while the model may be useful in projecting the oasis' overall agricultural output and land use, it could be of limited usefulness in predicting the configuration within the oasis under changing price expectations and production technology.

Since most of the primary data utilized in developing the linear programming model for Al-Hasa Irrigation and Drainage Project have not been adequately refined or verified, validity of the results generated by the model could undoubtedly be enhanced by using better estimates of resource needs, particularly with respect to water. Future research efforts should, therefore, be devoted to developing more accurate estimates of the factor-product relationships for the various crop enterprises. Improved knowledge of these physical relationships would provide more reliable grounds for making decisions concerning use of resources and levels of output. Future research should also be directed to examining and modifying some of the assumptions on which the model is based. Alternative designs of the model might be considered to include any of the following variables: soil productivity differences, crop rotations, intercropping, alternative levels of management, limited supply of labor, as well as different price levels for both factor inputs and product outputs.

There is a growing need for extending the present sand stabilization program so that more protection would be provided for cultivable lands against encroaching sand dunes. Ways should thus be sought to reduce the per hectare cost and to increase the effectiveness of sand stabilization efforts in the long run. In addition, the technical and economic feasibilities as well as the desirability of using drainage water for sand stabilization should be critically examined.

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APPENDIXES

APPENDIX A

ENTERPRISE BUDGETS

Budgets for crops incorporated into the linear programming model for Al-Hasa Irrigation and Drainage Project are synthesized in the following tables. The tables present per hectare estimates of yield, resource requirements, variable costs, and net returns for each crop. Since production practices for each of the various crops typically follow in some sequence, calendars of operations and schedules of inputs were developed for each crop enterprise. Direct capital and labor requirements for each operation were specified and costs were assigned to each. The sum of these variable costs was then subtracted from total receipts to get the per hectare net return for each crop.

Estimates used in constructing the budgets were based on technical and economic information obtained from research progress reports, official price bulletins, a limited farm survey, as well as interviews with input suppliers, extension personnel and other agricultural workers in the study area. It should be pointed out that although the figures on yields and input requirements were based on research results and considered judgements of the experts, these figures have not been verified adequately enough to be construed as representing the optimum. Nevertheless, the figures are assumed to represent a good farm management level manifestly being utilized by the better farm managers in the oasis.

Input and output prices used in the calculations approximate the average annual prices paid and received by farmers in the study area during 1977. The figures should not be interpreted as predictions or forecasts for any future period. Product prices were obtained mostly from official sources and from ARAMCO's Agricultural Assistance Division. Input prices, on the other hand, were determined from interviews with retail merchants, knowledgeable farmers, and extension agents in the area, since no reliable data were readily available.

The calculated net returns represent the residual income accruing to land, management, water and irrigation facilities. All other inputs, including labor and machinery, were costed at their market values even if they were provided by on-farm resources. This approach is used to facilitate comparing the costs of, thus the net returns from, producing alternative crops in the project area when charges for land, management, water, and irrigation facilities are the same for all crops.

All the labor needed over the pre-planting, growing and harvesting phases of each of the crop enterprises considered is valued at current market cost. While some labor is provided by farm operators, its magnitude seems to be insignificant (less than 12 percent) compared to the total human effort devoted to agricultural production in the oasis. Also, alternative off-farm employment opportunities and incentives are so plentiful that farm operators would, in all probability, give up farming if they could not earn enough income from farming to cover the opportunity cost of their labor.

All farm machinery needed for the various operations is assumed to be available for custom hire at constant rates. The size of most farms within the project area is too small to justify ownership of tractors and machinery. In addition, the majority of farmers lack the skills needed for proper utilization of farm machinery. The services can thus best be provided by skilled custom-hire operators.

