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and Hamid Faki*

Economic Policy and Technology Determinants of the Comparative Advantage of Wheat Production in Sudan

ECONOMICS
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Contents

Abstract

Relative profitability and the domestic resource cost (DRC)methodology are used to evaluate the comparative advantage of irrigated wheat versus cotton in Sudan's Gezira Scheme. Relative profitability analysis reveals the high tax paid by Gezira farmers prior to 1992 through an overvalued exchange rate. Results of the DRC analysis indicate that at 1990 prices it is more efficient to produce wheat using a full package of improved technologies than to produce long- and medium-staple cotton. However, at the 1992 trend and actual prices, cotton dominates all wheat technologies. Cotton dominates the full package of improved wheat technologies until the world price of wheat is 11% higher than trend, at which point full package wheat becomes more efficient. However, as wheat prices currently are below their long-run average, and since average yields in Gezira are much lower than potential yields under the full package of technology, at present it may not be economically efficient to expand wheat production at the expense of cotton. Before more land is removed from cotton and sown to wheat, priority should be given to closing the gap between farmers' current and potential wheat yields. Input procurement and delivery systems should be liberalized for more efficient and timely utilization of inputs. Research recommendations should be refined to suit the needs of different locations and farmer groups. It is also important for Sudan to devote more resources to improving the quality and marketing of its cotton crop, given the high potential gain in cotton export prices from higher quality lint.

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Acknowledgements

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Executive Summary

The Government of Sudan has launched a crash program to promote domestic wheat production and bridge an increasingly unsustainable gap between local supply and consumption of wheat. The program was motivated mainly by impressive results from on-farm tests of improved wheat production technologies recently released by the Agricultural Research Corporation (ARC) of Sudan. The main objectives of Sudan's new domestic wheat supply strategy are to reduce the reliance on imported food and reduce foreign exchange expenditures on wheat imports.

However, despite extensive demonstration of the recommended practices to farmers in the Gezira Irrigation Scheme, adoption of the new practices has been slow. A wide gap remains between potential yields and farmers' yields. The present analysis shows that the recommended practices generate net economic gains and dominate traditional methods. Rather than economic inefficiency, limited access to inputs, caused by institutional and infrastructural constraints such as controlled factor markets and inadequate water supplies, was the reason for low adoption and slow productivity growth. Practices which require certain inputs (e.g., the mechanical components of the new package) to be purchased from private markets were adopted faster than practices for which input supplies are controlled by the government (e.g., nitrogen and phosphorus fertilizers). Results also confirmed the significant effect of seasonal (weather) and spatial (locational) variability in farmers' circumstances on wheat yield and hence optimality of the recommended practices in Gezira. This indicates that Gezira farmers should be classified into target groups for efficient promotion of relevant technologies.

On the other hand, expanding local wheat production leads to higher competition for Sudan's scarce agricultural resources between wheat and alternative crop enterprises, especially cotton, that are important foreign exchange earners for Sudan. The foreign exchange resources saved by substituting local wheat for imported wheat therefore need to be compared to the opportunity cost of the domestic and foreign resources required to support local wheat production (or foreign exchange foregone as a result of reduced production of export crops).

To determine whether wheat represents the most efficient option for using Sudan's irrigated land resources, this study uses relative profitability and the domestic resource cost (DRC) methodology to evaluate the comparative advantage of various wheat technology levels versus other production alternatives in the Gezira Scheme, which produces more than 60% of Sudan's wheat. Economic prices were estimated for tradables by eliminating all taxes, subsidies, and other exchange rate and commercial policy distortions. Border prices were converted using one exchange rate, unified for all tradables at the shadow exchange rate, to derive economic prices of traded goods. Scarcity values or, when appropriate, market determined prices were used to price non-traded primary factors for the analysis of social profitability.

The relative profitability analysis reveals the high net tax paid by Gezira farmers before 1992 through an overvalued exchange rate. Results of the DRC analysis indicate that it is more efficient to produce wheat with the full package of improved technologies than to produce long- and medium-staple cotton at 1990 prices. On the other hand, traditional wheat production practices followed by the vast majority of Gezira farmers, and wheat technology intermediate between the full improved package and traditional practices, were highly inefficient compared to cotton. At trend and actual 1992 prices, however, long-staple cotton was more efficient than all three wheat technologies. Sensitivity analysis was conducted to examine the robustness of the DRC results under changing world prices of cotton and wheat and to define ranges of economic efficiency and threshold yields for wheat production in Gezira. Results of the sensitivity analysis show that cotton dominates the full package of improved wheat technology until the world price of wheat is 11% higher than its 1992 trend level.

As wheat prices are currently well below their long-run average, and since average yield levels in Gezira are much lower than potential yields obtained under the full package of improved wheat technologies, at present it may not be economically efficient for Sudan to expand wheat production at the expense of cotton in Gezira. Before more land and water are switched from producing cotton to wheat, the gap between potential and farmer's wheat yields needs to be closed to make wheat farming in Gezira efficient, and priority should be given to designing policies that promote growth in wheat yields. Moreover, Sudan needs to liberalize its input procurement and delivery systems to permit faster adoption as well as more efficient and timely utilization of inputs crucial to raising the productivity of wheat in Gezira.

On-farm testing of the new wheat technology in Gezira should continue, particularly at locations where water shortages are severe. Conditional recommendations modifying the new wheat technology to suit different locations in the scheme need to be formulated in order to realize the true potential for wheat production in Gezira. It is also important for Sudan to devote more resources to improving the quality and marketing of its cotton crop. This is crucial for the question of economic efficiency, given the high potential gain in cotton export prices from higher quality lint.

1

Introduction

Preamble

Wheat consumption has grown tremendously in Sudan through food aid in the form of wheat, high consumer subsidies, and rapid urbanization (Damous 1986, Bickersteth 1990, Hassan et al. 1991). On the other hand, wheat production has grown slowly, primarily because of low use of modern inputs and poor crop management practices (Ageeb, Mohamed, and Faki 1986; Hassan and Ageeb 1992) (Figure 1.1).

Because demand for wheat grew faster than domestic production, the share of local production in Sudan's total wheat supply declined from more than 70% in 1971 to about 20% by 1987 (Table 1.1). Wheat imports therefore increased substantially over the past two decades. In addition to threatening food security, increased reliance on imported wheat implies greater competition for Sudan's meager foreign exchange resources. In 1986 Sudan imported about 600,000 t of wheat, valued at US$ 94 million, whereas the country's total foreign exchange earnings for the same year amounted to only US$ 333 million (FAO 1988).

Facing severe budgetary and trade deficits and reduced food aid, the government of Sudan launched a crash program in 1989 to achieve self-sufficiency in wheat by 1992. In addition to expanding Sudan's wheat area, the government strategy aims to exploit the potential gains from improved wheat production technologies developed by the Agricultural Research Corporation (ARC) and independently tested in farmers' fields over the last five years by ARC and the Sasakawa-Global 2000 Agricultural Project (SG 2000).[1] As a result

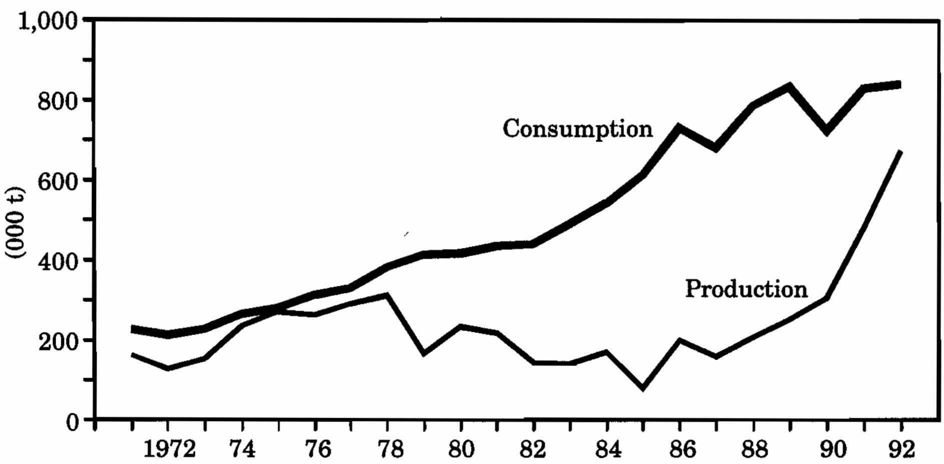

Figure 1.1. Trends in total wheat production and consumption, Sudan, 1971-92.
Source: Ministry of Finance and Economic Planning, *Economic Survey* (various issues).

of these efforts, larger areas were sown to wheat and higher yields were realized, leading to increased wheat self-sufficiency over the past three years (Table 1.1). Quantitative restrictions on wheat imports and rationing of consumption also improved self-sufficiency by slowing growth in demand. In addition, the government gradually removed the high subsidy on bread prices during 1991, leading to reduced consumption.

Expanding local wheat production, however, increases competition for land, water, and other agricultural resources between wheat and alternative crop enterprises, especially cotton, that are important foreign exchange earners. Moreover, the improved production practices promoted by ARC require greater use of imported modern inputs. The foreign exchange resources saved from substituting local wheat for imported wheat must be compared to the opportunity cost of the domestic and foreign resources required to support local wheat production. This study summarizes available information on the productivity and profitability of alternative wheat production technologies in the Gezira Irrigation Scheme, which produces more than 60% of Sudan's wheat. The study then goes on to evaluate Sudan's decision to promote production of local wheat in terms of economic efficiency, especially with regard to whether wheat production represents the best use of the country's irrigated land resources. The contribution to net social gains and the economic efficiency of wheat and competitive crops in the Gezira Scheme are determined under various policy and technological scenarios. This analysis is part of a wider effort by CIMMYT to define conditions under which wheat can be grown efficiently in the tropics, where environmental conditions for wheat production are sometimes difficult and wheat consumption and deficits have grown steadily (Byerlee 1985, Byerlee and Morris 1990).

This study also delineates the range of relative prices within which wheat production is efficient and defines threshold wheat yield levels in Gezira for various combinations of relative world cotton and wheat prices. Results obtained from the domestic resource cost (DRC) analysis offer information useful to policy makers in directing production and research resources in Sudan to their most productive uses. This information will also help international agricultural research institutions and funding agencies decide on the level of resources to commit to wheat research and production in Sudan.

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1 The ARC is the national agricultural research organization of Sudan. Almost all applied agricultural research in Sudan is undertaken by the ARC, which was founded in 1967 with a mandate to investigate the scientific basis of crop production so as to increase crop yields at the lowest cost. Other research functions added in 1975 included livestock, food processing, fisheries, marine biology, forestry, range and pastures, and game and wildlife.

SG 2000 Agricultural Projects have been established by the Sasakawa Africa Association and Global 2000, Inc., in various African countries; their objective is to develop programs for demonstrating technology to farmers in cooperation with national extension services.

Wheat in the Gezira Scheme

The best potential for expanding wheat production in Sudan exists in the Gezira Scheme, and most recent expansion in wheat production has occurred there. Wheat area in Gezira was 250,000 ha in 1991 compared to 106,000 in 1988, an increase of 136% (Table 1.1). However, this expansion has been at the expense of cotton and other crops. For example, cotton area has declined by more than half in Gezira since 1987 (Figure 1.2).

Table 1.1. Wheat self-sufficiency and the contribution of Gezira wheat to domestic supply, Sudan, 1971-92

Season	Gezira wheat area (000 ha)	Gezira wheat yield (t/ha)	Gezira contribution to domestic supply (%)	Self-sufficiency (%)
1970-71	59	0.95	35	72
1971-72	55	1.03	44	61
1972-73	61	0.99	40	67
1973-74	107	1.08	49	89
1974-75	180	0.96	64	96
1975-76	238	0.88	80	84
1976-77	212	1.28	94	88
1977-78	196	1.12	70	82
1978-79	207	0.60	75	41
1979-80	152	1.12	73	56
1980-81	154	0.49	35	50
1981-82	113	0.78	62	32
1982-83	65	1.42	66	29
1983-84	112	0.93	62	31
1984-85	.. [a]	.. [a]	0	13
1985-86	101	1.20	61	27
1986-87	76	1.20	58	23
1987-88	106	1.34	69	26
1988-89	115	1.54	71	30
1989-90	165	1.44	78	42
1990-91	250	1.10	57	58
1991-92	220	2.10	69	80

Source: Ministry of Finance and Economic Planning, *Food Security Study* (1988); Ministry of Finance and Economic Planning, *Economic Survey* (various issues); Ministry of Agriculture, *Agricultural Statistics* (various issues); and Sudan Gezira Board, *Annual Report* (various issues).

a No wheat was planted in 1984 in Gezira because of severe water shortages caused by the drought.

Although wheat area has expanded substantially in Gezira over the past five years, growth in wheat yields has been disappointing (Figure 1.3a, 1.3b). The average yield achieved by wheat farmers over the last five seasons (excluding 1991-92)[2] was 1.36 t/ha, only 6% higher than the average of 1.28 t/ha for the 20 years prior to 1989. Thus a wide unexploited gap remains between the high potential for wheat production in Gezira (revealed by the ARC and SG 2000) and current yield levels. Farmers' failure to adopt the new wheat technology promoted by ARC in Gezira was considered the major factor behind the sluggish growth in wheat yields (Hassan and Ageeb 1992). However, the reasons why farmers failed to adopt the new technology package have not been analyzed adequately.

A better understanding of the causes of the low and differential rates of adoption of the ARC technology is needed to identify the barriers to growth in wheat yields in Gezira. This study analyzes the effects of characteristics of the technology and farmers' access to the technology on adoption patterns. Variations in adoption patterns are explained by variations in the profitability of the major components of the recommended package as well as by their availability, which is determined by different systems of input procurement and distribution.

Moreover, on-farm research conducted over the last five years has not divided Gezira farmers into more homogeneous groups ("recommendation domains"),

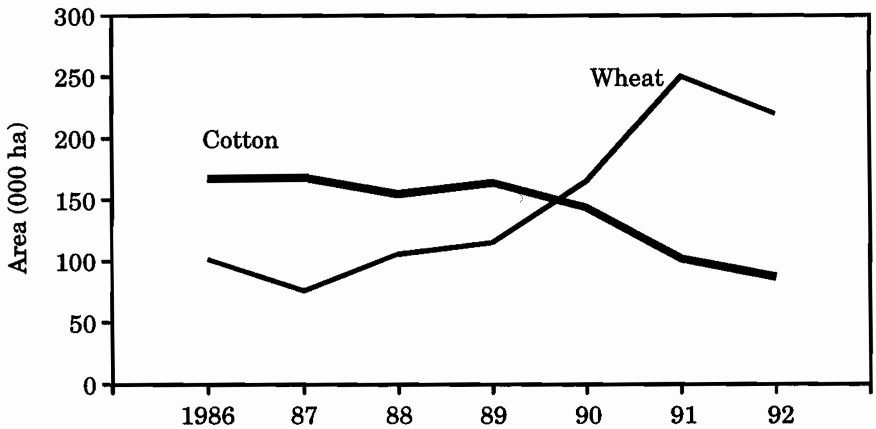

Figure 1.2. Area sown to wheat and cotton in the Gezira Scheme, Sudan, 1986-92.
Source: Sudan Gezira Board, *Annual Report* (various issues).

[2] Although average wheat yields in Gezira reached their highest levels ever in 1991-92 (Table 1.1), the wheat season that year was abnormally cold. Thus in assessing the yield potential of wheat in Gezira, 1991-92 was excluded as atypical.

thereby assuming away any significant variation between fields and farmers' conditions. The new technology has been promoted to all farmers in the Gezira Scheme as a package of standard practices. Optimal levels of components of the package may differ from one location to another in Gezira, since agroclimatic as well as other conditions are not the same for all farmers across such a large area. The present study therefore analyzes the structure and characteristics of the new wheat technology to identify significant interaction effects among and between the various components of the package and site-specific factors. This analysis helps to define the important classifiers that can be used to stratify Gezira tenants into more homogeneous groups and contribute to more efficient testing and reformulation of research recommendations.

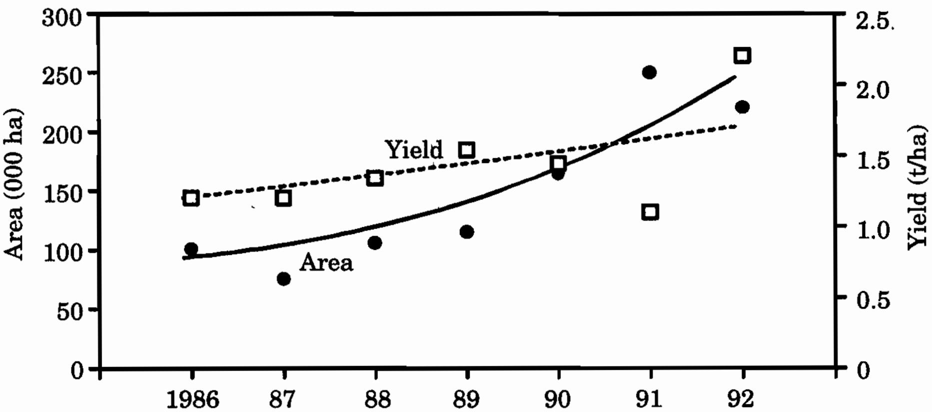

Figure 1.3a. Exponential trends in wheat area and yield in the Gezira Scheme, Sudan, 1986-92.

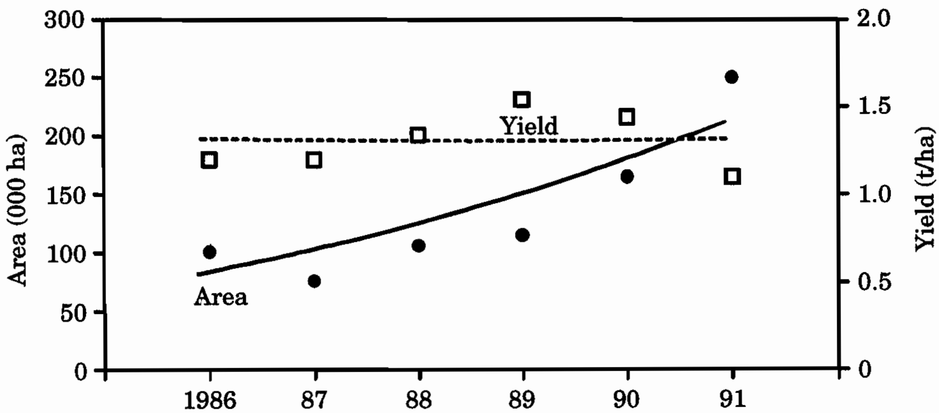

Figure 1.3b. Exponential trends in wheat area and yield in the Gezira Scheme, Sudan, 1986-91 (1992 excluded as exceptional).

The paper is organized as follows. The DRC methodology is outlined in the remainder of Chapter 1. Chapter 2 describes wheat farming in Sudan and discusses the important factors influencing the economic efficiency of wheat production in the Gezira Scheme. Traditional and improved wheat production practices in Gezira are compared and causes of differential rates of adoption are analyzed in Chapter 3. In Chapter 4 private and social prices are derived, enterprise budgets are constructed, and the relative profitability and DRC analyses are performed. Chapter 5 summarizes the findings and presents recommendations.

Comparative Advantage Analysis and the Domestic Resource Cost (DRC) Methodology

To evaluate the comparative advantage of wheat over alternative uses of Sudan's irrigated land resources in Gezira, this study uses the domestic resource cost (DRC) framework.[3] Results obtained from previous DRC studies in Sudan's irrigated areas are inconsistent (Nashashibi 1980, Ministry of Finance and Economic Planning 1982 and 1989, Sigma One Corporation 1983, Jansen 1986). Although most of these studies conclude that wheat has shown a comparative disadvantage, they have suffered from some common problems. First, none of them evaluated the efficiency of the potential new wheat production technology recently released and tested by ARC and SG 2000. Second, analyses and results were based on calculating nominal levels of costs and returns. No attempt was made to develop technical coefficients separate from prices. The results of these studies therefore were useful for only one year, as they could not be updated easily to examine the validity of the conclusions under changing relative prices, technologies, and policy environments. In this study, costs and returns are decomposed into technical parameters and prices to enable quick updating.

The DRC framework

To attract research and production resources, wheat must show a comparative advantage over alternative crops available to Gezira farmers. For wheat to be the most efficient user of Sudan's irrigated land resources, two conditions must be met:

1) Locally produced wheat has to generate foreign exchange earnings (savings) that exceed the value of traded inputs used in its production. In other words, the foreign exchange cost of producing wheat must be less than its import price.

[3] A comprehensive review of the DRC methodology is given in Morris (1989).

2) In addition, the foreign exchange savings in producing wheat must be greater than the opportunity cost of using domestic land, labor, and water resources in producing other crops, which can generate or save foreign exchange (e.g., cotton for export).

The DRC method provides the analytical tool for an empirical evaluation of economic efficiency among alternative enterprises. The basic formula used to generate DRC ratios is:

$$C_i = \frac{\Sigma_r N_r X_{ri}}{P_i Q_i - \Sigma_j R_j Q_{ji}}, \qquad (1.1)$$

where C_i measures the value of domestic resources used in saving or generating a unit value added in activity i; N_r is the opportunity cost of a unit of non-tradable primary factor r; X_{ri} is the quantity of factor r used in activity i; P_j and Q_j are the import or export parity price and quantity of tradable product i; and R_j and Q_{ji} are the import or export parity price and quantity of tradable input j used in activity i.

The denominator of Equation 1.1 derives value added in activity i (VAD_i), and the numerator calculates the economic value or cost of domestic resources (CDRS) used to produce Q_i. When CDRS is expressed in local currency and VAD in foreign currency, C_i computes the DRC ratio of activity i. Thus the DRC analysis measures relative efficiency in terms of the cost in local currency of domestic resources required to save or generate one unit of foreign exchange. This coefficient is then compared to the effective or parallel exchange rate.

If:

$DRC_i < e$, then the country has a comparative advantage in producing commodity i.

But if:

$DRC_i > e$, there is no comparative advantage. In other words, in the case of Sudan, it would cost more Sudanese pounds (£s) to produce one unit of commodity i locally than to buy the same unit abroad.

An alternative measure of economic efficiency that is easier to interpret is the resource cost ratio (RCR). The RCR is obtained from Equation 1.1 when both the numerator and denominator are expressed in the same currency units. The RCR value is then interpreted as follows:

$0 < RCR_i < 1$	implies that value added per unit of product i is larger than the value of domestic resources used to produce that unit; thus i has comparative advantage.
$RCR_i > 1$	implies that the value of domestic resources used to generate one unit of i is greater than the value added per unit of i; thus there is no comparative advantage.
$RCR_i < 0$	implies that the value of the tradable inputs used to generate one unit of i is larger than the unit price of i (negative value added); hence there is a net loss of foreign exchange and no comparative advantage.

Social profitability, measured as the net economic benefit (NEB) from activity i, is obtained by subtracting the numerator (CDRS) from the denominator (VAD) of Equation 1.1. The NEB criterion is therefore equivalent to the RCR with terms rearranged.

The major difficulty with using DRC and RCR methods arises in valuing inputs and outputs. This is particularly so when choosing the appropriate opportunity cost of non-traded primary factors such as land, labor, capital, and water, especially when no market for the factor exists. Similarly, prices of tradables often do not correspond to their true economic value because market imperfections and government intervention to control prices and ration the distribution of goods result in distorted prices. The DRC framework therefore distinguishes between social or economic and market (private) prices.

Private profitability (i.e., profitability calculated using market prices) is the criterion used by farmers to assess and compare alternative plans open to them for exploiting resources at their disposal. Prices paid and received by farmers, however, often do not reflect the true economic cost of resources used and products generated because of various market distortions such as taxes, subsidies, and other restrictions on prices and trade commonly imposed by government agencies for various purposes. Choices made by individual producers may not correspond to the social optima and could lead to inefficient allocation of the country's resources.

In this study, in order to calculate a measure of the economic efficiency of local wheat production from the national viewpoint, prices are based on opportunity values, such as the price of imported wheat valued at the equilibrium exchange rate. The DRC analysis uses these economic prices to assess the comparative advantage of various alternatives. Table 1.2 defines some measures of profitability, comparative advantage, and policy distortions.

The analysis of profitability and computation of RCRs therefore begins by determining social prices of inputs and outputs and constructing enterprise budgets. In Chapter 4 we derive social prices, develop detailed farm budgets, compare private and social returns, and compute indicators of economic efficiency for wheat and competing crop enterprises in Gezira using the RCR framework. However, before proceeding to the analysis, some background on Sudan's wheat subsector and wheat production practices in Gezira is necessary.

Table 1.2. Measures of economic efficiency and policy distortions

	Tradables			Non-traded domestic resources
	Products		Inputs	
1. Value at market prices	MP		MR	Y
2. Value at social prices	P		R	N
3. Policy effect (tax/subsidy)	MP-P		MR-R	Y-N
4. Private profitability	PP	=	MP-MR-Y	
5. Social profitability	SP	=	P-R-N	
6. Nominal protection ratio	NPR	=	MP/P	
7. Effective protection ratio	EPR	=	(MP-MR) /(P-R)	
8. Total net policy effect	NPE	=	PP-SP	
9. Value added	VAA	=	P-R	
10. DRC ratio	DRC	=	N/(P-R)	

Source: Adapted from Monke and Pearson (1989).

2

The Wheat Subsector of Sudanese Agriculture

The Setting

Before World War II, all wheat produced in Sudan was cultivated under irrigation along the banks of the River Nile north of Khartoum. Wheat was also consumed mainly in the northern region until the 1960s, when its consumption began to spread to other parts of Sudan (Salih 1983).

Wheat was first introduced in the central clay plains of Sudan south of Khartoum in 1942 on about 5,000 ha in the Gezira Scheme (Figure 2.1). However, wheat production was discontinued in Gezira from 1947 to 1959 because of poor yields, high production costs, and competition with cotton for labor for harvesting. Wheat production in Gezira was revived on 2,100 ha in 1959 after promising yield results were obtained on the Gezira research farm. Since then the land under wheat in the central plains of Sudan has increased substantially, especially in the Gezira-Managil and New Halfa Schemes. Although climatic conditions in these schemes are less favorable for wheat production than conditions in the northern part of the country, these schemes have abundant land. In addition, gravity irrigation systems in the New Halfa and Gezira Schemes provide irrigation water more cheaply than the pump systems used in the north.

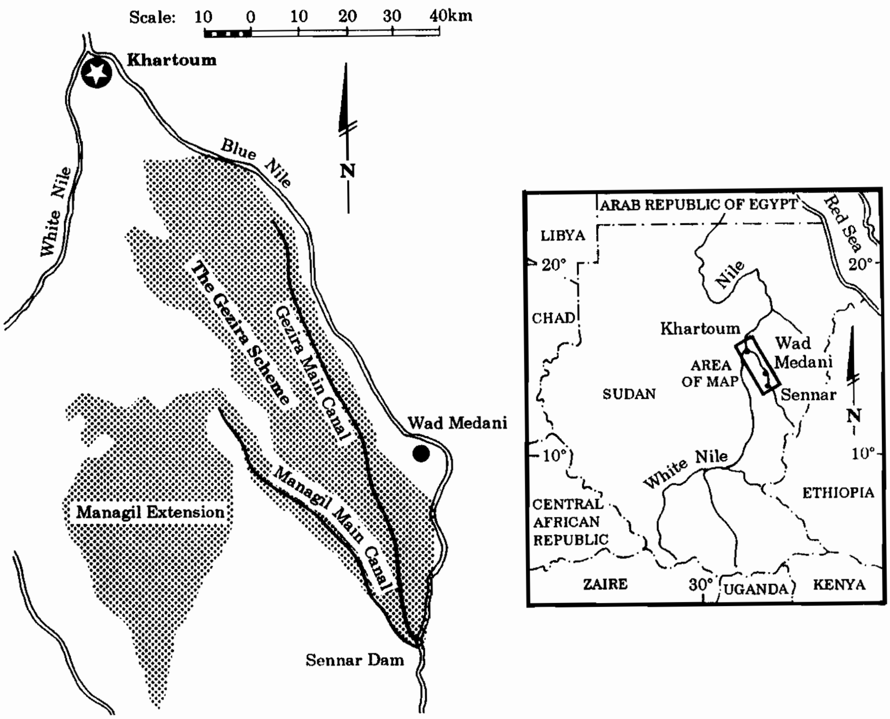

Figure 2.1. Location of the Gezira Irrigation Scheme, Sudan.

The largest expansion in wheat area has occurred in the Gezira Scheme. Increased supplies of irrigation water became available for Gezira in the early 1970s after a new dam was constructed on the Blue Nile south of the old Sennar Dam that supplied Gezira with water. The additional water enabled wheat area to reach an average of 207,000 ha between 1974 and 1979, with a very small coefficient of variation (C.V.) of 10% (Table 1.1). Gezira farmers produced an average of 200,000 t of wheat, which at that time was about 77% of the country's total wheat production. Since then both area and yields have declined considerably, mainly as a result of insufficient weed control and siltation of the irrigation canals (Plusquellec 1990). Between 1981 and 1988, wheat area in Gezira dropped to an average of 104,000 ha, or about half the 1974-79 average. Average yields were about 1 t/ha.

Despite decreased production in the 1980s, the Gezira Scheme remained the main producer of Sudan's wheat, contributing on average more than 60% of total production (Table 1.1). During the same period, wheat area in the north fluctuated slightly around an average of 11,000 ha (Ministry of Agriculture 1989). Yields are higher in the north (1.8 t/ha), mainly because of the relatively cooler and longer winter and farmers' greater familiarity with the crop.

Factors Influencing the Comparative Advantage of Wheat in Gezira

Several factors affect the productivity and competitiveness of wheat in Gezira. The presence of higher value alternative crops such as cotton raises the opportunity cost of resources employed in wheat production. Production technology and input use levels, on the other hand, affect yield and hence returns to wheat. Input procurement and delivery systems, marketing of products, and pricing policies are also important in promoting or discouraging wheat production. The following paragraphs review the impact of these factors on wheat production in Gezira.

Proximity to consumption centers
The Gezira Scheme starts about 30 km south of Khartoum, the largest city and hence the biggest wheat consumption center in Sudan. This gives Gezira wheat a significant advantage over imported wheat, as the only port (Port Sudan) is more than 1,000 km from Khartoum. The cost of transporting wheat between Port Sudan and Khartoum is approximately £s 400/t, which amounted to more than 19% of the border price of wheat in 1989, at the average exchange rate of £s 12.2/US$ 1.0 (Table 2.1). Moreover, milling capacity is concentrated around Khartoum. This means that Gezira wheat is processed and delivered to consumers at a lower transport cost than imported wheat, which needs to be moved inland from Port Sudan for milling and distribution. The extraction rate in milling local wheat (80%) is also higher than imported wheat (70%). In the absence of quality differences, this is one more advantage for Gezira wheat.

Competition for resources
Wheat in Gezira is grown in a four-course rotation, preceded by cotton and followed by a combination of groundnuts and sorghum and then fallow. The crop rotation is depicted together with the irrigation schedule in Figure 2.2 and Table 2.2. Each farmer in the scheme is allotted a tenancy of 8.4 ha. There is no double cropping in the Gezira Scheme. Every year the 8.4-ha tenancy is divided into four plots of 2.1 ha each. Land allocation to wheat and cotton is decided by the Gezira administration. Farmers are required to devote one plot to cotton, another to wheat, and to leave the third plot fallow. The remaining land (the fourth plot) is allocated between sorghum and groundnuts. The four phases of the rotation are completed over four years as the different crops or fallow replace one other on each plot according to the sequence shown in Table 2.2. Competition among the four crops for resources is influenced by irrigation capacity and the cropping sequence and calendar.

Land and irrigation water—Cropping intensity in the Gezira Scheme averaged only 62% between 1974-79 and 1988-89 (Plusquellec 1990). Currently the Gezira irrigation network can support only 50% cropping intensity — that is, only 50% of the land can be irrigated at one time. By introducing wheat as a winter crop in the rotation, 75% cropping intensity is being achieved on the 0.88 million hectares comprising the Gezira and Managil Extension Schemes. Bottlenecks occur, however, when some operations overlap. Nevertheless, 210,000 ha (25% of the land) remain idle during the fallow phase, indicating that area planted to wheat (210,000 ha) can be doubled easily if irrigation capacity is increased.

Table 2.1. Exchange rates in Sudan (Sudanese pounds, £s, per US $1.00)

	Average annual exchange rate				
	1988	1989	1990	Nov. 1991	Mar. 1992
Official rate (e_0)	4.5	4.5	4.5	15.0	89.7
Parallel market rate(e_p)	10.0	12.2	12.2	30.0	89.7
Free market rate (e_f)	14.8	20.6	24.6	70.0	94.0
Effective rates (e_i)					
Wheat	8.0	12.2	12.2	30.0	89.7
Cotton	4.5	5.5	8.0	12.0	72.5
Machinery	6.4	8.6	9.3	20.0	72.5
Fertilizer	4.5	4.5	5.5	12.0	72.5

Source: Unpublished records of The Agricultural Bank of Sudan, the Sudan Gezira Board, the Rahad Agricultural Corporation, Customs Department (Khartoum), and Wheat and Cotton Pricing Committees; *Annual Report* of The Bank of Sudan (1989, 1990, 1991); *International Financial Statistics* (1991); El Badawi (1990); Ministry of Planning (1992), and Al Ingaz Alwatani (1992).

Insufficient irrigation water is therefore the main factor limiting the expansion of wheat area in Gezira. Wheat area frequently has been reduced because of water shortages. Except for the 1975, 1976, 1991, and 1992 seasons, wheat has never used its full share of land in Gezira. In fact, on average only half of the total area allowed was sown to wheat over the past 10 years (Table 1.1).