Table 14. Estimated Net Returns from Producing One Hectare of Alfalfa in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production	Dry Matter	Ton	32	1,500	48,000
Total Receipts		Riyal			48,000
Establishing Costs					
Land Preparation:	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	E. P. T. C.	Liter	6.2	40	248
Machinery	3-HP Sprayer	Hour	6	25	150
Fertilize:					
Material	Triple Superphosphate	Kg	100	0.65	65
Machinery	Tractor & Spreader	Hour	2	40	80
Make Borders	18-HP Tractor	Hour	2	27	54
Fix to Irrigate	18-HP Tractor	Hour	4	27	108
Pre-irrigate	Labor	Hour	12	7	84
Planting:					
Material	Seed	Kg	45	70	3,150
Machinery	Tractor & Seed Drill	Hour	4	45	200
Irrigate (10x)	Labor	Hour	50	7	350
Insect Control:					
Material	Chemical	Liter	4	40	160
Machinery	3-HP Sprayer	Hour	6	25	150
Total Establishing Costs		Riyal			5,123
Production Costs					
1/4 Establishing Cost[a]		Riyal			1,794
Irrigate (52x)	Labor	Hour	260	7	1,820
Fertilize (12):					
Material	Triple Superphosphate	Kg	1,200	0.65	780
Machinery	Tractor & Spreader	Hour	24	40	960

Table 14. Continued.

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Swath (12)	Walking Mower	Hour	96	20	1,920
Remove from Field (12)	Labor	Hour	192	7	1,344
Total Production Costs		Riyal			8,618
Net Returns		Riyal			39,382

[a] Establishment costs are prorated over four years at 15 percent opportunity cost of capital.

Table 15. Estimated Net Returns from Producing One Hectare of Dates in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production	Tamr	Ton	11.35	2,110	23,949
Total Receipts		Riyal			23,949
Irrigate (37X)	Labor	Hour	185	7	1,295
Cultivate & Fertilize:[a]					
Machinery	18-HP Tractor	Hour	5	27	135
Fertilizer	Animal Manure	Cu.m	12	110	1,320
Labor		Hour	12	7	84
Prune & Dethorn	Labor	Hour	120	12	1,440
Pollinate	Labor	Hour	80	12	960
Thin and Support Fruit	Labor	Hour	50	12	600
Remove Weeds (2X)	5-HP Weeder	Hour	12	20	240
Cut Dead Leaf Bases and Palm Webbing[b]	Labor	Hour	27	20	540
Harvest[c]	Labor	Hour	64	12	768
Debunch & Remove Fruit from Field	Labor	Hour	192	7	1,344
Total Specified Costs					8,726
Net Returns		Riyal			15,223

[a] Involves breaking the soil and incorporating animal manure once every other year.

[b] Done once every three years.

[c] Cutting the entire bunch of fully mature and partially dehydrated fruits. Some dates are hand picked while in their soft stage for fresh consumption.

Table 16. Estimated Net Returns from Producing One Hectare of Hasawi Rice in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production	Grain	Ton	3.4	9,030	30,702
Total Receipts		Riyal			30,702
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Make Borders	18-HP Tractor	Hour	2	27	54
Fix to Irrigate	18-HP Tractor	Hour	4	27	108
Buy or Raise Seedlings	45-day old	Hectare	1	1,500	1,500
Transplant:					
Machinery	2-row Transplanter	Hour	10	25	250
Labor		Hour	20	7	140
Irrigate (30x)	Labor	Hour	150	7	1,050
Fertilize[a]:					
Machinery	Tractor and Spreader	Hour	2	40	80
P-Fertilizer	Triple Superphosphate	Kg	215	0.65	140
N-Fertilizer	Urea	Kg	261	0.65	170
Labor		Hour	60	7	420
Weed Control:					
Material	Benthiocarb-M	Kg	3.0	35	105
Labor		Hour	10	7	70
Insect Control:					
Material	40% Aldrin PW	Kg	6	35	210
Labor		Hour	15	7	105
Harvest:					
Machinery	11-HP Combine	Hour	18	70	1,260
Labor		Hour	36	7	252
Hull	5-HP Huller	Hour	7	26	182
Polish	8-HP Polisher	Hour	7	25	175
Total Production Costs		Riyal			6,595
Net Returns		Riyal			24,107

[a] All the triple superphosphate fertilizer and 10% of the urea fertilizer are applied prior to transplanting. The remaining urea fertilizer is applied as top dressing in four splits of equal doses.