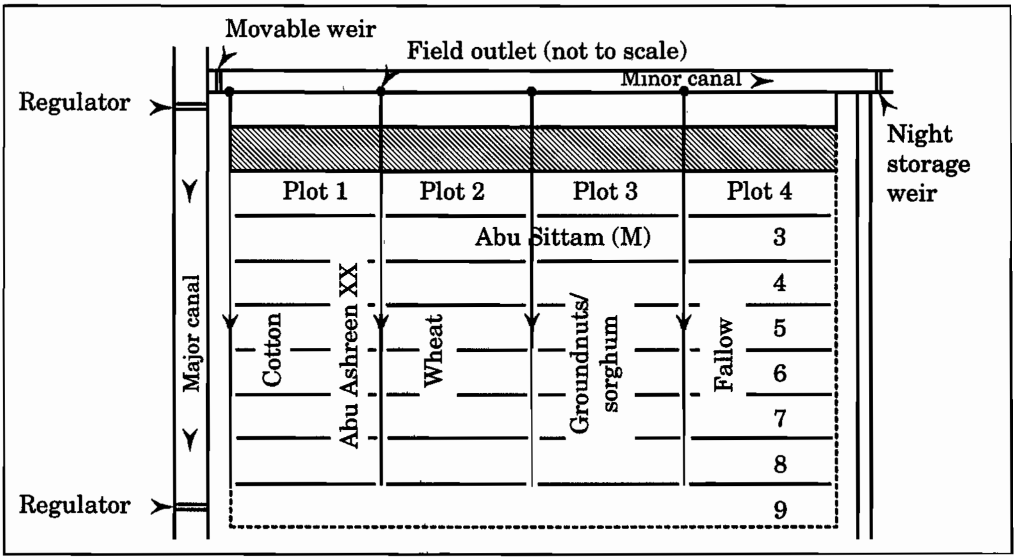

Figure 2.2. Typical field layout showing crop rotation and irrigation schedule, Gezira, Sudan.

Table 2.2. Crop rotation in the Gezira Scheme, Sudan

	Crop tenancies				
Year	**Plot 1 (2.1 ha)**	**Plot 2 (2.1 ha)**	**Plot 3 (2.1 ha)**	**Plot 4 (2.1 ha)**	**Total farm size (ha)**
Year 1	Cotton	Wheat	Groundnuts/ sorghum	Fallow	8.4
Year 2	Wheat	Groundnuts/ sorghum	Fallow	Cotton	8.4
Year 3	Groundnuts/ sorghum	Fallow	Cotton	Wheat	8.4
Year 4	Fallow	Cotton	Wheat	Groundnuts/ sorghum	8.4

Note: Although the groundnut/sorghum tenancy is mainly devoted to a combination of groundnuts and sorghum, at certain locations farmers are allowed to grow vegetables.

Even though land is not yet a limiting factor for expanding wheat production in Gezira, wheat competes with the other crops in the rotation, mainly cotton, for irrigation water. Figure 2.3 shows that only cotton remains on the land after wheat is planted (P) and hence competes with wheat for irrigation water. The peak demand for water occurs between mid-October and mid-November, especially when the sorghum and groundnut harvest (H) is delayed and overlaps with the first irrigation and planting (P) of wheat.

Labor and mechanical power—Wheat cultivation in Gezira is highly mechanized and unlike cotton requires little labor. Table 2.3 compares the number of person and machine hours used per hectare of wheat and cotton by activity. As indicated in Figure 2.3, only three major operations overlap in wheat and cotton production: irrigation, weeding, and harvesting. The fact that wheat is not weeded and is harvested mechanically, whereas cotton weeding and harvesting are labor intensive, means that competition for labor and machinery between the two crops is minimal.

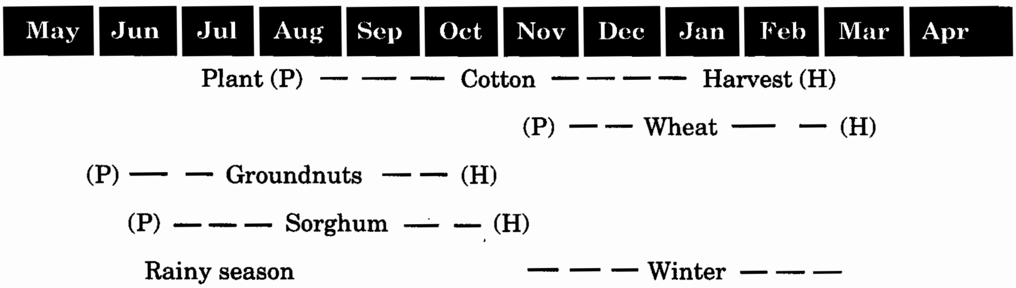

Figure 2.3. Crop calendar, Gezira, Sudan.

Table 2.3. Person and machine hours for different crop operations, per hectare of wheat and cotton, Gezira Scheme, Sudan

	Person h/ha			Machine h/ha		
Operation	**Traditional wheat[a]**	**Full package wheat[b]**	**Cotton**	**Traditional wheat[a]**	**Full package wheat[b]**	**Cotton**
Land preparation and planting	9.5	6.3	14.1	1.9	6.3	6.2
Weeding	0.0	0.0	71.6	0.0	0.0	0.0
Irrigation	47.6	60.7	79.9	0.5	0.5	0.5
Harvesting	18.3	21.1	235.1	0.7	0.7	0.0
Other	5.2	3.1	32.0	0.0	0.0	0.0
Total	80.6	91.2	433.7	3.1	7.5	6.7

[a] Wheat practices followed by most farmers in the Gezira Scheme (see Table 3.1 for a list of the components of this technology).
[b] The new wheat technology package fully applied (see Tables 3.1. and 3.5).

To summarize, in Gezira cotton is the major crop that competes with wheat for resources, and irrigation water is the most scarce resource. Both extra-fine cotton (Barakat and Tokar, long-staple cottons) and fine cotton (Maryoud, Huda, and Shambat B, medium-staple cottons) are grown in Gezira. Medium- and long-staple cotton differ in lint quality and agronomic performance. The fibers of long-staple cotton have superior strength and durability and therefore command much higher prices. Medium-staple cotton, on the other hand, has higher yields and tolerance to pests and drought stress.

Technology and yield-influencing factors
Results of experiment station and on-farm trials by scientists at the ARC in Sudan over the past five years (ARC/ICARDA 1988, 1989, 1990) indicate that the important factors affecting wheat production in Gezira are:

- temperature, cultivar, and sowing date;
- crop establishment practices;
- nutrients;
- irrigation practices; and
- harvesting date.

These factors and some of their interactions are discussed below.

Temperature, cultivar, and sowing date—The most important single factor affecting wheat productivity in Gezira is probably weather, especially winter temperature, which is critical for optimal sowing of wheat. High temperatures reduce yield potential at the flowering and grain filling stages. In the 20 years between 1965-66 and 1984-85, minimum temperatures ranged between 14°C and 19°C in early December and 11°C and 16°C around mid-January. Maximum temperatures were high, however, ranging between 30°C and 37°C within the last 10 days of December and through January (ARC 1990). These two months coincide with flowering and grain filling, depending on the sowing date. Accordingly, researchers recommend replacing the relatively long-season cultivar Giza 155 with shorter cycle, higher yielding cultivars such as Mexicani, Condor, and Debeira. These cultivars, which respond to high fertilization, occupied 95% of the total wheat area in Sudan in 1989-90.

In the past, researchers recommended that wheat sowing take place from mid-October to mid-November. However, actual planting extends over a longer period because of difficulties with irrigation water supply and land preparation (Faki and Abdel Fattah 1986). More recent research has shown that for the varieties currently grown, later planting in November leads to higher yields (Ageeb et al. 1988, 1989). The recommended sowing date has therefore been changed to extend through November, preferably between the 12th and the 26th, so that the critical physiological stages for the new varieties coincide with the coolest part of the growing season. Sometimes sorghum and groundnuts are planted late and continue to receive water in November, leading to very late sowing of wheat as a result of water shortages. The area that can be sown to wheat annually in the Gezira Scheme is thus influenced by the availability of irrigation water as well as by sorghum and groundnut production. The Gezira administration currently emphasizes timely sowing and harvesting of groundnuts and sorghum.

Crop establishment—A number of practices, including land preparation operations, seed rate, and sowing date and method influence crop stand and yields. Land preparation is done mechanically. It involves a ridging operation and levelling using a tractor-drawn metal bar. Seed is then broadcast by hand. Disc plowing, harrowing, and mechanical sowing are not common. Precision in land preparation operations, especially in levelling land and broadcasting seed, is critical for uniform plant growth, optimum plant population, and avoidance of waterlogging (to which wheat seedlings are very sensitive). Where farmers can apply a pre-sowing irrigation, crop stands are much better. A survey conducted in 1985-86 (Faki and Abdel Fattah 1986) showed that the degree of levelling and the presence of patchiness and weeds were important factors affecting wheat yields.

The recommended seeding rate used to be 120 kg/ha. Some farmers, aware of shortcomings in their land preparation, sow more seed. At present, the Gezira administration provides farmers with 145 kg of seed per hectare.

Nutrients—Research recommendations call for nitrogen in the form of urea to be applied at a rate of 86 kg/ha at sowing or before harrowing. However, delays in providing fertilizer sometimes result in late application. The grain yield response to nitrogen is high, especially with the high yielding cultivars. Using experiment station data, researchers estimated that optimum economic levels of nitrogen range between 79 and 105 kg/ha for the cultivar Condor and between 88 and 112 kg/ha for the cultivar Mexicani (ARC 1990). Further researcher-managed on-farm trials found the application of nitrogen and phosphorus to be more profitable than the application of nitrogen alone (Ageeb, Mohamed, and Faki 1986). Phosphorus in the form of triple super phosphate (TSP) is now recommended to supplement the nitrogen dose. However, this recommendation was practiced only in on-farm trials to verify the effects of a package of technologies on wheat yields. The trials, conducted from 1985-86 to 1988-89, yielded positive results (ARC/ICARDA 1987, 1988, 1989), and the Gezira administration is on its way to implementing the package on a larger scale.

However, a broad fertilizer recommendation for an irrigation scheme as large as Gezira is not expected to lead to an economically optimum use of inputs. Soils in Gezira differ in their nutritional status and thus require different levels of fertilizer application and nutrient mixes.

Irrigation practices—Water is fed to Gezira by gravity flow from the Sennar Dam on the Blue Nile through a network of irrigation canals. Figure 2.1 shows how two main canals (the Gezira and Managil Canals, running 261 km) deliver water from the source at the southern end of the Gezira Scheme into a distribution network of about 150,000 km (Plusquellec 1990). This indicates the long distance water has to travel to reach many farmers at remote locations in Gezira, and also indicates the losses en route.

The research recommendation is that irrigation should commence every fortnight during the vegetative stage and every 10 days during flowering and grain filling for a total of seven to eight irrigations. In practice, water supply problems keep the number of irrigations well below the recommended number. Moreover, for well-controlled irrigation, a 2.1-ha wheat field should be divided into 56 small basins. Fields with large basins are common, and farmers often allow water to flow into the field unattended, sometimes at night. The 1985-86 field survey showed that farmers who applied an average of 7.8 irrigations obtained yields 23% higher than the average in the Gezira Scheme, realized with 5.7 irrigations, and 43% higher than yields obtained under 4 irrigations (Faki and Abdel Fattah 1986). Experiment station and researcher-managed on-farm trials indicated that a profitable yield increase of 750 kg/ha could be obtained with the application of 8 versus 5 irrigations (Ageeb, Mohamed, and Faki 1986).

Harvesting date—Farmers sustain sizeable losses in the Gezira Scheme because the limited availability of combine harvesters delays harvesting. Moreover, the wheat harvest coincides with that of sorghum in the large mechanized rainfed areas in eastern Sudan. Competition between the two crops is high and wheat harvesting often has to wait for a mobilization of combines from the sorghum-producing areas. Regression analysis of field data collected from a pilot project to promote wheat technology in the Gezira Scheme showed a loss of 6% occurring when harvesting was delayed (Faki and Ismail 1989).[4]

Marketing, exchange rate, and pricing policies

The Sudan Gezira Board (SGB), which administers the Gezira Scheme, performs most mechanical operations required for producing cotton, whereas the majority of farmers hire private machine services for wheat. The rates paid by farmers to machine owners, however, are set by the SGB. The Gezira administration distributed all fertilizer and seed for both crops at set prices. The SGB also provides credit under easy terms for financing cotton operations and contracts for chemical spraying with private firms. Farmers supply labor and working capital and are required to deliver their harvested cotton and wheat to the government, again at prices set by the government. Out of each farmer's gross returns, the SGB deducts charges for mechanical operations, materials, loans, and other services provided by the Gezira Scheme, as well as a fixed land and water charge on all crops.

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[4] Less significant factors depressing wheat yields include noxious weeds and insect pests. Gezira wheat farmers report that they do not weed wheat and mention rare cases of insecticidal spraying to counteract aphid infestations.

The Cotton Board processes and markets the cotton crop on behalf of the farmers, and wheat is taken to mills where the government controls its distribution thereafter. Sorghum and groundnuts, on the other hand, are sold by farmers to private traders. Wheat and cotton prices as well as land and water rates are determined every year by special committees. Farmers receive the border price equivalent minus processing, transport, and handling margins.

Before February 1992, different exchange rates were applied to different commodities. The government used to maintain two rates for exchanging foreign currency. One rate (£s 4.5 per US$ 1.0) was used for official transactions, and a parallel rate of £s 12.5 per US$ 1.0 was used for commercial purposes (Table 2.1). Both rates were considerably below the black market exchange rate (Table 2.1), which was much more risky because of the penalities (even the death sentence) applied to those caught converting foreign exchange at this rate. These exchange rates have been applied in different ways at different times to various crop outputs and inputs to give an effective rate at which the value of output/input is converted to local currency (Table 2.1).

In February 1992, Sudan adopted a flexible exchange rate regime pegged to the US dollar (adjustable-peg). Though the new rate was unified for all commodities and transactions, an exchange rate tax was maintained on cotton exports. Imports of fertilizer and agricultural machinery continued to enjoy an exchange rate subsidy relative to other imports (Table 2.1).

Wheat imports have now been moved from the official to the parallel rate, whereas cotton is purchased at a relatively lower official rate. This has provided a strong incentive for wheat production in Gezira and other parts of Sudan. A parallel market price for wheat also existed; the market price in the 1990 season was double the official procurement price. The existence of this parallel market suggests that there was excess demand for wheat at the official consumer price (a result of the quota on wheat imports). The high price differential motivated farmers to under-report their wheat production and sell in the free market (Salih 1983, Damous 1986, Hassan 1989).

The official exchange rate was used to price fertilizers. The effective exchange rate that applied to various types of machinery averaged £s 9.3 per US$ 1.0 in 1990, intermediate between the official and parallel rates. A parallel market for fertilizer emerged, due to several restrictions on fertilizer marketing and distribution, in addition to farmers' increased awareness of the high returns to fertilizer under the new technology and the high price subsidy. In 1990, nitrogen and phosphorus fertilizers were sold in the free market at a price 50% higher than the official Gezira price of £s 1,487/t. In 1992, the producer price of wheat was also decontrolled, and farmers were allowed to sell their produce directly in the market. Cotton is still delivered to the marketing board and fertilizer imports and distribution have not been liberalized.

3

Traditional and Improved Wheat Production Practices in Gezira

Over the past 20 years, average wheat yields in Gezira have remained at a very low level of 1.3 t/ha, partly because of the production practices in use. Conventional land preparation consists of only two ridging operations. Seed is broadcast by hand at an average rate of 120 kg/ha, leading to irregular plant spacing and low plant density. Disc harrowing, levelling, and mechanical sowing were not used. Farmers applied only nitrogen fertilizer to wheat, broadcasting it manually and at very late dates. The average amount of nitrogen fertilizer applied to wheat during 1978-88 was only 24 kg/ha (SGB 1989). During the 1990 season Gezira wheat received an average of 5 irrigations (SGB 1990); very few farmers applied more than 5 irrigations to wheat over the growing season, which extends more than four months (Table 3.1).

A new package of improved wheat production practices has been extensively tested under farmers' conditions in Gezira over the past five years. On-farm testing of the new technology was conducted as part of the ARC/International Center for Agricultural Research in the Dry Areas (ICARDA) pilot project for verification and adoption of improved wheat technologies in Sudan. The project started in 1985 with funding from the Organization of Petroleum Exporting Countries (OPEC) and the Government of the Netherlands and technical backing from ICARDA and CIMMYT (ARC/ICARDA 1988, 1989, 1990). Results of on-farm research indicated the high potential gain in wheat yields from good seedbed preparation, optimal sowing by machine, and timely application of

Table 3.1. Wheat technologies in Gezira, Sudan

Practice	Traditional technology	Potential intermediate technology (Gezira Pilot Farm)	Potential full package (ARC technology)
Seed rate (kg/ha)	120	143	143
Nitrogen (kg/ha)	43	86	86
Phosphorus (kg/ha)	0	0	43
Disc harrow	No	Yes	Yes
Number of irrigations	5	6	7
Levelling	No	Conventional	Precision
Planting method	Broadcast	Mechanical	Mechanical
Yield (t/ha)	1.28	1.90	3.10

adequate amounts of water. Based on that research, the following package is promoted by the ARC for Gezira wheat farmers:

1. Replacing the long-season variety Giza 155 by the relatively short-maturing semidwarf wheat cultivars Condor and Debeira, which respond to high fertilization and yield better.

2. Disc harrowing and levelling to improve crop establishment and avoid waterlogging.

3. Mechanical planting on 20-cm rows at a seeding rate of 143 kg/ha for optimum population, uniform plant growth, and better root development.

4. Planting between 12 and 26 November.

5. Mechanical application of 86 kg/ha nitrogen immediately before planting, and a seed dressing of 43 kg/ha phosphorus.

6. Irrigating seven to eight times at 14-day intervals.

Over the past five years, versions of this package have been tested independently on farmers' fields in Gezira by ARC, SG 2000, and the SGB. The ARC demonstration plots featured the full package described above and in Table 3.1, whereas SG 2000 tested several combinations of the package components on farmers' fields, varying the number of harrowings and irrigations, and comparing mechanical planting and fertilizer application to broadcasting. The wheat package was also tested on the World Bank-funded Gezira Pilot Farm, but without phosphorus and with less than 7 irrigations on average (Table 3.1). Results from these trials are given in Tables 3.2 and 3.3, together with other data on farmers' current practices.