Table 17. Estimated Net Returns from Producing One Hectare of Wheat in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production: Grain		Ton	5.5	3,250	17,875
Straw	Dry Matter	Ton	7.0	600	4,200
Total Receipts		Riyal			22,075
Production Costs					
Land Preparation	18-HP Tractor	Hour	12	27	324
Make Borders	18-HP Tractor	Hour	2	27	54
Fix to Irrigate	18-HP Tractor	Hour	2	27	54
Plant:					
Material	Seeds	Kg	120	4	480
Machinery	Tractor & Seed Drill	Hour	4	45	180
Irrigate (13)	Labor	Hour	65	7	455
Fertilizer[a]:					
Machinery	Tractor & Spreader	Hour	2	40	80
P-Fertilizer	Triple Superphosphate	Kg	215	0.65	140
N-Fertilizer	Urea	Kg	261	0.65	170
Labor		Hour	15	7	105
Harvest:					
Machinery	11-HP Combine	Hour	18	70	1,260
Labor		Hour	36	7	252
Remove Straw from Field	Labor	Hour	20	7	140
Total Production Costs		Riyal			3,694
Net Returns		Riyal			18,381

[a] All the triple superphosphate and one half of the urea fertilizers are applied as basic dressing prior to sowing. The other half of the urea fertilizer is applied as top dressing 45 days after sowing.

Table 18. Estimated Net Returns from Producing One Hectare of Sweet Corn in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production: Grain	Fresh Ears	Ton	15	2,750	41,250
Stalks	Dry Matter	Ton	7.0	400	2,800
Total Receipts		Riyal			44,050
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Alachlor-Simazine	Kg	6	40	240
Labor		Hour	10	7	70
Fix to Irrigate	18-HP Tractor	Hour	4	27	108
Plant:					
Material	Seed	Kg	30	15	450
Machinery	Tractor & Seed Drill	Hour	2	45	90
Irrigate (12X)	Labor	Hour	60	7	420
Fertilize[a]:					
N-Fertilizer	Urea	Kg	180	0.65	117
P-Fertilizer	Triple Superphosphate	Kg	80	0.65	52
Machinery	Tractor & Spreader	Hour	2	40	80
Labor		Hour	30	7	210
Mechanical Weeding	Power Tiller	Hour	17	15	255
Pick and Remove from Field	Labor	Hour	120	7	840
Cut Stalks	Walking Mower	Hour	12	20	240
Remove from Field	Labor	Hour	16	7	112
Total Production Costs		Riyal			3,608
Net Returns		Riyal			40,442

[a] All the triple superphosphate and one third of the urea fertilizer are applied as basic dressing at sowing time. The remaining urea is applied as top dressing in two splits of equal doses.

Table 19. Estimated Net Returns from Producing One Hectare of Grain Sorghum in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production: Grain		Ton	6.2	1,750	10,850
Stalks	Dry Matter	Ton	6.0	600	3,600
Total Receipts		Riyal			14,450
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Herbicide	Liter	3	40	120
Machinery	3-HP Sprayer	Hour	6	25	100
Make Borders	18-HP Tractor	Hour	2	27	54
Fix to Irrigate	18-HP Tractor	Hour	2	27	54
Plant:					
Material	Seed	Kg	35	3.0	105
Machinery	Tractor & Seed Drill	Hour	4	45	180
Irrigate (23X)	Labor	Hour	115	7	805
Fertilize[a]:					
N-Fertilizer	Urea	Kg	450	0.65	293
P-Fertilizer	Triple Superphosphate	Kg	100	0.65	65
Machinery	Tractor & Spreader	Hour	2	40	80
Labor		Hour	30	7	210
Harvest	Labor	Hour	150	7	1,050
Thresh	Power Thresher	Hour	5	25	125
Cut Stalks	Walker Mower	Hour	8	25	200
Remove from Field	Labor	Hour	16	7	112
Total Production Costs		Riyal			3,877
Net Returns		Riyal			10,573

[a] All the triple superphosphate and one third of the urea fertilizers are applied as basic dressing at sowing. The remaining urea is applied as top dressing in two splits of equal doses.

Table 20. Estimated Net Returns from Growing One Hectare of Sugar Beets in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production: Roots	Fresh	Ton	79	275	21,725
Tops	Fresh	Ton	60	180	10,800
Total Receipts		Riyal			32,525
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Chemical	Liter	6	30	180
Machinery	3-HP Sprayer	Hour	4	20	80
Fertilize[a]:					
N-Fertilizer	Urea	Kg.	750	0.65	488
P-Fertilizer	Triple Superphosphate	Kg.	350	0.65	228
Machinery	Tractor & Spreader	Hour	2	40	80
Labor		Hour	30	7	210
Make Borders	18-HP Tractor	Hour	2	27	54
Fix to Irrigate	18-HP Tractor	Hour	4	27	108
Plant:					
Material	Seed	Kg.	4	50	200
Machinery	Tractor & Seed Drill	Hour	4	45	180
Irrigate (20X)	Labor	Hour	100	7	700
Hand Thin (2X)	Labor	Hour	30	7	210
Hand Weed (2X)	Labor	Hour	40	7	280
Cut Tops	Walking Mower	Hour	8	20	160
Dig Beets	18-HP Tractor	Hour	10	27	270
Remove from Field	Labor	Hour	40	7	280
Total Production Costs		Riyal			4,032
Net Returns		Riyal			28,493

[a] All the triple superphosphate and one third of the urea fertilizers are applied mechanically at sowing. The remaining urea is applied manually as top dressing in two equal doses at 40-day intervals after sowing.

Table 21. Estimated Net Returns from Growing One Hectare of Dry Onions in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production	Bulbs	Ton	40	2,750	110,000
Total Receipts		Riyal			110,000
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Chemical	Ronstar	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	6	25	150
Make Borders	18-HP Tractor	Hour	2	27	54
Fix to Irrigate	18-HP Tractor	Hour	4	27	108
Plant:					
Material	Seed	Kg	3.5	110	385
Machinery	Tractor & Seed Drill	Hour	4	45	180
Fertilize[a]:					
Manure	Animal/Chicken	Cu. M.	20	110	2,200
Complete Fertilizer	15-15-16-4	Kg	1,200	0.65	780
Labor		Hour	110	7	770
Machinery	Tractor & Spreader	Hour	2	40	80
Irrigate (30X)	Labor	Hour	150	7	1,050
Insect Control (2X)					
Material	Benlate	Liter	12	40	480
Machinery	3-HP Sprayer	Hour	12	25	300
Thin and Hand Weed (2X)	Labor	Hour	100	7	700
Cut Leaves	Walking Mower	Hour	8	25	200
Dig Bulbs	18-HP Tractor	Hour	10	27	270
Pick and Sack	Labor	Hour	122	7	854
Total Production Costs		Riyal			9,125
Net Returns		Riyal			100,875

[a] All the manure and 200 kg of the complete fertilizer are worked into the soil prior to planting. The remaining chemical fertilizer is applied as top dressing in six equal doses at three-week intervals after germination.

Table 22. Estimated Net Returns from Growing One Hectare of Potatoes in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production	Roots	Ton	20	3,000	60,000
Total Receipts		Riyal			60,000
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Chemical	Ronstar	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Make Borders	18-HP Tractor	Hour	2	27	54
Fix to Irrigate	18-HP Tractor	Hour	4	27	108
Plant:					
Material	Seed	Ton	1.8	3,750	6,750
Labor		Hour	100	7	700
Irrigate (18X)	Labor	Hour	90	7	630
Fertilize[a]:					
N-Fertilizer	Urea	Kg	480	0.65	312
P-Fertilizer	Triple Superphosphate	Kg	450	0.65	293
Machinery	Tractor & Spreader	Hour	2	40	80
Labor		Hour	47	7	329
Apply Insecticide (2X)					
Material	Chemical	Liter	12	40	480
Machinery	3-HP Sprayer	Hour	12	25	300
Hand Weed	Labor	Hour	50	7	350
Cut Tops	Walking Mower	Hour	8	25	200
Dig Tubers	18-HP Tractor	Hour	10	27	270
Pick and Sack	Labor	Hour	110	7	770
Total Production Costs		Riyal			12,290
Net Returns		Riyal			47,710

[a] All the triple superphosphate and one-fourth of the urea fertilizers are applied as basic dressing prior to planting. The remaining urea is applied manually as top dressing in three equal doses at 30-day intervals after planting.