Table 3.2 shows the wide gap between yield levels realized under current practices (row 4) and those obtained with improved methods (rows 1-3). Row 4 also indicates that average yield levels in Gezira have improved over the last four years as a result of partial adoption of the improved wheat production methods by some farmers.

The relatively higher adoption rates among SG 2000 farmers compared to the average across the Gezira Scheme explains the wide productivity gap between the two groups. Farmers participating in SG 2000 demonstrations are selected by the Department of Agricultural Extension of the SGB. Demonstration sites are changed every year to test the new technology under a range of farm conditions and to diffuse the package to more farmers across Gezira. Extension personnel together with SG 2000 staff explain the advantages of the recommended practices, supervise their application, facilitate early arrival of machinery and inputs to participating farmers, and supervise application of the

Table 3.2. Wheat yields under various levels of technology and mean monthly temperatures, Gezira, Sudan, 1986-91

	1986-87		1987-88		1988-89		1989-90		1990-91		Average yield over five years (t/ha)
	Yield (t/ha)	Area (ha)	Yield (t/ha)	Area (ha)	Yield (t/ha)	Area (ha)	Yield (t/ha)	Area (ha)	Yield (t/ha)	Area (ha)	
Technology level[a]											
1. ARC plots (full package)	(3.8)	45	(3.7)	45	(4.6)	45	(..)	0	(2.7)	25	3.7
2. SG 2000 demonstrations	(2.9)	41	(2.2)	1,051	(3.2)	975	(2.8)	1,635	(..)	..	2.8
3. Gezira Pilot Farm	(..)	0	(2.1)	320	(2.6)	380	(2.6)	572	(2.1)	25,000	2.3
4. Average, all Gezira Scheme	(1.2)	75,630	(1.3)	106,302	(1.5)	115,261	(1.4)	164,706	(1.1)	250,000	1.4

Mean monthly temperature	Max. (°C)	Min. (°C)	Max. (°C)	Min. (°C)	Max. (°C)	Min. (°C)	Max. (°C)	Min. (°C)	Max. (°C)	Min. (°C)	Long-term average[b] Max. (°C)	Long-term average[b] Min. (°C)
November	37.0	19.3	38.0	19.6	36.7	20.2	37.5	19.4	38.9	20.8	36.0	18.3
December	32.1	13.2	34.0	16.1	35.2	17.3	32.3	14.4	37.4	19.2	33.5	15.7
January	33.7	14.1	33.1	15.0	29.0	11.0	33.4	15.2	32.1	13.7	32.8	14.5

Source: Agricultural Research Corporation (unpublished reports, 1990); Sudan Gezira Board Annual Report (1989, 1990) and SG 2000 Annual Report (1989, 1990).

[a] Table 3.1 describes the ARC full package wheat technology and the Pilot Farm technology. The SG 2000 demonstrations are described on page 20.

[b] Average over 20 years (1965-85).

technological components in farmers' fields. These farmers therefore can be considered favored, as they enjoy relatively more timely and adequate delivery of the recommended inputs. However, the higher adoption rates and wheat yields of former SG 2000 farmers indicate the effectiveness of SG 2000 field demonstrations as an extension program.

Adoption Patterns and Causes of Variation

It has been argued that one major reason for low wheat yields and the wide gap between potential yields and farmers' yields is slow adoption of the recommended package of improved practices (Hassan and Ageeb 1992, Faki 1991). These studies have suggested that because of problems associated with availability of inputs, particularly fertilizer and irrigation water, many farmers could not use the full package of technologies. Table 3.3 gives examples of the partial adoption of improved wheat technologies in Gezira. Several patterns are displayed by the data in Table 3.3.[5]

1. A very small proportion of farmers applied the new practices, except for sowing before the end of November; hence there is a large gap between yields obtained by using the ARC full package of technology and the average yield for the entire Gezira Scheme.

2. Adoption rates among farmers who participated in SG 2000 demonstrations in 1989 were higher. These former SG 2000 farmers achieved yields more than 60% higher than the Gezira Scheme average, indicating the impact of SG 2000 in disseminating the new technology.

3. The "All-Gezira Scheme average" column shows that rates of adoption are much lower for the recommended number of irrigations and fertilizer rates than for improved varieties and the mechanical practices.

4. It is also clear that even former SG 2000 farmers still apply suboptimal rates of phosphorus and irrigation, as well as continue to broadcast fertilizer by hand.

5. Almost all farmers used the recommended varieties Condor and Debeira. Very few farmers were supplied seed of Giza 155 in 1990; only 13 of the SG 2000 farmers (12%) sowed Giza 155 in 1989.

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[5] Similar findings were reported for the 1990-91 season by 214 wheat farmers surveyed in Gezira. The farmers were split equally between those who used the full package of ARC technology and those who did not (Faki 1991).

Clearly, mechanical technologies (except for fertilizer application) have been adopted more widely than recommendations concerning fertilizer use and irrigation. Whereas the Gezira Board is responsible for procuring and distributing the seed and fertilizer needed by farmers, private dealers in Gezira

Table 3.3. Farmers' adoption of components of the improved wheat technology in Gezira, Sudan, 1989-90

Technology component	All-Gezira Scheme average	ARC full package farmers	SG 2000 farmers	Former SG 2000 farmers
Percent use improved variety				
Condor	58	100	56	100
Debeira	40	0	33	0
Giza 155	2	0	11	0
Percent use machinery				
Disc harrow	40	100	90	62
Levelling	31	100	100	100
Mechanical planting	44	100	79	54
Mechanical application of fertilizer	8	100	62	5
Fertilizer				
Percent use recommended N dose (kg/ha)	22	100	98	92
Average N level used (kg/ha)	59	86	82	76
Percent use recommended P dose (kg/ha)	18	100	92	72
Average P level used (kg/ha)	8	43	26	34
Optimal application date	11	100	78	71
Other				
Percent sow on optimal date	97	100	96	100
Percent receiving first irrigation at optimal date	80	100	90	86
Optimal number of irrigations	16	100	80	74
Average number applied	5.0	7.4	6.2	6.4
Average yield (t/ha)	1.4	4.7	2.8	2.3
Number of farmers	80,018	18	111	111

Source: Ageeb et al. (1990), Sudan Gezira Board *Annual Reports* (1989, 1990), survey data (1989-90), SG 2000 *Annual Reports* (1989, 1990), and Faki (1991).
Note: The components of these technologies are described in Table 3.1 and on page 20.

rent out equipment or provide services to farmers for most mechanical operations. The level and timeliness of fertilizer applications are accordingly beyond farmers' control, whereas private market arrangements seem to function more efficiently in delivering machinery services. This could be the main reason for farmers' lower adoption of the chemical components of the new technology compared to the mechanical ones. Similarly, the number of irrigations farmers can apply to their wheat depends mainly on exogenous variables such as total water availability and the farm's location. Water is released into field canals by the irrigation authority according to an indenting system of requests made by Gezira field inspectors. Under the supervision of canal attendants, farmers discharge irrigation water from canals into their fields. Although farmers control the distribution of water along field canals, the total amount of water available in the system is a function of river water levels and decisions made by higher authorities to allocate water between irrigation, power generation, and domestic and other uses. This indicates that while the government monopoly in the fertilizer market is a barrier to higher adoption and productivity, physical and infrastructural constraints also limit the ability of Gezira farmers to exploit yield gains that could be obtained from adequate irrigation. On the other hand, the government seed supply system is effective, enabling the SGB to deliver seed of recommended cultivars to the vast majority of farmers.

Market distortions can be eliminated through more liberal policies for input procurement and allocation, whereas improving the supply and distribution of irrigation water may require substantial investment in rehabilitating the irrigation infrastructure to increase carrying capacity, conveyance efficiency, as well as the overall water supply. To improve water-use efficiency and contribute to higher productivity in Gezira, research is also required on more efficient methods of irrigation management at the farm level.

A follow-up survey of 111 former SG 2000 farmers was done in 1990. Those who had stopped using all or some components of the new technology were asked why they had done so. Nearly all farmers thought the new technology was profitable (that is, they wanted to use it), except for 10% of those who did not adopt harrowing, who considered the practice unimportant (Table 3.4). Also, 70% of those who did not apply enough nitrogen indicated that they would apply more if fertilizer were cheaper, implying that the recommended levels of nitrogen are not profitable. To a large extent, however, farmers agreed that they failed to adopt the new practices because they lacked access to inputs, which confirms the results of the previous analysis.

Farmers were asked to identify the most serious problem facing wheat production in Gezira in a survey done by the ARC/ICARDA project during the 1990-91 season (Faki 1991). Gezira farmers identified irrigation bottlenecks as the largest problem, followed by the amount and quality of seed, and pre-irrigation.

Among the many reasons that farmers have for accepting or rejecting a new technology, the following three factors are basic:

- **Profitability:** The new technology must show an economic advantage over existing practices (that is, generate positive net returns).
- **Knowledge:** Farmers must be aware of the new methods and their advantages.
- **Access:** The new inputs or methods must be available for farmers to use.

The most common criterion for assessing the economic advantage of new technologies is marginal analysis based on partial farm budgets. This method is suitable for analyzing data generated by on-farm trials, in which one or two treatments are varied at a finite number of fixed levels. In the survey data, however, levels of all treatments vary continuously, and hence it is difficult to estimate incremental gains and costs at discrete points where treatment levels change. The production function approach is employed to estimate technology parameters that measure the important interactions among the various yield

Table 3.4. Reasons given by former SG 2000 farmers for failure to adopt components of the new package of wheat technology, Gezira, Sudan, 1990

		Reason for not adopting (% of non-adopters)		
Technology component[a]	**Adopted (%)**	**Not available**	**Expensive**	**Did not want to adopt**
Mechanical				
Harrowing	62	90	..	10
Levelling	100	..	..	..
Mechanical sowing	54	98	..	2
Mechanical fertilization	5	99	..	1
Chemical				
Full nitrogen dose	92	31	69	..
Full phosphorus dose	60	93	7	..
Optimal application	74	100	..	..
Other				
More irrigations	66	100	..	..
Optimal sowing	100	..	..	..

[a] Rates given in Table 3.1.

influencing factors. The transcendental production function specified in Equation 3.1 is used to estimate a wheat yield response function.

$$\ln Y_w = \ln A + \Sigma_i \alpha_i \ln X_i + g(x), \qquad \textbf{(3.1)}$$

where Y_W refers to wheat yield and X_i measures variable levels of the continuous as well as discrete factors. Appendix A provides details of the functional form used to estimate the wheat yield response function and presents parameter estimates.

To determine whether components of the new package dominate existing practices, MPP (marginal phsyical product) and VMP (value of marginal product) were calculated using levels of input use under the improved technology and estimates of the production function parameters given in Table A.1 (Appendix A).

The marginal productivity of the inputs forming part of the new and traditional technologies is compared in Table 3.5. Mechanical application of fertilizer has the highest economic value, but it is the least adopted practice. Clearly the problem is one of access. Although capital constraints and input indivisibility are important barriers to acquiring the services of planters and fertilizer broadcasters, the fact that there is a private rental market for machinery

Table 3.5. Marginal productivity of inputs under the new and traditional wheat technologies in Gezira, Sudan

	Marginal product (kg/unit/ha)	Marginal value of product (£s/unit/ha)[a]	Price of input in 1990 (£s/unit)
Nitrogen (kg/ha)	20	61	2.5
Phosphorus (kg/ha)	163	189	4.1
Number of irrigations	161	183	37
Harrowing (Yes, No)	40	121	85
Levelling (Yes, No)	171	513	41
Mechanical sowing (Yes, No)	114	342	57
Mechanical application of fertilizer	192	576	36
Date of fertilizer application (weeks after sowing)	-40	-121	..
Sowing date (weeks from mid-November)	-10	-31	..

Source: Calculated from Appendix A.
Note: The components of these technologies are described in Table 3.1.
[a] Evaluated at the 1990 producer price of wheat (£s 3/kg).

services in Gezira indicates that low adoption of these practices is merely a question of availability. The market for machine services seems to be more efficient with respect to harrowing and levelling operations, as higher adoption rates exist among SG 2000 and former SG 2000 farmers, compared to adoption rates for mechanical sowing and fertilization.

Table 3.5 shows that all components of the new package raise yields and are profitable (VMP > price of input).[6] It also shows that all components dominate existing practices, as net positive gains are still feasible at higher levels of input use under the new package. There is no price for sowing date and time of fertilizer application. The model, however, computes a marginal value (cost) of £s 30/ha for every week that sowing is delayed after mid-November and £s 240/ha for every week that fertilizer application is delayed after sowing.[7] In summary, Table 3.5 indicates that all components of the new package are expected to be attractive to farmers if the components are accessible. This means that there is no evidence that economic inefficiency has caused the failure to adopt the new technology.

Characteristics of the New Technology, Variation in Farmers' Circumstances, and the Potential for Wheat in Gezira

The new wheat technology has been tested and promoted as a standard package to all farmers in the Gezira Scheme. While the package approach captures the benefits from positive interactions among the technological components, it does not generate adequate information for evaluating individual treatments or partial combinations of recommended practices. This kind of evaluation is a useful intermediate step in adaptive research, given that farmers have been found to adopt components of packages sequentially over time as they gradually learn about the new practices and adjust them to fit their particular circumstances (Byerlee and Hesse de Polanco 1986).

Blanket recommendations for all farmers in a scheme as large as Gezira will not lead to an economically optimum use of inputs. Soil characteristics, access to irrigation water and other inputs, temperature, and many other physical and

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6 The negative signs on dates of sowing and fertilizer application indicate an inverse relationship between yield and sowing after mid-November and late application of fertilizer (measured in weeks after sowing). These findings confirm the optimality of the improved package recommendations with regard to these two practices.

7 Results of research at the ARC, however, indicate that small yield losses are incurred if fertilizer application is delayed up to four weeks and that about 15% losses can be expected after the fourth week, amounting to about 0.5 t/ha (ARC 1988) or £s 1,500/ha at the 1990 price of wheat.

economic conditions vary significantly between farmers and locations in Gezira. Optimal levels and combinations of the practices that constitute the new technology may vary over different locations.

Previous studies have shown that irrigation water is distributed unequally among tenant farmers in Gezira, depending on where their farms are located in the irrigation network (Faki et al. 1984, Ishag and El Obeid 1989). Unequal distribution of irrigation water significantly affects wheat and cotton yields and net farm incomes, which tend to decline toward the tail ends of the irrigation system (Faki et al. 1984, Ishag and El Obeid 1989, Faki and Ismail 1989). This effect was not significant for groundnuts and sorghum, which are grown during the rainy season when more water is available. Wheat and cotton, on the other hand, complete critical phases of their physiological development over a period when no rainfall occurs and river water levels are low.

In addition to influencing access to timely and adequate supplies of water, farm location may also reflect variations in soils, temperature, rainfall, and weed infestation. Insufficient data on these factors prevented proper stratification of Gezira into agroclimatic zones. This study therefore adopts an arbitrary system to classify Gezira into three zones: South, Center, and North. Moreover, farmers are also stratified by location into "Head" and "Tail" groups to analyze how variations in location on the canal affect wheat production efficiency and the design of appropriate technologies.

The effects of seasonal and locational variability in farmers' circumstances on wheat yield in Gezira are presented in Table 3.6. The table shows that average yields are higher in the southern parts of Gezira and at the head of the canal for both seasons of the survey. Average yields, however, were much higher in 1989 than 1990. While December was warmer, January was cooler in 1989 compared to 1990. This variability indicates that choosing an optimal sowing date for wheat in Gezira is a complex management decision, given the uncertainty of weather. The high F-values of Table 3.6 also indicate the statistical significance of site and weather.

Table 3.7 presents estimates of the interaction parameters obtained from the wheat yield response function specified in Equation 3.1. The table confirms the ANOVA results of Table 3.6 on the statistical significance of the location in the Scheme, site on the canal, and year influences on wheat yields (after controlling for the effects of all other factors in the regression). The parameter estimates measure the contribution of each factor to the natural logarithm of wheat yield. The intercept parameter (d_l in Equation A.3 of Appendix A) measures the deviation of mean wheat yields under condition l from the overall average (shifting the common intercept up or down). The indirect effect of condition l is given by the interaction parameter d_{il} (shifting the slope or marginal product curve of factor i). According to Table 3.7, the marginal productivity (slope) of nitrogen and phosphorus fertilizers is lower in the southern parts of Gezira and at the head of the canal. This means that optimal levels of nitrogen and phosphorus should be lower on average in the south and at the head end of the canal, indicating that fertilizers are more productive at lower levels of irrigation and soil fertility (i.e., in the north). In other words, the application of sufficient water substitutes for high fertilizer levels, and more nitrogen is needed at the tail end. This result is consistent with the fact that soil fertility declines towards the north in Gezira and the productivity of nitrogen and phosphorus is relatively higher. On the other hand, agronomic research commonly finds a positive interaction between nutrient levels and moisture supply, which contradicts the implied substitutability of nitrogen and water levels in Gezira. While the lower productivity of nitrogen at the head of the canal, where relatively more water is applied, could be attributed to random sampling errors, further research and investigation are needed to generate better explanations for this finding.