Table 23. Estimated Net Returns from Growing One Hectare of Cabbage in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production	Fresh	Ton	40	2,500	100,000
Total Receipts		Riyal			100,000
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Herbicide	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Make Borders	18-HP Tractor	Hour	2	27	54
Fix to Irrigate	18-HP Tractor	Hour	4	27	108
Plant:					
Material	Seed	Kg	0.75	90	68
Machinery	Hand-pushed Seeder	Hour	25	10	250
Irrigate (28X)	Labor	Hour	140	7	980
Fertilize[a]:					
Complete Fertilizer	18-18-5	Kg	600	0.65	390
N-Fertilizer	Urea	Kg	300	0.65	195
Manure	Animal/Chicken	Cu. M.	20	110	2,200
Labor		Hour	80	7	560
Thin and Hand Weed (2X)	Labor	Hour	100	7	700
Apply Insecticide (2X):					
Material	Chemical	Liter	8	40	320
Machinery	3-HP Sprayer	Hour	12	25	300
Cut and Pack	Labor	Hour	105	7	735
Total Production Costs		Riyal			7,524
Net Returns		Riyal			92,476

[a] The manure is incorporated into the soil at land preparation. The urea and the complete fertilizers are applied as top dressing in four equal doses at three-week intervals, with the first dose applied at sowing time.

Table 24. Estimated Net Returns from Growing One Hectare of Cantaloupe in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production		Ton	15	2,500	37,500
Total Receipts		Riyal			37,500
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Herbicide	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Plant:					
Material	Seed	Kg	3	50	150
Labor		Hour	60	7	420
Irrigate (34X)	Labor	Hour	170	7	1,190
Fertilize[a]:					
Chemical Fertilizer	18-18-5	Kg	1,380	0.65	897
Labor		Hour	60	7	420
Hand Weed (2X)	Labor	Hour	80	7	560
Apply Insecticide (2X)					
Material	Chemical	Liter	8	40	320
Machinery	3-HP Sprayer	Hour	12	25	300
Pick and Haul	Labor	Hour	135	7	945
Total Production Costs		Riyal			5,866
Net Returns		Riyal			31,634

[a] The fertilizer is applied as top dressing in four equal doses at 30-day intervals, the first dose being applied at planting.

Table 25. Estimated Net Returns from Growing One Hectare of Carrots in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production		Ton	22	2,250	55,000
Total Receipts		Riyal			55,000
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Herbicide	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Make Borders	18-HP Tractor	Hour	2	27	54
Fix to Irrigate	18-HP Tractor	Hour	4	27	108
Plant:					
Material	Seed	Kg	4	54	216
Machinery	Hand-pushed Seeder	Hour	40	10	400
Irrigate (35X)	Labor	Hour	175	7	1,225
Fertilize[a]:					
Chemical Fertilizer	18-18-5	Kg	1,380	0.65	897
Labor		Hour	60	7	420
Thin and Hand Weed (2X)	Labor	Hour	160	7	1,120
Pull and Top	Labor	Hour	150	7	1,050
Total Production Costs		Riyal			6,154
Net Returns		Riyal			48,846

[a] The fertilizer is applied as top dressing in four equal doses at 30-day intervals; the first dose is applied at sowing time.

Table 26. Estimated Net Returns from Growing One Hectare of Cauliflower in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production		Ton	31	3,500	108,500
Total Receipts		Riyal			108,500
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Herbicide	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Make Borders	18-HP Tractor	Hour	2	27	54
Fix to Irrigate	18-HP Tractor	Hour	4	27	108
Plant:					
Material	Seed	Kg	0.75	200	150
Machinery	Hand-pushed Seeder	Hour	20	10	200
Irrigate (29X)	Labor	Hour	145	7	1,015
Fertilize[a]:					
Manure	Animal/Chicken	Cu. M.	30	110	3,300
Complete Fertilizer	18-18-5	Kg	600	0.65	390
N-Fertilizer	Urea	Kg	300	0.65	195
Labor		Hour	90	7	630
Thin and Hand Weed	Labor	Hour	100	7	700
Apply Insecticide (2X):					
Material	Insecticide	Liter	8	40	320
Machinery	3-HP Sprayer	Hour	12	25	300
Cut and Pack	Labor	Hour	105	7	735
Total Production Costs		Riyal			8,761
Net Returns		Riyal			99,379

[a] The manure is incorporated into the soil at land preparation. The chemical fertilizers are applied as top dressing in four equal doses at three-week intervals, the first dose being applied at planting time.

Table 27. Estimated Net Returns from Growing One Hectare of Cucumbers in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production		Ton	24	3,500	84,000
Total Receipts		Riyal			84,000
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Herbicide	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Plant:					
Material	Seed	Kg	3.5	70	245
Labor		Hour	60	7	420
Irrigate (35X)	Labor	Hour	175	7	1,225
Fertilize[a]:					
Complete Fertilizer	18-18-5	Kg	332	0.65	216
N-Fertilizer	Urea	Kg	330	0.65	195
Labor		Hour	75	7	525
Hand Weed (2X)	Labor	Hour	80	7	560
Apply Insecticide (3X)					
Material	Insecticide	Liter	12	40	480
Machinery	3-HP Sprayer	Hour	18	25	450
Pick and Crate	Labor	Hour	150	7	1,050
Total Production Costs		Riyal			6,030
Net Returns		Riyal			77,970

[a] The fertilizer is applied as top dressing in five equal doses at three-week intervals starting at planting time.

Table 28. Estimated Net Returns from Growing One Hectare of Eggplant in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production		Ton	40	3,250	130,000
Total Receipts		Riyal			130,000
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Herbicide	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Plant:					
Raise or Purchase Seedlings	50-day old	Hectare	1	1,000	1,000
Transplanting	Labor	Hour	90	7	630
Irrigate (43X)	Labor	Hour	215	7	1,505
Fertilize[a]:					
Manure Fertilizer	Animal/Chicken	Cu. M.	30	110	3,300
Chemical Fertilizer	18-18-5	Kg	1,100	0.65	715
Labor		Hour	135	7	945
Hand Weed (3X)	Labor	Hour	110	7	770
Apply Insecticide (3X):					
Material	Insecticide	Liter	12	40	480
Machinery	3-HP Sprayer	Hour	18	25	450
Pick and Crate	Labor	Hour	180	7	1,260
Total Production Costs		Riyal			11,719
Net Returns		Riyal			118,281

[a] All the manure and 157 kg of the chemical fertilizer are incorporated into the soil prior to planting. The remaining chemical fertilizer is applied as top dressing in six equal doses at three-week intervals after planting.

Table 29. Estimated Net Returns from Growing One Hectare of Lettuce in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production		Ton	35	3,250	113,750
Total Receipts		Riyal			113,750
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Herbicide	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Make Borders	18-HP Tractor	Hour	2	27	54
Fix to Irrigate	18-HP Tractor	Hour	4	27	108
Plant:					
Material	Seed	Kg	3.5	90	315
Machinery	Hand-pushed Seeded	Hour	25	10	250
Irrigate (25X)	Labor	Hour	125	7	875
Fertilize[a]:					
Manure	Animal/Chicken	Cu. M.	30	110	3,300
Complete Fertilizer	18-18-5	Kg	600	0.65	390
N-Fertilizer	Urea	Kg	300	0.65	195
Labor		Hour	90	7	630
Thin and Hand Weed (2X)	Labor	Hour	100	7	700
Apply Insecticide (2X):					
Material	Insecticide	Liter	8	40	320
Machinery	3-HP Sprayer	Hour	12	25	300
Cut and Pack	Labor	Hour	128	7	896
Total Production Costs		Riyal			8,997
Net Returns		Riyal			104,753

[a] The manure is incorporated into the soil prior to planting. The urea and the complete fertilizers are applied as top dressing in four equal doses at three-week intervals, with the first dose being applied at planting time.

Table 30. Estimated Net Returns from Growing One Hectare of Zucchini Squash in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production		Ton	22	4,750	104,500
Total Receipts		Riyal			104,500
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	22	324
Weed Control:					
Material	Herbicide	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Plant:					
Material	Seed	Kg	4.5	50	225
Labor		Hour	40	7	280
Irrigate (26X)	Labor	Hour	130	7	910
Fertilize[a]:					
Manure	Animal/Chicken	Cu. M.	20	110	2,200
Chemical Fertilizer	18-18-5	Kg	1,200	0.65	780
Labor		Hour	110	7	770
Hand Weed (2X)	Labor	Hour	60	7	420
Hand Pollinate	Labor	Hour	80	7	560
Apply Insecticide (3X):					
Material	Insecticide	Liter	12	40	480
Machinery	3-HP Sprayer	Hour	18	25	450
Pick and Crate	Labor	Hour	170	7	1,190
Total Production Costs		Riyal			8,929
Net Returns		Riyal			95,571

[a] The manure fertilizer is incorporated into the soil prior to planting. The chemical fertilizer is applied as top dressing in six equal doses at two-week intervals starting at planting time.