Table 3.6. Effects of farm location and season on wheat yields (t/ha) in Gezira, Sudan (three-way ANOVA)

	South	Center	North	Average
1. 1989 season				
Head	1.53	1.18	1.57	1.36
Tail	0.90	1.17	1.35	1.13
Average	1.44	1.18	1.37	1.30
2. 1991 season				
Head	1.16	0.99	0.75	0.97
Tail	0.72	0.89	0.64	0.75
Average	1.16	0.92	0.66	0.91
Average	1.42	1.17	0.77	1.11
No. of farmers[a]	107	168	36	311
				F-value
Main effects				14.20 ***
1. Location in the Gezira Scheme (South, center, etc.)				0.95
2. Site on the canal (head, tail)				27.6 ***
3. Year				38.5 ***
2-way interactions				8.1 **
Total explained (main effect and interactions)				10.8 **

Note: ** and *** indicate significance at the 5% and 1% levels, respectively.

[a] Does not include SG 2000 farmers in 1990 (783) as no information was recorded on the farm site on the canal.

Table 3.7 also shows a significant interaction between site on the canal and number of irrigations applied. The interaction parameter indicates that the marginal contribution of an extra irrigation to yield is higher at the head end and hence more irrigations are used. This result implies that even if farmers can apply the same number of irrigations, the amount of water per irrigation delivered into fields is higher at the head end, and hence more irrigations are less efficient than more water per irrigation for the tail end farmer.

The results presented in Tables 3.6 and 3.7 clearly show the importance of defining recommendation domains in Gezira to permit more relevant technology recommendations to be tested with greater efficiency. More secondary and survey data need to be compiled, however, to identify significant spatial variations in factors critical to productivity in Gezira.

Table 3.7. Least squares estimates of the intercept and slope effects of farmers' circumstances on wheat yield (t/ha), Gezira, Sudan, 1988-89 and 1989-90

		Slope effects		
Source of variation	**Intercept effect**	**Level of nitrogen (kg/ha)**	**Level of phosphorus (kg/ha)**	**Number of irrigations**
1. Location				
South	1.469***	-0.026***	-0.023***	..
Center	1.347***	-0.041***	0.012**	..
North	-2.816***	0.067***	0.011	..
2. Site				
Head	0.310**	-.0036**	..	0.051**
Tail	-0.310**	+.0036**	..	-0.051**
3. Year				
1989	0.146***	..	..	..
1990	-0.146	..	..	..

Note: ** and *** indicate significance at the 5% and 1% levels, respectively.

4

Evaluating the Economic Efficiency of Wheat Production in the Gezira Scheme

Competing Enterprises and Feasible Wheat Technologies in Gezira

As seen in Chapter 3, different components of the new technology have been adopted to varying degrees by farmers in Gezira. While yield levels achieved under the full package of wheat technology are a feasible alternative for Gezira, not all farmers in Gezira may be able to obtain such yields, for several reasons.

First, the full package of wheat technology was tested by ARC in the fields of 18 farmers in only two of the 107 blocks in Gezira (there were nine cooperating farmers per block). This represents a relatively small demonstration of 45 ha compared to the 100,000 ha average total wheat area in Gezira during the period of on-farm testing. Second, yields achieved under large-scale testing of the new wheat technology by SG 2000 in fields scattered over 43 blocks across Gezira (1,635 ha in 1990) averaged 2.8 t/ha for the same period, only 75% of the average yield achieved in the ARC demonstrations (Table 3.1). Moreover, the average yield for the entire Gezira Scheme during the same period (1986-90) was 1.4 t/ha, or 40% of the 3.7 t/ha attained on the full package test plots. This wide yield gap needs to close if the efficiency of the new wheat technology is to be realized.

The quality and quantity of inputs applied and operations done under the supervision of ARC are considered the major reason behind the high yields achieved with the full package of wheat technology. The prospects for all farmers in Gezira to achieve the same precision and timeliness in applying the recommended technology are not very high, given the current adoption rates and farmers' current yields. This is particularly true for inputs such as irrigation water, for which the level and allocation are not controlled by farmers or the Gezira management.

As mentioned earlier, a farmer's ability to apply adequate water at the recommended time and frequency depends on several factors, including the total amount of water available in the Gezira network of irrigation canals and the location of the tenancy within the Gezira Scheme. The total quantity of water available to the system is a function of the amount of rainfall, river water levels, and the overall pattern of water use and distribution in Sudan. Only 16% of the Gezira farmers could apply 7 irrigations to their wheat in 1990. Even if all other inputs are made available at the right time to all farmers, irrigation water cannot be distributed evenly across the 0.88 million ha Gezira Scheme. A large number of farmers may be unable to apply enough water to achieve higher yields. Unless ways are found to improve the supply and distribution of irrigation water, Sudan should not consider it feasible for all farmers in Gezira to achieve the yields obtained in tests of the full package of wheat technology.

Furthermore, because inputs are sometimes not available or not delivered to farmers, farmers adopt only some components of the full ARC wheat technology. For that reason, the economic efficiency of wheat production in Gezira is evaluated here under three scenarios: the traditional practices that have dominated wheat production in Gezira, an intermediate method of wheat production used at the Gezira Pilot Farm, and the full package of new wheat production methods used in ARC demonstration plots. (The components of each technology are listed in Table 3.1 in the previous Chapter).

The intermediate technology deviates from the full package mainly in recommending no phosphorus, less than 7 irrigations, and conventional land levelling. Average yields obtained on the Gezira Pilot Farm (Table 3.2) are adjusted to levels attainable under farmers' conditions and management using the 82% achievement factor of former SG 2000 farmers indicated in Table 3.3 (that is, the ratio of yields achieved with and without SG 2000 supervision). The same achievement factor was used to adjust average full package yields obtained in ARC demonstrations, reflecting the effect of ARC management. The 20-year average yield of 1.02 t/ha of wheat (from 1967-68 to 1987/88), adjusted to reflect farmers' under-reporting of wheat yields in Gezira, was used to represent the yield level attainable under traditional practices. Earlier research estimated that wheat production in Gezira was under-reported by 25% (Saleh 1983, Hassan 1989). Thus the 25% factor was used to adjust the long-run yield trend for traditional wheat practices.

As noted in Chapter 2, irrigation water is the scarce resource in Gezira, and only cotton competes with wheat for water. Wheat is mechanically harvested and receives no weeding, compared to cotton picking and weeding, which are labor intensive; as no major operations except weeding and harvesting overlap, no competition was assumed between cotton and wheat for labor and machinery services. The DRC analysis that follows accordingly evaluates the economic efficiency of Gezira cotton as well as wheat in using Sudan's resources devoted to irrigated agriculture.

Farm Budgets and the Pricing of Tradables and Domestic Resources

Enterprise budgets were constructed for the profitability analysis. Technical coefficients were compiled from various sources for the physical input-output relationships associated with the production and marketing of wheat and cotton (Appendix B). Capital budgets were constructed to calculate the hourly cost of machinery services (Appendix C). Products and traded inputs were valued at their border price equivalents with transportation and handling costs added to imports and subtracted from exports (Appendix D). Several regimes, described below, were used to price inputs, services, and products.

Market pricing
Actual prices at which farmers buy inputs and sell output were used to compute private profitability. These prices, mainly determined by the government, contain various distortions resulting from overvalued exchange rates and indirect taxation on imports and exports. Different tradables had been valued at different exchange rates in Sudan (Table 2.1). Border prices were adjusted for handling and transport costs and all direct and indirect subsidies and taxes (Appendix D).

The average wage rate in the Gezira Scheme was used as the price of labor. Land, water, and capital, on the other hand, are not freely traded in Gezira, although the SGB charges farmers for their use. Appendix E describes the method employed by irrigation authorities to calculate water rates. The water rate charged by the Gezira Scheme for each crop appears as the "irrigation costs" item in the crop budget tables of Appendix F. Tenant farmers have access to subsidized credit from the SGB at 10% interest, whereas the commercial interest rate was around 20% in 1990. The effective price of capital (actual interest rate) was therefore considered to be 10% for computing private returns.

Economic prices
For the analysis of social profitability, world prices were converted into Sudanese pounds using estimated shadow exchange rates. Before the adjustable-peg regime was adopted in February 1992, none of the rates given in Table 2.1 provided an adequate estimate of the scarcity value of foreign currency in Sudan (El Badawi 1990, Brown 1992). The official and parallel rates set by the government overvalued Sudan's currency, but the black market rate, being illegal, contained a large risk premium. Although it is difficult to define an equilibrium rate of exchange under currency controls, attempts were made to estimate the shadow price of Sudanese currency.

Private and social profitability were compared and the extent of distortions in relative prices was examined for 1990, the year the surveys were conducted, and for 1992. The black market exchange rate prevailing in 1990 (£s 24.6) was used as the economic price of foreign currency in that year. The exchange rate set at £s 89.7 in February 1992 was used with trend prices to evaluate social profitability in 1992 and test the sensitivity of the results of profitability and DRC analysis to exchange rate adjustments.

While devaluation of the Sudanese pound in 1992 corrected for the deviation of the parallel exchange rate from its equilibrium level, the devaluation did not eliminate the relative price distortions caused when multiple official exchange rates are used for different commodities. Unification of the effective exchange rate on all tradables is therefore an important adjustment towards economic pricing. Prices of all imports and exports were accordingly calculated using the same exchange rate, set at its economic value.

As with the market for foreign exchange, there is more than one source and price for capital in the Gezira Scheme. These sources include: 1) subsidized credit extended by the SGB to its farmers at 10% interest, 2) the commercial rate of return on investment in the Islamic banking system of Sudan, which averaged above 20% in 1990 (survey of commercial banks, Khartoum 1990), and 3) the free market price prevailing in informal money markets, which ranged between 50% and 100% in 1990 (survey of wheat farmers in Gezira, 1990). The free market price is considered excessive due to the power of discriminating monopolists in non-institutional credit markets, as well as other risks involved. However, given that the rate of inflation was about 25% in 1989-90 (Ministry of Finance 1990), informal money markets provided the only investment with positive real returns. Sensitivity analysis was performed in this study by using two rates as the economic cost of capital to generate a real rate of return of 5% and 15%, respectively, given the current rate of inflation.

As the labor market is considered competitive in Gezira, the average wage rate in the Gezira Scheme was used as the economic price of labor. While there is a market and economic price for labor and capital, land and water are not traded in Gezira. The analysis therefore derives private and social returns to land and water.

Analysis of Relative Profitability

Net private and economic returns per hectare and per millimeter of irrigation water, derived (at 1990 prices) from the detailed crop budgets of Appendix F, are presented in Table 4.1. The table also computes the total net policy effect (NPE) and the effective protection ratios (EPR) defined earlier in the policy analysis matrix of Table 1.2.

According to Table 4.1, private profitability calculated at 1990 market prices (section A) indicates that wheat dominates cotton with the highest net returns realized for the full package of wheat technology. However, this ranking changes under economic pricing (section B). While full package wheat continues to generate the highest economic returns per millimeter of irrigation water, cotton dominates the intermediate and traditional wheat technologies, which are the most common in Gezira.

Economic pricing reveals distortions created by the various input and output pricing policies that were in effect in Sudan in 1990. Section C of Table 4.1 measures such policy distortions by calculating the NPE and EPR for the competing crop enterprises. The negative values of NPE and an EPR of less than unity indicate that both cotton and wheat producers were taxed heavily in 1990. Gezira tenants paid a tax on cotton of more than £s 14,000/ha if all tradables are valued at the economic exchange rate. This is equivalent to about £s 30,000 or US$ 1,200 per farmer (2.1 ha) at the economic exchange rate. On the other hand, Gezira farmers benefited from indirect subsidies on fertilizer and machinery through the overvalued exchange rates applied to these imports. At the economic exchange rate, however, the tax on product prices was higher in 1990 than the subsidy on prices of inputs used per hectare of wheat and cotton. Table 4.1 shows that if the free exchange rate of £s 24.6/US$ 1.0 was the economic price of Sudanese currency in 1990, traditional wheat growers in Gezira paid a net tax of more than £s 30,000 (or US$ 1,300) on their cotton/ wheat tenancies, i.e., US$ 620/ha.

These results indicate that cotton production bears a much higher tax compared to wheat in Sudan. Such distortions in relative prices and terms of trade bias the structure of incentives against cotton and lead to inefficient allocation of productive resources away from cotton and into wheat. In brief, Table 4.1 says that unless the improved wheat production technology of ARC is adopted fully, wheat cannot compete with cotton for an economically optimal allocation of productive resources in Gezira. Although both cotton and wheat are taxed, farmers will continue to earn higher returns on wheat than cotton if current price policies continue to tax cotton production relative to wheat.

Table 4.1. Net private and economic returns to land and water in Gezira, Sudan (1990 prices)

	Cotton		Wheat technologies		
	Long staple	Medium staple	Traditional	Inter-mediate	Full package
A. Net private returns to land (£s/ha)	1,278	828	2,884	4,444	7,975
Net private returns to water (£s/mm)	0.4	0.3	2.4	3.0	4.7
B. Net economic returns to land (£s/ha)	15,360	16,944	4,094	6,164	11,009
Net economic returns to water (£s/mm)	5.2	5.8	3.4	4.2	6.4
C. Measures of policy distortion at economic exchange rate[a]					
NPE (£s/ha)	-14,082	-16,116	-1,210	-1,720	-3,034
EPR	0.22	0.20	0.71	0.72	0.73

[a] NPE denotes the net policy effect and EPR the effective protection ratio (see Table 1.2). The EPR is the ratio of value added (VAD) at market prices to the VAD at economic prices, i.e., (MP-MR)/(P-R), where MP, MR, P, and R are as defined in Table 1.2.

The Domestic Resource Cost Analysis

In deriving RCR coefficients, one needs to decompose the cost of traded inputs into tradable and non-tradable components. The contribution of labor, capital, and other non-traded factors to the value of transportation, machinery repairs, irrigation, processing, and other services is then added to the cost of domestic resources. An average factor for each cost item was obtained from various sources and used for estimating the non-traded component of the value of tradables (Appendix D). Then RCR ratios were calculated for competing crop enterprises in Gezira (see Appendix G). Since irrigation water is the limiting factor of production, RCR calculations were based on the per-unit water costs and returns.

The analysis assumes that the availability of irrigation water is limited, so water has a positive opportunity value independent of pumping costs. As there is no market for irrigation water in Gezira, it was difficult to estimate the scarcity value of water. Under the assumption that all five alternative wheat and cotton production methods under consideration compete for irrigation water in Gezira, net social returns to land and water in the best production alternative were therefore used to determine the opportunity cost of irrigation water. A more appropriate measure of the economic value of water would be an estimate of the marginal value productivity of irrigation. Measuring marginal productivity of irrigation water, however, requires the measurement of many complex biophysical processes influencing the utilization of and response to irrigation water. Such data are usually generated from controlled irrigation experiments, which were not available for this investigation.

Resource cost ratios were computed for the survey year (1990) using the 1990 prices and the free market rate as the shadow price of foreign exchange. To provide for the important policy changes that took place in Sudan in 1992, such as the movement towards liberalized trade and prices and the adoption of a flexible exchange rate regime, the 1990 analysis was updated as follows and shown in Table 4.2:

- Long-run trend prices of wheat, cotton, fertilizer, and machinery were derived for 1992. Trend prices were derived from linear regressions fitted to 25 years of price data (1965-90).

- The unified exchange rate of £s 89.7/US$ 1.0 adopted in 1992 was used as the economic price of foreign exchange.

- Opportunity costs of domestic resources were updated for prices ruling in 1992.

As indicated above, at 1990 prices full package wheat generates the highest net economic return per millimeter of irrigation water. When the opportunity cost of water in the most profitable alternative (full package wheat) is used to value irrigation water, all options other than full package wheat are inefficient (Table 4.2). It is clear, however, that the dominance of full package wheat over cotton is weak, if one considers the small margin of efficiency between the RCR of 0.9 for full package wheat and 1.1 for medium-staple cotton (Table 4.2). It is also important to note that in 1990 the price of wheat was higher than the long-run price level, whereas cotton prices were below trend.

When RCRs were recalculated for the five crop enterprises using long-run price trends in 1992, long-staple cotton dominated all three wheat technology levels. Nevertheless, although traditional and intermediate wheat technologies are highly inefficient under trend prices (Table 4.2), the dominance of long-staple cotton (RCR of 0.99) over full package wheat (RCR of 1.2) is very weak. This indicates that the economic efficiency of full package wheat technology in Gezira is highly sensitive to the relative wheat and cotton prices. Whereas linear trend models do not capture the structural patterns in movements of market prices, they indicate the central tendency for prices in the long run. The results of Table 4.2 thus imply that on average cotton dominates wheat in Gezira in economic efficiency as world wheat prices drop below their long-run mean.

These results are unchanged if a real rate of interest of 15% is assumed. The insensitivity of the RCR results to variations in real interest rates occurs mainly because capital costs amounted to a low percentage of the total cost of domestic

Table 4.2. Resource cost ratios for cotton and wheat enterprises in the Gezira Scheme, Sudan, under economic pricing (social exchange rate)

	Cotton		Wheat technologies		
	Long staple	Medium staple	Traditional	Inter-mediate	Full package
1990 prices (US$/t)	1,958	1,530	170	170	170
Net economic returns (£s/mm)	5.2	5.8	3.4	4.2	6.4
Value added (£s/mm)	6.3	7.0	4.5	5.4	5.6
Resource cost ratio	1.2	1.1	1.7	1.4	0.9
Long-run trend prices for 1992 (US$/t)[a]	2,025	1,575	140	140	140
Net economic returns (£s/mm)	19.8	19.6	9.2	11.1	16.8
Value added (£s/mm)	21.8	21.8	11.8	13.7	19.4
Resource cost ratio	0.99	1.01	1.91	1.64	1.16

[a] Long-run trend prices obtained from a linear regression of 25 years of time-series price data (1965-89).

resources (total row 1 of Table 4.3), i.e., labor, capital, and the domestic components of tradables. The share of capital in the total value of domestic resources becomes less than 2% when the opportunity cost of land and water is added (Table 4.3).