Table 31. Estimated Net Returns from Growing One Hectare of Tomatoes in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production		Ton	54	3,250	175,500
Total Receipts		Riyal			175,500
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Herbicide	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Plant:					
Raise or Buy Seedlings	60-Day Old	Hectare	1	1,000	1,000
Transplanting	Labor	Hour	80	7	560
Irrigate (50X)	Labor	Hour	250	7	1,750
Fertilize[a]:					
Manure	Animal/Chicken	Cu. M.	20	110	2,200
Chemical Fertilizer	18-18-5	Kg	1,100	0.65	715
Labor		Hour	125	7	875
Hand Weed (3X)	Labor	Hour	95	7	665
Apply Insecticide (10X):					
Material	Insecticide	Liter	40	40	1,600
Machinery	3-HP Sprayer	Hour	60	25	1,500
Pick and Crate	Labor	Hour	325	7	2,275
Total Production Costs		Riyal			13,804
Net Returns		Riyal			161,696

[a] All the manure and 110 kg of the chemical fertilizer were applied prior to planting. The remaining chemical fertilizer is applied as top dressing in six equal doses at three-week intervals after planting.

Table 32. Estimated Net Returns from Growing One Hectare of Watermelon in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production		Ton	20	2,250	45,000
Total Receipts		Riyal			45,000
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Herbicide	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Plant:					
Material	Seed	Kg	3.5	50	175
Labor		Hour	30	7	210
Irrigate (34X)	Labor	Hour	170	7	1,190
Fertilize[a]:					
Manure	Animal/Chicken	Cu. M.	20	110	2,200
Chemical Fertilizer	18-18-5	Kg	1,380	0.65	897
Labor		Hour	95	7	665
Hand Weed (2X)	Labor	Hour	60	7	420
Apply Insecticide (3X):					
Material	Insecticide	Liter	12	40	480
Machinery	3-HP Sprayer	Hour	18	25	450
Pick and Haul	Labor	Hour	70	7	490
Total Production Costs		Riyal			7,841
Net Returns		Riyal			37,159

[a] Manure is incorporated into the soil prior to planting. The chemical fertilizer is applied as top dressing in five equal doses starting at planting.

Table 33. Estimated Net Returns from Growing One Hectare of Okra in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production		Ton	15	9,000	135,000
Total Receipts		Riyals			135,000
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Herbicide	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Plant:					
Material	Seed	Kg	13.6	35	476
Machinery	Hand-pushed Seeder	Hour	20	10	200
Irrigate (26X)	Labor	Hour	130	7	910
Fertilize[a]:					
Manure	Animal/Chicken	Cu. M.	30	110	3,300
Chemical Fertilizer	18-18-5	Kg	2,000	0.65	1,300
Labor		Hour	90	7	630
Hand Thin and Weed	Labor	Hour	50	7	350
Apply Insecticide (5X):					
Material	Insecticide	Liter	20	40	800
Machinery	3-HP Sprayer	Hour	30	25	750
Pick and Crate	Labor	Hour	180	7	1,260
Total Production Costs		Riyal			10,640
Net Returns		Riyal			124,360

[a] The manure is incorporated into the soil prior to planting. The chemical fertilizer is applied as top dressing in four equal doses at three-week intervals after planting.

Table 34. Estimated Net Returns from Growing One Hectare of Radish in Al-Hasa Oasis--Saudi Riyals

Operation	Type	Unit	Quantity	Price or Cost Per Unit	Value
Production		Ton	20	2,250	45,000
Total Receipts		Riyal			45,000
Production Costs:					
Land Preparation	18-HP Tractor	Hour	12	27	324
Weed Control:					
Material	Herbicide	Liter	6	40	240
Machinery	3-HP Sprayer	Hour	4	25	100
Make Borders	18-HP Tractor	Hour	2	27	54
Fix to Irrigate	18-HP Tractor	Hour	4	27	108
Plant:					
Material	Seed	Kg	18	30	540
Machinery	Hand-pushed Seeder	Hour	40	10	400
Irrigate (17X)	Labor	Hour	85	7	595
Hand Thin and Weed	Labor	Hour	50	7	350
Fertilize[a]:					
Chemical Fertilizer	18-18-5	Kg	800	0.65	520
Labor		Hour	60	7	420
Pull and Bunch	Labor	Hour	120	7	840
Total Production Costs		Riyal			4,491
Net Returns		Riyal			40,509

[a] The fertilizer is applied as top dressing in four equal doses at 14-day intervals; the first dose is applied at sowing time.