Sensitivity Analysis and the Efficient Range for Wheat Production in Gezira

Since DRC results are based on partial equilibrium methodology, linear and static technology, and assumptions of constant prices, their validity should be further tested under conditions that deviate from the basic assumptions of the DRC framework.

The effect of technical change in wheat production has already been incorporated in the analysis to some extent by calculating the efficiency of wheat production at various technology levels. Changing world prices and their effects on such measures of economic efficiency also have been tentatively explored. Other factors, however, are important to determining the economic efficiency of wheat production in Gezira.

Due to a number of processing and marketing problems that have seriously affected the quality of Sudanese cotton, Sudan has been selling its cotton for almost half the world price of comparable products, such as Egyptian cotton. In

Table 4.3. Decomposition of total cost of production per millimeter of water applied to cotton and wheat in Gezira, Sudan (1992 economic prices)

	Long-staple cotton	Traditional wheat	Full package wheat
Gross returns (£s/mm)	25.2	15.1	25.6
Cost of traded components (£s/mm)	3.4	3.3	6.2
Value added (£/mm)	21.8	11.8	19.4
Cost of domestic resource (£s/mm)			
1. Labor	1.0	0.4	0.4
2. Capital	0.4	0.3	0.4
3. Component of tradables	0.6	2.0	1.8
Total 1	**2.0**	**2.7**	**2.6**
4. Land and water	19.6	19.8	19.8
Total 2	**21.6**	**22.5**	**22.4**
Cost of capital (% of total 1)	25.0%	11.0%	15.0%
Cost of capital (% of total 2)	1.9%	1.3%	1.8%

1989 Sudan sold its long-staple cotton (average grade) for US$ 0.98/lb, whereas Egypt received about US$ 1.8/lb for the same extra-fine grades of cotton (Cotton Marketing Corporation 1990). If improvements are achieved on the marketing front, the potential for a much higher price for Sudan's cotton is great.

While an investigation into the potential gains from research and investment in improving the cotton processing and marketing infrastructure in Sudan is beyond the scope of this study, it is important to test the efficiency limits of wheat production in Gezira against possible movements in the world cotton to wheat price ratio. This is also important because of the many imperfections in the world wheat market and the prospects for higher world wheat prices (despite recent declining wheat prices with increased competition among suppliers and the record harvests of 1990-91). The weak dominance of long-staple cotton under trend prices, plus the fact that world wheat prices are expected to rise by 15-30% as world trade regimes change and subsidies on wheat production and exports decline (CIMMYT 1991), are additional reasons for examining the sensitivity of the RCR results to changing relative prices.

The RCRs were therefore recalculated for different levels of relative cotton to wheat prices. The sensitivity analysis helped delineate the region of economic efficiency of wheat production in Gezira, including threshold yields. According to Equation 1.1 and the preceding discussion, it is clear that the RCR of wheat is a function of the price of cotton, as the price of cotton determines the economic value of land and irrigation water and hence affects the value or cost of domestic resources — CDRS (the numerator of Equation 1.1, defined in Chapter 1).

$$RCR_w (P_w, P_c, P, a) = \frac{CDRS (P_c, a)}{VAD(P_w, P, a)} \qquad \textbf{(4.1)}$$

Equation 4.1 defines the RCR of wheat (RCR_w) as a function of the price of wheat (P_w), price of cotton (P_c), and a vector of other prices (P), and technology and policy parameters (a). To test the sensitivity of the results to changing relative world prices of cotton and wheat, all other variables are held constant. The following relationships between efficient wheat yields and the relative prices of cotton and wheat are defined.

1) **Threshold yield.** This relationship is used to define the range of wheat yields (Y_w) below which the value added (VAD) is negative, which means that local wheat generates foreign exchange losses.

$$VAD = Y_w P_w - \Sigma_j R_j Q_{jw} \qquad \textbf{(4.2)}$$

From Equation 4.2, threshold yield levels are defined along the curve at which VAD is equal to zero. Rearranging Equation 4.2 leads to:

$$Y_w = \frac{\Sigma_j R_j Q_{jw}}{P_w} \qquad \textbf{(4.3)}$$

Holding constant the numerator of Equation 4.3, we solve for levels of wheat yield (Y_w) for different levels of the international wheat price (P_w).

2) **Efficiency range.** The region of efficient wheat production in Gezira is defined in this simulation exercise. The efficiency range is represented by the area in which $0 < RCR_w < 1$ in the wheat yield and relative price space.

Equation 4.4 defines the curve on which the RCR_w ratio is equal to 1. Rearranging Equation 4.1 according to the condition that $RCR_w = 1$ defines the following relationship between wheat yield and relative world prices of cotton and wheat:

$$CDRS(P_c, a) = VAD\ (P_w, P, a)$$

or:

$$Y_w = \frac{CDRS(P_c, a) + \Sigma_j R_j\ Q_{jw}}{P_w} \qquad \textbf{(4.4)}$$

Holding other variables constant, Equation 4.4 is used to solve for levels of Y_w for various combinations of P_c and P_w.

Figure 4.1 defines efficiency ranges for the full package of improved wheat production practices in Gezira over a range of relative prices of long-staple cotton to wheat. Figures 4.2 and 4.3 display efficiency ranges and threshold levels of wheat yield for traditional and intermediate wheat technologies, respectively. Table 4.4 presents the sensitivity analysis results depicted in Figures 4.1, 4.2, and 4.3. Table 4.4 also compares threshold yields with yield levels realized under the three wheat technologies considered in this study.

Figures 4.1, 4.2, and 4.3 and Table 4.4 indicate that full package wheat is almost in the efficiency range (point B in Figure 4.1). Results of the sensitivity analysis also show that the world wheat price has to rise to US$ 155/t for the full package wheat technology to become efficient at its current yield levels (point A in Figures 4.1, 4.2, and 4.3 and row 3a of Table 4.4). Thus the world wheat price has to be about 11% higher than the 1992 trend price for full package wheat to become the most efficient alternative in Gezira. This measures the narrow margin of economic efficiency and dominance of long-staple cotton over full package wheat in terms of relative and absolute price movements. This factor is important, since the prospects for stronger world wheat prices are higher under the unfolding new international economic order of freer world trade.

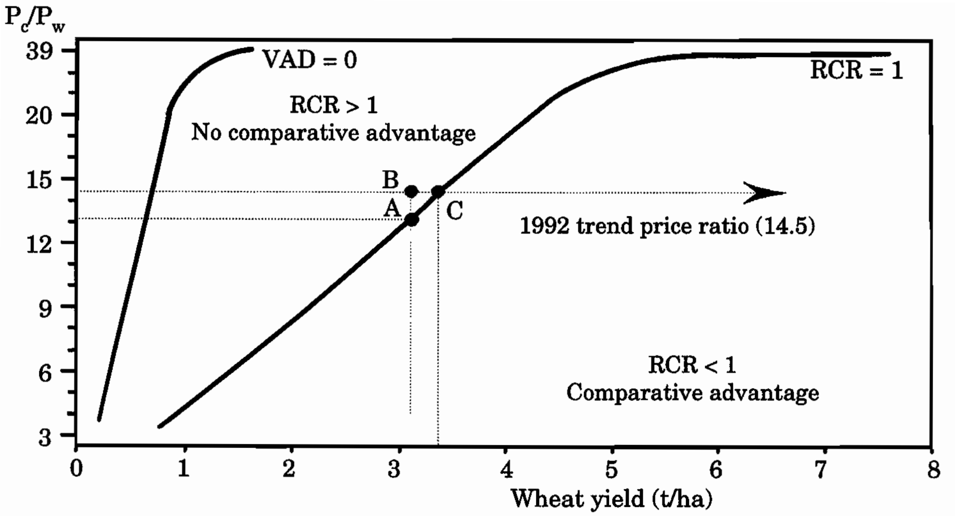
Moreover, Table 4.4 and Figure 4.2 show that the import price of wheat has to exceed US$ 240/t for traditional practices at current yield levels to become efficient. This wheat price is more than 70% higher than the 1992 trend price. A substantial shift in the relative world prices of cotton and wheat would have to occur for the traditional wheat practices currently used by the vast majority of Gezira farmers to compete with cotton for the irrigated land resources of Gezira. Sensitivity analysis also shows that wheat yields in Gezira need to rise from current levels by 10% for full package technologies, 47% for intermediate technologies, and 67% for traditional wheat technologies to compete with long-staple cotton at the 1992 trend prices (row 5 of Table 4.4 and point C on the graph).

Also, one should not forget that Sudanese cotton currently receives about half the world price of comparable kinds of cotton because of quality problems. This price differential shows the high potential returns to investment and research directed toward more efficient cotton processing and marketing, which would improve the quality and competitiveness of Sudan's cotton exports and thus decrease the attractiveness of wheat.

Table 4.4. Threshold and current yields (t/ha) for 1990 and 1992 prices (US$/t) of wheat and cotton, Gezira, Sudan

	Wheat technologies		
	Traditional practices	Intermediate technology	Full package
1. CIF trend prices of wheat, 1992 (US$/t)	140	140	140
2. Price ratio of long-staple cotton to wheat, 1992	14.5	14.5	14.5
3. Threshold price ratio of cotton to wheat for efficiency at current yield levels[a]	8.1	9.5	13.1
a. Threshold price of wheat (US$/t)	249	213	155
b. CIF world prices, 1990 (US$/t)	170	170	170
Price ratio	(11.5)	(11.5)	(11.5)
c. CIF world prices, 1992 (US$/t)	125	125	125
Price ratio	(16.9)	(16.9)	(16.9)
4. Currently feasible yield levels (t/ha)	1.3	1.9	3.1
5. Threshold yield (t/ha) for production efficiency (RCR <1) at trend prices[b]	2.2	2.8	3.4
Percent yield increase required	67%	47%	10%
6. Threshold yield (t/ha) for positive value added (VAD>0) at trend prices	0.3	0.5	0.9

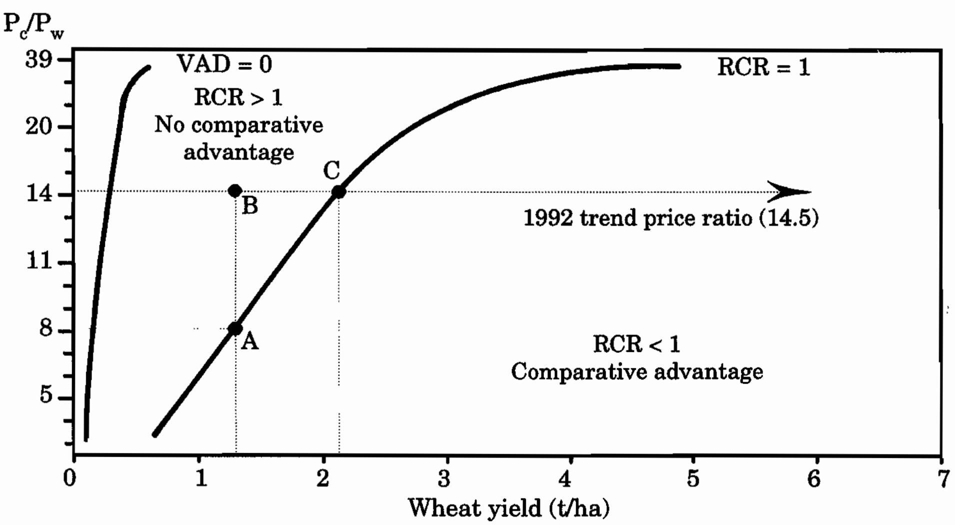
[a] Point A in Figures 4.1, 4.2, and 4.3.
[b] Point C in Figures 4.1, 4.2, and 4.3.



Points on the graph:

A. Threshold price ratio (13.1) for FPW to enter the efficiency region at current yield levels (3.1 t/ha).
B. Position of FPW at the 1992 trend prices (inefficient).
C. Indicates threshold yields (3.4 t/ha) for FPW to become efficient at the 1992 trend prices.

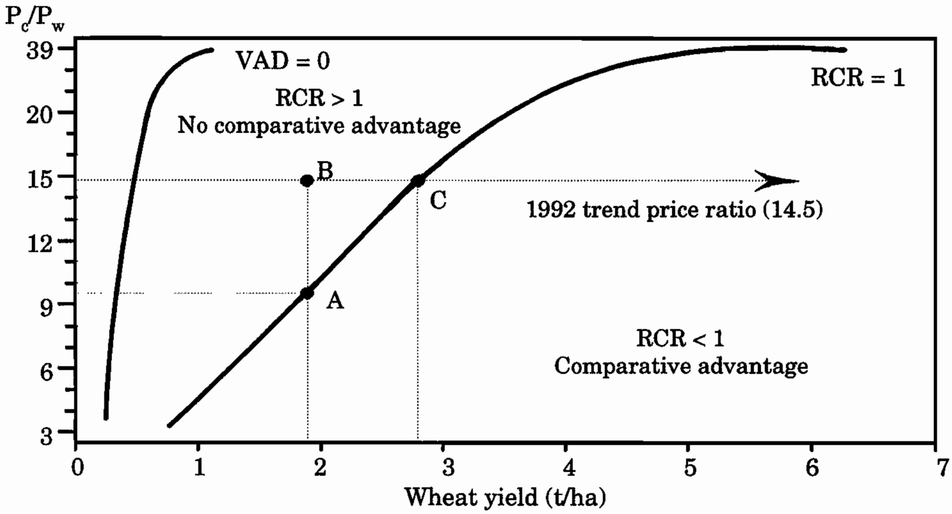
Figure 4.1. Efficiency range for full package wheat technology in Gezira, Sudan (trend prices).



Points on the graph:

A. Threshold price ratio (8.1) for TWP to enter the efficiency region at current yield levels (1.28 t/ha).
B. Position of TWP at the 1992 trend prices (inefficient).
C. Indicates threshold yields (2.16 t/ha) for TWP to become efficient at the 1992 trend prices.

Figure 4.2. Efficiency range for traditional wheat technology in Gezira, Sudan (trend prices).



Points on the graph:
A. Threshold price ratio (9.5) for IWT to enter the efficiency region at current yield levels (1.9 t/ha).
B. Position of IWT at the 1992 trend prices (inefficient).
C. Indicates threshold yields (2.8 t/ha) for IWT to become efficient at the 1992 trend prices.

Figure 4.3. Efficiency range for intermediate wheat technology in Gezira, Sudan (trend prices).

5

Conclusions

During the 1980s, Sudan maintained low consumer prices for wheat through food aid, overvalued currency, and direct subsidies, which resulted in rapid growth in wheat consumption and increased reliance on imports. The government, motivated partly by promising results attained in demonstration trials of improved wheat production practices, decided to promote domestic wheat production. Larger areas have consequently been planted to wheat, especially in the Gezira and Managil Schemes, where more than 60% of Sudan's wheat is produced. However, this increased wheat production has removed resources from other important crops such as cotton.

This study has evaluated the economic viability of Sudan's wheat import-substitution strategy by using the domestic resource cost (DRC) methodology to compute indices of economic efficiency for wheat and competitive crops in Gezira. The findings should assist decision makers in Sudan as well as in international research and funding agencies to allocate research and production resources between wheat and other enterprises in Sudan.

The present analysis has shown that the new wheat technology generates net economic gains and dominates traditional practices. However, limited access to some inputs has restricted the adoption of recommended practices and growth in wheat yields. Practices for which inputs are bought from private markets, such as the mechanical components of the new package, have been adopted faster than practices for which input supplies are controlled by the government, such as nitrogen and phosphorus fertilizers. In addition, variability in farmers' circumstances, especially the effects of weather and location, significantly affects wheat yields and hence the optimality of the recommended practices across Gezira. Gezira farmers should be classified into more homogeneous target groups for testing technologies.

Relative profitability analysis revealed that the ARC full package of wheat technology generated the highest net economic returns per unit of water (the most limiting resource in Gezira) at 1990 prices. Effective protection ratios and net policy effect measures showed that both cotton and wheat farmers in Gezira were taxed in 1990. Relative profitability analysis also revealed the high net tax paid by cotton producers through an overvalued exchange rate. The tax paid on cotton in Gezira amounted to more than £s 14,000/ha of cotton in 1990, which is equivalent to US$ 1,200 per farmer (2.1 ha cotton tenancy) when valued at the social exchange rate. The analysis indicated that if the shadow exchange rate of £s 24.6/US$1.0 was the right price of Sudanese currency in 1990, traditional growers in Gezira paid a net tax of more than US$ 1,300 on their cotton and wheat tenancies (4.2 ha) in that season.

Results of the DRC analysis indicate that, at 1990 prices, wheat dominates long- and medium-staple cotton when the complete package of improved wheat production methods is applied. On the other hand, the traditional wheat production practices used by the vast majority of Gezira tenants, and the intermediate technology level tested in the scheme, were highly inefficient compared to cotton at 1990 prices. At trend prices in 1992, long-staple cotton dominated all wheat technologies (including the full package). Sensitivity analysis showed that even if full package wheat is a feasible option for Gezira farmers, it will require a world wheat price that is 11% higher than the long-run trend to become the most efficient alternative in Gezira. Average yield levels currently achieved under traditional wheat production methods in Gezira will require a wheat price higher than US$ 240/t to become efficient. This threshold price is more than 70% above the trend price of wheat in 1992.

As wheat prices are currently below their long-run average, and since average yield levels in Gezira are much lower than potential yields obtained under the full package of improved wheat technologies, at present it may not be economically efficient for Sudan to expand wheat production at the expense of cotton in Gezira. Before more land and water are switched from producing cotton to wheat, the gap between potential and farmer's wheat yields needs to be closed so as to make wheat farming in Gezira efficient. According to sensitivity analysis results, Gezira tenants who currently produce wheat using traditional methods would have to raise their yield levels (at the same input costs) by more than 80% to compete with cotton at the 1992 price levels (i.e., from 1.28 t/ha to 2.4 t/ha).

To raise the productivity and enhance the efficiency of wheat production in the Gezira Scheme, policy makers in Sudan must therefore focus on removing the obstacles to higher and faster adoption of improved wheat production technologies tested by ARC in Gezira. Doing so requires policies designed to increase wheat yields. Input procurement and delivery systems need to be liberalized for more efficient and timely utilization of modern inputs. More flexibility is also needed in the system used to allocate land and water among competing crops within the public irrigation schemes. Thus domestic resources can be employed to respond to changing international economic opportunities and realize their comparative advantage and competitive position in the world market.

On-farm testing of the new wheat technology in Gezira should continue, particularly at locations where water shortages are severe, to realize the true range of yields that can potentially be obtained in the Gezira Scheme. Adaptive research should focus on formulating conditional recommendations that modify the package of wheat technologies currently promoted by ARC to suit different locations in Gezira. It is also important for Sudan to invest more research resources in efforts to refine the lint quality and improve the marketing processes of its cotton crop. Such research is crucial for answering the question of economic efficiency, as potential yield gains from applying improved wheat production methods need to be weighed against potential gains in cotton export prices from better quality lint.

Appendix A

The Transcendental Production Function

In log form:

$$\ln Y = \ln A + \Sigma_i \alpha_i \ln X_i + g(x) \qquad \textbf{(A.1)}$$

where the general form for g(x) is:

$$g(x) = \Sigma_i B_i X_i \qquad \textbf{(A.2)}$$

extended in the present case to be:

$$g(x) = \Sigma_i B_i X_i + \Sigma_i \Sigma_i B_{ij} X_i X_j + \Sigma_l d_l D_l + \Sigma_i \Sigma_l d_{il} D_l X_i, \qquad \textbf{(A.3)}$$

where Y is output and X_i measures the level of continuous variable i. The set of factor inputs contains continuous (X) as well as discrete factors (D). The specification of g(x) used in this study allows for interaction effects as measured by B_{ij} and d_{il} of Equation A.3, where:

B_{ij} measures the interaction effect between continuous variables i and j (i,j = 1,2,...,n);

D_l is a dummy for the effect of categorical variable l(l = 1,2,...,L);

d_l measures the deviation of the mean effect of category l from the overall mean effect (common intercept); and

d_{il} measures the interaction between continuous (X_i) and categorical variables (D_l). In other words, d_{il} measures the deviation of the marginal effect of variable i for category l from the overall effect (common slope) of variable i.

Table A.1. Least squares estimates of the parameters of the restricted transcendental model fitted to wheat yields (t/ha) in Gezira, Sudan

Variable	Regression coefficient	T statistic
1. Constant (common intercept)	-4.624	-3.60***
2. Estimates of the α's (variables in log form)		
a. Nitrogen (kg/ha)	-0.212	-0.77
b. Phosphorus (kg/ha)	-0.040	-3.56***
c. Number of irrigations	2.109	3.53***
d Number of ridgings	0.039	1.85*
e. Sowing date (number of weeks from mid-November)	0.011	0.78
f. Date of fertilizer application (weeks after planting)	0.034	2.29**
g. Date of first irrigation (weeks since sowing)	0.012	1.61*
h. Date of harvesting (months since sowing)	0.197	1.00
3. Estimates of the B_i's (variables in levels)		
a. Nitrogen	0.079	3.38***
4. Estimates of the d_l's (discrete variables)		
a. Method of fertilizer application (machine)	0.572	4.40***
b. Method of sowing (machine)	-0.362	-6.44***
c. Chisel plow (used)	0.112	3.52***
d. Levelling (used)	-0.267	-5.80***
e. Disc harrow (used)	0.032	2.07**
f. Region (northern parts of scheme)	-2.816	-5.57***
g. Region (central parts of scheme)	1.347	5.13***
h. Year-season effect (1989-90)	-0.146	-4.52***
i. Site (head)	0.310	2.11**
j. Variety (Debeira)	-0.487	-2.01**
k. Variety (Condor)	0.167	2.13**
5. Interaction parameters B_{ij} (continuous variables)		
a. Nitrogen with phosphorus	0.0002	0.86
b. Nitrogen with number of irrigations	-0.0064	-2.56***
c. Nitrogen with date of application	-0.002	-1.64*
6. Interaction parameters d_{il} (discrete variables)		
a. Nitrogen with method of application	-0.011	-3.18
b. Nitrogen with region (north)	0.067	5.25***
c. Nitrogen with region (center)	-0.041	-6.03***
d. Nitrogen with variety (Debeira)	0.013	1.99**
e. Phosphorus with sowing method	0.025	7.69***
f. Phosphorus with region (north)	0.011	1.18
g. Phosphorus with region (center)	0.012	2.36**
h. Phosphorus with levelling	0.023	4.29***
i. Number of irrigations with site	0.051	2.39**

R-squared	.67	Mean of dependent variable	.095
Durbin-Wetsun statistic	1.999	F-statistic	14.79
Log-likelihood	33.52	Number of observations	311

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Appendix B

Input-Output Coefficients for Gezira

The farm-level technology coefficients presented in Tables B1, B2, and B3 were derived from several sources:

1. The irrigated sector study surveys of Gezira tenant farmers, 1987-88 and 1988-89 seasons (470 farmers).

2. A survey of SG 2000 and neighboring farmers in Gezira, 1988-89 (200 farmers).

3. A follow-up survey of former SG 2000 farmers in 1989-90 (120 farmers).

4. A survey of SG 2000 farmers in 1989-90 (784 farmers).

5. Gezira Pilot Farm data, SGB, for the 1987-88 and 1988-89 seasons (49 farmers).

6. The ARC demonstration farms, 1987-88 and 1988-89 (18 farmers).

7. *Annual Report* (1988 and 1989) of the Socio-economic Unit, SGB.

8. Department of Agricultural Engineering, SGB.

9. Survey of field inspectors, SGB, 1990.

10. Survey of machine owners in Gezira, 1990.

11. *Proceedings* of the Annual National Wheat Coordination Meetings, Nile Valley Project, ARC/ICARDA, Wad Medani, Sudan, 1988 and 1989.

12. Irrigation and crop water requirement coefficients were taken from Farbrother (1984), Hidaytalla et al. (1984), and Plusquellec (1990).

Table B1. Machine and labor time (h/ha), Gezira, Sudan

Operation	Tractor and tillage	Combine harvest	Skilled labor	Unskilled labor
Plow				
Conventional	0.9	..	0.9	..
Chisel	2.2	..	2.2	..
Deep	2.9	..	2.9	..
Harrow-offset disk	1.1	..	1.1	..
Ridge	0.7	..	0.7	..
Split ridge	0.7	..	0.7	..
Green ridge	0.7	..	0.7	..
Planting				
Drill	0.7	..	0.7	..
Broadcast	..	..	..	6.6
Cover seed	0.4	..	0.4	..
Fertilizer				
Nitrogen, mechanical application	0.4	..	0.4	..
Nitrogen, broadcast	..	..	..	4.5
Phosphorus, dressed	1.1	..	1.1	..
Phosphorus, broadcast	..	..	..	4.5
Conventional level	0.5	..	0.5	..
Precision level	1.1	..	1.1	..
Ditching				
Abo XX[a]	0.2	..	0.2	..
Abo VI[a]	0.3	..	0.3	..
Thinning	..	..	..	7.9
Weeding	..	..	..	32.4
Raise canal	..	..	..	9.1
Weeding				
Abo XX[a]	..	..	..	6.2
Abo VI[a]	..	..	..	3.8
Irrigate	..	..	..	5.9
Break Gadwals[a]	..	..	..	11.2
Combine harvest	..	0.7	0.7	0.7
Slash/burn residue	..	..	..	6.9
Hand pick cotton	..	..	..	..
Bag/bale product	..	..	..	..

[a] Abo XX, Abo VI, and Gadwals are names of water courses in the irrigation network of the Gezira Scheme.

Table B2. Frequency of operation, by crop enterprise, Gezira, Sudan

Operation	Long-staple cotton	Medium-staple cotton	Traditional wheat	Intermediate wheat	Full package wheat
Plow					
Conventional	..	..	..	..	..
Chisel	..	..	..	..	..
Deep	1.0	1.0	..	..	..
Harrow-offset disk	1.0	1.0	..	1.0	1.0
Ridge	1.0	1.0	1.0	1.0	1.0
Split ridge	1.0	1.0	1.0	1.0	1.0
Green ridge	..	..	..	..	..
Planting					
Drill	..	..	..	1.0	1.0
Broadcast	1.2	1.2	1.0	..	..
Cover seed	1.0	1.0	1.0	..	..
Fertilizer					
Nitrogen, mechanical application	..	..	..	..	2.0
Nitrogen, broadcast	1.8	1.8	1.0	2.0	..
Phosphorus, dressed	..	..	..	..	1.0
Phosphorus, broadcast	..	..	..	..	..
Conventional level	..	..	..	1.0	..
Precision level	0.3	0.3	..	..	1.0
Ditching					
Abo XX[a]	1.0	1.0	1.0	1.0	1.0
Abo VI[a]	1.0	1.0	1.0	1.0	1.0
Thinning	1.0	1.0	..	..	..
Weeding	2.0	2.0	..	..	..
Raise canal	1.0	1.0	1.0	1.0	1.0
Weeding					
Abo XX[a]	1.0	1.0	0.5	0.5	0.5
Abo VI[a]	1.0	1.0	0.4	0.4	0.4
Irrigate	12.0	12.0	5.0	6.0	7.0
Break Gadwals[a]	..	..	1.0	1.0	1.0
Combine harvest	..	..	1.0	1.0	1.0
Slash/burn residue	1.0	1.0	0.4	0.4	0.4
					(h/kg)
Hand pick cotton	..	..	..	..	0.2
Bag/bale product	..	..	..	..	0.0

[a] Abo XX, Abo VI, and Gadwals are names of water courses in the irrigation network of the Gezira Scheme.

Table B3. Material, contract, and other services, Gezira, Sudan

	Quantity/frequency				
	Long-staple cotton	Medium-staple cotton	Traditional wheat	Intermediate wheat	Full package wheat
Materials					
Nitrogen fertilizer (commercial product, kg/ha)	188	188	96	192	192
Phosphorus fertilizer (commercial product, kg/ha)	0	0	0	0	96
Seed (commercial product, kg/ha)	48	48	120	144	144
Contract/hire services					
Spray insecticide (no. times)	12	12	0.1	0.1	0.1
Spray herbicide (no. times)	1	1	0	0	0
Cotton pickers (no. times used)	1	1	0	0	0
Irrigations (no.)	12	12	5	6	7
Water (mm/ha)	244	244	244	244	244
Total water (mm/ha)	2,928	2,928	1,220	1,464	1,708
	Amount (kg/ha)				
Other operations					
Transport product	1,383	1,870	1,280	1,890	3,050
Transport fertilizer	287	287	96	191	287
Transport seed	48	48	119	143	143
Packing material	1,383	1,870	1,280	1,890	3,050
Taxes	1,383	1,870	1,280	1,890	3,050
Yield	1,393	1,870	1,280	1,890	3,050

Appendix C

Capital Budgets for Machinery in the Gezira Scheme

Table C1. Capital budgets for machinery, Gezira, Sudan (1990 social exchange rate)

	Tractor	Tillage	Combine
Fixed costs			
CIF Port Sudan (US$ 000)	35.0	2.4	80.0
Effective exchange rate (£s/US$ 1.00)	24.6	24.6	24.6
CIF Port Sudan (£s 000)	861.0	59.0	1,968.0
Port, handling, and transport (£s 000)	58.0	7.0	180.0
Duties, taxes (£s 000)	48.8	3.3	111.6
Purchase price (£s 000)	967.8	69.4	2,259.6
Salvage value (£s 000)	121.0	4.9	155.3
Hours of use (h/yr)	1,800.0	680.0	1,380.0
Years of life (yr)	8.0	16.0	8.0
Annual depreciation (£s 000)	100.4	3.3	111.8
Annual capital cost (£s 000)	12.0	0.9	29.8
Total annual fixed costs (£s 000)	**112.4**	**4.2**	**141.5**
Hourly fixed costs (£s/h)	**62.4**	**6.2**	**102.6**
Variable costs			
Repair cost coefficient	0.1	0.0	0.1
Annual repair costs (£s 000)	67.8	0.7	180.8
Hourly repair costs (£s/h)	37.6	1.0	131.0
Hourly fuel consumption (gal/h)	1.6	..	3.0
Average fuel price (£s/gal)	7.0	..	7.0
Hourly fuel costs (£s/h)	11.2	..	21.0
Hourly oil consumption (gal/h)	0.0	..	0.1
Average oil price (£s/gal)	80.0	..	80.0
Hourly cost of oil (£s/h)	2.1	..	6.4
Annual insurance (£s 000)	3.0	0.5	3.0
Hourly insurance (£s/h)	1.7	0.7	2.2
Hourly variable costs (£s/h)	**52.6**	**1.8**	**160.6**
Hourly total costs (£s/h)	**115.0**	**7.9**	**263.1**

Source: Commerce Department, Agricultural Bank of Sudan, Port Sudan, 1990; survey of machine dealers in Wad Medani and Khartoum, May 1990; and survey of machine owners in Gezira, May 1990.

Appendix D

Economic and Market Prices of Tradables and Non-traded Primary Factors

Information on the nominal indices and macrovariables of the economy presented in Tables D1 and D2 was compiled from the following sources:

1. SGB, various published and unpublished reports.

2. Agricultural Bank of Sudan, various unpublished reports.

3. Ministry of Finance and Economic Planning, *Economic Survey* (1990).

4. Bank of Sudan, *Annual Report* (1990).

5. Department of Agricultural Statistics, Ministry of Agriculture, Sudan, *Annual Statistics* (1990).

6. *International Financial Statistics* (1990).

7. Survey of commercial banks in Khartoum, Sudan, 1990.

8. Tenant farmer surveys listed in Appendix A.

The tradable/non-tradable composition of the value of inputs and products given in Tables D1 and D2 was determined as follows:

	Percent traded	Percent non-traded
1. Fixed cost of machine services	90	10
2. Variable cost of machine services	65	35
3. Contract services	65	35
4. Handling and transport costs	65	35
5. Purchased inputs	90	10
6. Irrigation costs	50	50

These decomposition margins were based on:

1. Own calculation and survey data.

2. Ministry of Finance and Economic Planning (1989), *Study of International Competitiveness of Selected Products in Sudan.*

3. D.J. Jansen (1986), *Economic and Financial Analysis of Sudan's Major Crops*, Ministry of Finance and Economic Planning, Sudan.

4. Ministry of Finance and Economic Planning (May 1982), *Study of Cost of Production and Comparative Advantage of Crops in Sudan.*

Table D1. Costs/prices of inputs and services at the effective and shadow exchange rates, Sudan, 1990-92

	1990		1992
	Market prices	Economic prices	Economic prices
Machine services (£s/h)			
Fixed tractor/tillage costs	28.0	68.6	230.5
Variable tractor/tillage costs	33.1	54.5	131.5
Fixed combine costs	47.0	102.5	325.5
Variable combine costs	89.7	160.0	408.6
Irrigation costs (£s/irrigation/ha)	50.0	50.0	88.0
Nitrogen fertilizer			
Port Sudan (US$/t)	180.0	180.0	200.0
Exchange rate (£s/US$ 1.00)	9.3	24.6	89.7
Port, handling, transport (£s/t)	600.0	600.0	2,767.8
Duties/taxes (£s/t)	148.0	0.0	0.0
Producer price (£s/kg)	2.4	5.0	20.7
Phosphorus fertilizer			
Port Sudan (US$/t)	210.0	210.0	230.0
Producer price (£s/kg)	2.7	5.8	23.4
Packing material (£s/kg)	0.0	0.0	0.1
Contract/hire services			
Spray insecticide (£s/ha/application)	61.4	61.4	82.2
Spray herbicide (£s/ha/application)	211.0	211.0	360.0
Field transport (£s/kg)	0.3	0.3	0.5
Skilled labor (£s/h)	6.0	6.0	8.0
Unskilled labor (£s/h)	3.5	3.5	6.5
Other costs and charges			
Cotton pickers (£s/ha)	62.0	62.0	84.0
Taxes (£s/kg)	0.0	0.0	0.0
Interest rate	0.1	0.3	0.3

Table D2. Costs/prices of products at the effective and shadow exchange rates, Sudan, 1990-92

	1990		1992
	Market prices	**Economic prices**	**Economic prices**
Wheat			
Port Sudan (US$/t)	170.0	170.0	140.0
Exchange rate (£s/US$ 1.00)	12.2	24.6	89.7
Port, handling, transport (£s/t)	1,200.0	1,200.0	1,800.0
Duty/tax (£s/t)	580.0	0.0	0.0
Producer price (£s/kg)	3.9	5.4	14.4
Long-staple cotton			
Port Sudan (US$/kantar)[a]	87.0	87.0	90.0
Exchange rate (£s/US$ 1.00)	8.0	24.6	89.7
Ginning, handling, transport (£s/kantar)	320.0	440.0	1,783.0
Duty/tax (£s/kantar)	140.0	0.0	0.0
Lint value at Gezira (£s/kantar)	236.0	1,700.0	6,290.0
Producer price, seed cotton (£s/kg)	4.6	15.9	53.4
Medium-staple cotton			
Port Sudan (US$/kantar)	68.0	68.0	70.0
Exchange rate (£s/US$ 1.00)	8.0	24.6	89.7
Ginning, handling, transport (£s/kantar)	320.0	360.0	1,783.0
Duty/tax (£s/kantar)	140.0	0.0	0.0
Lint value at Gezira (£s/kantar)	84.0	1,312.8	4,496.0
Producer price, seed cotton (£s/kg)	3.4	12.9	39.6
Cotton seed (£s/kantar)	200.0	200.0	360.0

[a] One kantar = 100 pounds.