APPENDIX B

WATER FLOW THROUGH MAIN IRRIGATION AND DRAINAGE CANALS

Since the summer of 1973, the total water flow through the main irrigation and drainage canals has been monitored by the staff of the Hydrology Section, Al-Hasa Irrigation and Drainage Authority, in cooperation with specialists from the Hofuf Agricultural Research Center. The average monthly flow through the main irrigation canals for the period 1974/78 is presented in Table 35. Since the flow in each of the main canals is regulated according to the demand for irrigation water within the area covered, the figures in the table may not represent the discharge capacity of the springs. As indicated by the data, the average total monthly flow during the five-year period varied between a minimum of 15.00 million cubic meters for January and a maximum of 23.44 million cubic meters for May; the latter figure represents the peak demand for water when the sluice gates of the springs were fully opened to allow for maximum flow into the canals.

The data in Table 36 show the average monthly discharge by the main drainage canals for the 1974/76 period. High water flows observed during the winter months are probably an indication of excessive water application. However, such flows could have been influenced by drainage from wells and private springs, by infiltration from village seweges, and by immediate or delayed seepages from rains.

Table 35. Average Monthly Flow Through the Main Irrigation Canals, Al-Hasa Irrigation and Drainage Project, for the Period 1974/1978[a]

Canal	Month Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
$F_1 + Z_{1.6}$	7.21	7.38	9.18	10.53	11.08	8.82	8.28	8.11	8.42	9.42	9.05	7.46	104.94
$F_2 + Z_4$	1.25	1.15	1.13	1.41	1.64	1.86	1.88	1.89	1.71	1.69	1.31	1.18	18.10
F_3	0.16	0.16	0.16	0.09	---	---	---	---	---	---	---	0.03	0.60
F_4	0.95	1.02	1.04	0.97	1.03	1.00	1.08	1.11	1.03	1.09	0.88	1.20	12.40
F_5	1.21	1.18	1.19	1.25	1.73	1.85	1.75	1.76	1.70	1.65	1.15	0.96	17.38
F_6	0.53	0.55	0.57	0.45	0.33	0.20	0.19	0.23	0.21	0.36	0.49	0.41	4.52
F_7	0.13	0.23	0.17	0.10	---	---	---	---	---	---	---	---	0.63
P_1	1.16	1.24	1.55	1.87	2.17	2.13	2.15	2.08	1.87	1.61	1.55	1.23	20.61
P_2	0.96	0.89	1.10	1.26	1.45	1.40	1.44	1.55	1.09	1.16	1.04	0.87	14.21
P_4	1.44	1.33	1.73	2.75	4.01	4.26	4.47	4.18	3.25	2.74	2.42	1.87	34.45
Total	15.00	15.13	17.82	20.68	23.44	21.52	21.24	20.91	19.28	19.72	17.89	15.21	227.84

Source: Hydrology Section, Al-Hasa Irrigation and Drainage Authority.

[a] In million cubic meters.

Table 36. Average Monthly Discharge Through Main Drainage Canals, Al-Hasa Irrigation and Drainage Project, for the Period 1974/76[a]

Month	Main Drainage Canal D_1	D_2	D_3	Total
January	10.714	4.375	0.066	15.155
February	10.958	5.179	0.084	16.221
March	10.669	6.714	0.093	17.476
April	8.748	4.190	0.098	13.036
May	5.910	3.727	0.107	9.744
June	4.126	1.339	0.035	5.500
July	3.861	0.759	0.021	4.641
August	3.701	0.637	0.017	4.355
September	4.208	0.630	0.013	4.851
October	4.660	0.839	0.021	5.520
November	6.113	2.039	0.041	8.193
December	8.100	2.969	0.041	11.110
Annual Total	81.768	33.397	0.637	115.802

Source: Hydrology Section, Al-Hasa Irrigation and Drainage Authority.

[a] In million cubic meters.

VITA

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Saleh Halwan Humaidan

Candidate for the Degree of

Doctor of Philosophy

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