Appendix E

The Land and Water Charge and Irrigation Costs in Gezira

A fixed charge per unit area under each crop is collected by the SGB from tenant farmers every year as a land and water tax. The water charge is usually recovered from farmers' proceeds of their wheat and cotton crops, since these are the crops farmers are required to deliver to marketing boards. Land and water charges are determined every year to recover 1) the administrative costs of the SGB and the Ministry of Irrigation, 2) the costs of operating and maintaining the irrigation system, and 3) and part of capital replacement.

These charges are based on the annual budgets allocated to operating the Gezira irrigation network. The method of calculating the 1989-90 land and water charges for the Gezira and Managil Extension Schemes is presented below. (The sources of this information are the Ministry of Irrigation, Sudan, the 1989-90 water rates, and the SGB, 1989-90 water rates.)

A) The following items make up the total cost of irrigating the Gezira/Managil Schemes.

	(£s millions)
1. Salaries and allowances - Chapter I	34.40
2. Operation and maintenance - Chapter II	
Civil	127.90
Mechanical	18.60
3. Capital recovery costs - Chapter III	
Betterment of irrigation means	0.83
Renewal of Sennar Dam gates	0.15
Roseries Dam recovery	0.86
Managil Scheme recovery	3.77
Total annual	**186.47**

The annual recovery of capital was computed using the straight line method of estimating depreciation costs and a zero salvage value. A low interest of 8% on initial outlays was used to generate capital depreciation costs.

B) The total annual cost of £s 186 million is then divided by a total cotton area equivalent for the scheme. Based on the number of irrigations required, the total area under each crop is converted into cotton area equivalent as follows for 1989-90.

Crop	**Planned area (000 ha)**	**Number of irrigations**	**Cotton area equivalent (000 ha)**	
Cotton	184.8	16	..	184.8
Wheat	168.0	10	168 x 10/16	105.0
Groundnuts	84.0	8	84 x 8/16	42.0
Sorghum	109.0	4	109 x 4/16	27.3
Vegetables	27.3	14	27.3 x 14/16	23.9
Forests	4.2	16	..	4.2
Total	**577.3**			**387.2**

1. Water rate per hectare of cotton, 186,470/387.3 = £s 481.59/ha.
2. The cost of one irrigation per hectare, 481.59/16 = £s 30.1/ha/irrigation.
3. The water rate per hectare of wheat, 30.1 x 10 = £s 301/ha of wheat. The water rate per hectare of sorghum, 30.1 x 4 = £s 120.4/ha of sorghum.

The procedure and data described above were adjusted for actual areas planted in 1989-90 and used to compute a water rate of £s 31.92/irrigation/ha, which was used in the calculations for this study. The average number of irrigations applied to each crop was also different from the required irrigations shown above.

Appendix F

Enterprise Budgets for Gezira Cotton and Wheat, Various Levels of Technology

Table F1. Enterprise budgets (£s/ha) for long-staple cotton, Gezira, Sudan

	1990		1992
	Market prices	Economic prices	Economic prices
Gross returns	6,397.2	21,956.0	73,879.3
Machinery costs			
Fixed tractor/tillage	188.5	461.7	1,551.3
Variable tractor/tillage	222.8	366.8	885.0
Fixed combine	0.0	0.0	0.0
Variable combine	0.0	0.0	0.0
Labor costs			
Skilled	40.4	40.4	53.8
Unskilled	1,494.1	1,494.1	2,774.7
Irrigation costs	600.0	600.0	960.0
Purchased inputs			
Seed	95.2	95.2	171.4
Nitrogen fertilizer	694.3	1,441.4	5,936.5
Phosphorus fertilizer	0.0	0.0	0.0
Insecticide	0.0	0.0	0.0
Herbicide	0.0	0.0	0.0
Packing material	62.2	62.2	152.1
Contract/hire services			
Apply fertilizer	0.0	0.0	0.0
Spray insecticide	736.8	736.8	986.4
Spray herbicide	211.0	211.0	360.0
Combine harvest	0.0	0.0	0.0
Other costs			
Transport product	359.6	359.6	636.2
Transport fertilizer	74.5	74.5	131.9
Transport seed	12.4	12.4	21.9
Cotton pickers' costs	62.0	62.0	84.0
Tax	55.3	0.0	0.0
Capital costs—interest	192.8	578.4	1,055.0
Total costs	**5,101**	**6,596**	**15,760**
Net returns (£s/ha)	**1,277**	**15,359**	**58,119**
Net returns (£s/mm)	**0**	**5.2**	**19.8**

Table F2. Enterprise budgets (£s/ha) for medium-staple cotton, Gezira, Sudan

	1990		1992
	Market prices	**Economic prices**	**Economic prices**
Gross returns	6,439.1	24,114.9	74,088.6
Machinery costs			
Fixed tractor/tillage	188.5	461.7	1,551.3
Variable tractor/tillage	222.8	366.8	885.0
Fixed combine	0.0	0.0	0.0
Variable combine	0.0	0.0	0.0
Labor costs			
Skilled	40.4	40.4	53.8
Unskilled	1,792.5	1,792.5	3,329.0
Irrigation costs	600.0	600.0	960.0
Purchased inputs			
Seed	95.2	95.2	171.4
Nitrogen fertilizer	694.3	1,441.4	5,936.5
Phosphorus fertilizer	0.0	0.0	0.0
Insecticide	0.0	0.0	0.0
Herbicide	0.0	0.0	0.0
Packing material	84.2	84.2	205.7
Contract/hire services			
Apply fertilizer	0.0	0.0	0.0
Spray insecticide	736.8	736.8	986.4
Spray herbicide	211.0	211.0	360.0
Combine harvest	0.0	0.0	0.0
Other costs			
Transport product	486.2	486.2	860.2
Transport fertilizer	74.5	74.5	131.9
Transport seed	12.4	12.4	21.9
Cotton pickers' costs	62.0	62.0	84.0
Tax	74.8	0.0	0.0
Capital costs—interest	235.3	705.9	1,288.5
Total costs	**5,610**	**7,171**	**16,825**
Net returns (£s/ha)	**828**	**16,943**	**57,263**
Net returns (£s/mm)	**0.3**	**5.8**	**19.6**

Table F3. Enterprise budgets (£s/ha) for wheat produced using traditional practices, Gezira, Sudan

	1990		1992
	Market prices	**Economic prices**	**Economic prices**
Gross returns	4,933.1	6,889.0	18,378.2
Machinery costs			
Fixed tractor/tillage	67.2	164.6	553.2
Variable tractor/tillage	79.4	130.8	315.6
Fixed combine	32.9	71.8	227.9
Variable combine	62.8	112.0	286.0
Labor costs			
Skilled	18.6	18.6	24.8
Unskilled	282.1	282.1	523.9
Irrigation costs	250.0	250.0	400.0
Purchased inputs			
Seed	458.6	640.5	1,708.6
Nitrogen fertilizer	231.4	480.5	1,978.8
Phosphorus fertilizer	0.0	0.0	0.0
Insecticide	0.0	0.0	0.0
Herbicide	0.0	0.0	0.0
Packing material	57.6	57.6	140.8
Contract/hire services			
Apply fertilizer	0.0	0.0	0.0
Spray insecticide	4.3	4.3	5.8
Spray herbicide	0.0	0.0	0.0
Combine harvest	0.0	0.0	0.0
Other costs			
Transport product	332.8	332.8	588.8
Transport fertilizer	24.8	24.8	44.0
Transport seed	30.9	30.9	54.7
Cotton pickers' costs	0.0	0.0	0.0
Tax	51.2	0.0	0.0
Capital costs—interest	64.6	193.8	350.2
Total costs	**2,049**	**2,795**	**7,203**
Net returns (£s/ha)	**2,883**	**4,093**	**11,175**
Net returns (£s/mm)	**2.46**	**3.4**	**9.2**

Table F4. Enterprise budgets (£s/ha) for wheat produced using the intermediate technology, Gezira, Sudan

	1990		1992
	Market prices	Economic prices	Economic prices
Gross returns	7,284.1	10,172.0	27,136.6
Machinery costs			
Fixed tractor/tillage	123.2	301.8	1,014.2
Variable tractor/tillage	145.6	239.8	578.6
Fixed combine	32.9	71.8	227.9
Variable combine	62.8	112.0	286.0
Labor costs			
Skilled	30.6	30.6	40.8
Unskilled	305.2	305.2	566.8
Irrigation costs	300.0	300.0	480.0
Purchased inputs			
Seed	550.4	768.5	2,050.3
Nitrogen fertilizer	462.9	961.0	3,957.7
Phosphorus fertilizer	0.0	0.0	0.0
Insecticide	0.0	0.0	0.0
Herbicide	0.0	0.0	0.0
Packing material	85.1	85.1	207.9
Contract/hire services			
Apply fertilizer	0.0	0.0	0.0
Spray insecticide	4.3	4.3	5.8
Spray herbicide	0.0	0.0	0.0
Combine harvest	0.0	0.0	0.0
Other costs			
Transport product	491.4	491.4	869.4
Transport fertilizer	49.7	49.7	87.9
Transport seed	37.1	37.1	65.7
Cotton pickers' costs	0.0	0.0	0.0
Tax	75.6	0.0	0.0
Capital costs—interest	83.4	250.1	450.6
Total costs	**2,840**	**4,008**	**10,889**
Net returns (£s/ha)	**4,443**	**6,163**	**16,247**
Net returns (£s/mm)	**3.0**	**4.2**	**11.1**

Table F5. Enterprise budgets (£s/ha) for wheat produced using the full package of technology, Gezira, Sudan

	1990		1992
	Market prices	**Economic prices**	**Economic prices**
Gross returns	11,754.7	16,415.1	43,791.9
Machinery costs			
Fixed tractor/tillage	190.5	466.5	1,567.4
Variable tractor/tillage	225.1	370.6	894.2
Fixed combine	32.9	71.8	227.9
Variable combine	62.8	112.0	286.0
Labor costs			
Skilled	45.0	45.0	60.0
Unskilled	319.2	319.2	592.8
Irrigation costs	350.0	350.0	616.0
Purchased inputs			
Seed	550.4	768.5	2,050.3
Nitrogen fertilizer	462.9	961.0	3,957.7
Phosphorus fertilizer	258.1	551.0	2,236.0
Insecticide	0.0	0.0	0.0
Herbicide	0.0	0.0	0.0
Packing material	137.3	137.3	335.5
Contract/hire services			
Apply fertilizer	0.0	0.0	0.0
Spray insecticide	4.3	4.3	5.8
Spray herbicide	0.0	0.0	0.0
Combine harvest	0.0	0.0	0.0
Other costs			
Transport product	793.0	793.0	1,403.0
Transport fertilizer	74.5	74.5	131.9
Transport seed	37.1	37.1	65.7
Cotton pickers' costs	0.0	0.0	0.0
Tax	122.0	0.0	0.0
Capital costs—interest	114.9	344.8	618.4
Total costs	**3,779**	**5,406**	**15,048**
Net returns (£s/ha)	**7,974**	**11,008**	**28,743**
Net returns (£s/mm)	**4.7**	**6.4**	**16.8**

Appendix G

Resource Cost Ratios for Gezira Cotton and Wheat, Various Levels of Technology

Table G1. Calculation of resource cost ratios for long-staple cotton at economic prices (£s/mm), Gezira, Sudan

	Economic prices	
	1990	**1992**
Gross returns (£s/mm)	7.5	25.2
Traded component (£s/mm)		
Fixed machinery costs	0.1	0.5
Variable machinery costs	0.1	0.2
Contract services	0.2	0.3
Transport costs	0.1	0.1
Purchased inputs	0.5	2.1
Irrigation costs	0.1	0.2
Cotton pickers	0.0	0.0
Value added	6.3	21.8
Cost of domestic resources		
Labor	0.5	1.0
Capital	0.2	0.4
Component of tradables		
Fixed machinery costs	0.0	0.0
Variable machinery costs	0.0	0.1
Irrigation costs	0.1	0.2
Contract services	0.1	0.2
Transport costs	0.1	0.1
Purchased inputs	0.0	0.0
Land and water	6.4	19.6
Total cost of domestic resources	**7.5**	**21.5**
Resource cost ratio	**1.2**	**0.99**

Table G2. Calculation of resource cost ratios for medium-staple cotton at economic prices (£s/mm), Gezira, Sudan

	Economic prices	
	1990	1992
Gross returns (£s/mm)	8.2	25.3
Traded component (£s/mm)		
Fixed machinery costs	0.1	0.5
Variable machinery costs	0.1	0.2
Contract services	0.2	0.3
Transport costs	0.1	0.2
Purchased inputs	0.5	2.1
Irrigation costs	0.1	0.2
Cotton pickers	0.0	0.0
Value added	7.0	21.8
Cost of domestic resources		
Labor	0.6	1.2
Capital	0.2	0.4
Component of tradables		
Fixed machinery costs	0.0	0.0
Variable machinery costs	0.0	0.1
Irrigation costs	0.1	0.2
Contract services	0.1	0.2
Transport costs	0.1	0.2
Purchased inputs	0.0	0.0
Land and water	6.4	19.8
Total cost of domestic resources	**7.7**	**22.0**
Resource cost ratio	**1.1**	**1.01**

Table G3. Calculation of resource cost ratios for traditional wheat at economic prices (£s/mm), Gezira, Sudan

	Economic prices	
	1990	1992
Gross returns (£s/mm)	5.6	15.1
Traded component (£s/mm)		
Fixed machinery costs	0.2	0.6
Variable machinery costs	0.1	0.1
Contract services	0.0	0.0
Transport costs	0.2	0.3
Purchased inputs	0.6	2.0
Irrigation costs	0.1	0.2
Cotton pickers	0.0	0.0
Value added	4.5	11.8
Cost of domestic resources		
Labor 0.2	0.4	
Capital 0.2	0.3	
Component of tradables		
Fixed machinery costs	0.0	0.0
Variable machinery costs	0.1	0.3
Irrigation costs	0.1	0.2
Contract services	0.0	0.0
Transport costs	0.2	0.3
Purchased inputs	0.4	1.1
Land and water	6.4	19.8
Total cost of domestic resources	**7.5**	**22.5**
Resource cost ratio	**1.7**	**1.9**

Table G4. Calculation of resource cost ratios for wheat, intermediate technology level, at economic prices (£s/mm), Gezira, Sudan

	Economic prices	
	1990	1992
Gross returns (£s/mm)	6.9	18.5
Traded component (£s/mm)		
Fixed machinery costs	0.2	0.8
Variable machinery costs	0.2	0.4
Contract services	0.0	0.0
Transport costs	0.2	0.3
Purchased inputs	0.9	3.1
Irrigation costs	0.1	0.2
Cotton pickers	0.0	0.0
Value added	5.4	13.7
Cost of domestic resources		
Labor 0.2	0.4	
Capital 0.2	0.3	
Component of tradables		
Fixed machinery costs	0.0	0.1
Variable machinery costs	0.1	0.2
Irrigation costs	0.1	0.2
Contract services	0.0	0.0
Transport costs	0.2	0.3
Purchased inputs	0.4	1.1
Land and water	6.4	19.8
Total cost of domestic resources	**7.6**	**22.4**
Resource cost ratio	**1.4**	**1.6**

Table G5. Calculation of resource cost ratios for wheat, full package of technology, at economic prices (£s/mm), Gezira, Sudan

	Economic prices	
	1990	1992
Gross returns (£s/mm)	9.6	25.6
Traded component (£s/mm)		
Fixed machinery costs	0.3	1.0
Variable machinery costs	0.2	0.5
Contract services	0.0	0.0
Transport costs	0.3	0.5
Purchased inputs	1.1	4.1
Irrigation costs	0.1	0.2
Cotton pickers	0.0	0.0
Value added	7.7	19.4
Cost of domestic resources		
Labor 0.2	0.4	
Capital 0.2	0.4	
Component of tradables		
Fixed machinery costs	0.0	0.1
Variable machinery costs	0.1	0.2
Irrigation costs	0.1	0.2
Contract services	0.0	0.0
Transport costs	0.3	0.5
Purchased inputs	0.3	1.0
Land and water	5.8	19.8
Total cost of domestic resources	**7.0**	**22.4**
Resource cost ratio	**0.9**	**1.2**

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