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Wilfred M. Mwangi

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FARM LEVEL DERIVED DEMAND RESPONSES
FOR FERTILIZER IN KENYA

By

Wilfred Muthaka Mwangi

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ABSTRACT

FARM LEVEL DERIVED DEMAND RESPONSES FOR FERTILIZER IN KENYA

By

Wilfred Muthaka Mwangi

The role of chemical fertilizer in increasing agricultural output as well as substituting for land is well recognized. Hence the ability to quantify the relative contribution of the factors influencing fertilizer demand at the farm level becomes essential for agricultural policy formulation. However, the empirical evidence delineating these factors is rare in developing countries. Consequently, this study was designed to provide needed empirical evidence, using Kenyan data. Specifically the objectives of the study were:

1. To identify the major constraints for fertilizer use at the farm level as perceived by farmers.
2. To generate farm plans for a set of representative farms which will maximize net farm income within a set of objective and subjective constraints.
3. To assess the impact of increased fertilizer prices, product prices and capital on enterprise combination and net farm income.
4. To derive a series of demand responses for fertilizer under various levels of fertilizer prices, product prices and capital.

5. To estimate demand elasticities for fertilizer prices, product prices and capital, and to assess their policy implications.

The data used were obtained from various sources, viz., Central Bureau of Statistics (CBS), Ministry of Agriculture District Farm Guidelines, Fertilizer Yield Response from the FAO/Ministry of Agriculture Fertilizer Program, fertilizer distributors, publications, and a farm survey conducted by the author.

The methods of analysis included static and parametric linear programming and regression analysis. Linear programming solutions were obtained from a representative farm in each of three agro-ecological zones--the Tea, Coffee and High Altitude Grassland (HAG). The data from these optimum farm plans were used in a regression analysis to estimate continuous functions for the representative farm-firms' demands for fertilizer. The continuous functions were used to derive fertilizer, product price index and capital elasticities for the farm-firm in the analysis.

The results of these analyses indicated that optimum allocation of existing resources in the sample farms resulted in substantial increases in net farm income in all three of the agro-ecological zones. Further, on all the representative farms in all the zones, the marginal value products (MVPs) of operating capital and fertilizer were high, as were the MVPs of labor at peak seasons in the Tea and HAG Zones. This suggests that increasing the use of these resources would lead to income gains. The net farm income in all three zones was influenced by product prices and capital to a much greater extent than it was by fertilizer prices.

The sample farmers perceived lack of funds, lack of fertilizer supplies at the needed time, high transport costs, lack of fertilizer credit and low literacy level as the major factors constraining their use of fertilizer.

In all the zones the demand for fertilizer was most responsive to increases in capital level with capital elasticity of 2.32, 3.49 and 0.87, followed by fertilizer price with elasticity of -1.65, -0.71 and -0.24, and by product price index with price elasticity of 0.27, 0.32 and 0.04 for the Tea, Coffee and HAG Zones, respectively. All the elasticities were calculated at the mean values of observations. These results tend to refute the frequently made assumption that farmers respond symmetrically to a 1 percent decrease in fertilizer price and a 1 percent increase in product price.

The results obtained in this study depend on the realism of the assumptions made in the analysis. Nevertheless, if tempered with judgement, these results can be useful not only in the formulation of general agricultural policy, but even more so in the formulation of fertilizer policy which is of critical importance to the development of agriculture in a country like Kenya.

Dedicated to my dear parents Wangui and Mwangi

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CHAPTER I

INTRODUCTION

The growth of the Kenyan economy is very much dependent on the growth of agriculture. The agricultural sector is expected to perform all the roles often cited by development economists--supply food, earn much needed foreign exchange, capital formation, provide a market for the industrial sector, and supply labour to the development of the economy at large. In the period 1964-71, agriculture accounted for some 35 to 40 percent of the Gross Domestic Product (GDP) compared with 10 to 12 percent from the Government sector. It is further estimated that up to 90 percent of the population is directly dependent on agriculture for their livelihood [37]. Growth of agriculture thus has substantial direct and indirect effects on the growth of GDP.

The 1974-78 National Development Plan succinctly states the role of agriculture in the economy:

> Agriculture will continue for a long time to be the backbone of the country's economy and a vast majority of the population will be dependent upon agriculture for their living. Hence a rapid growth of agricultural production through intensification and increased productivity to ensure adequate and balanced food supplies and the rapid increases in standard of living in the farming community is a fundamental aim of the Government [37].

The agricultural sector in Kenya can be divided into two distinct subsectors based on size of land holdings: (1) large farms and (2) small farms (smallholders or small-scale farmers).[1]

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[1]Smallholders (small farmers) defined as holders owning up to 12 hectares.

The large farms market most of their output and purchase most of their inputs. The farms in the small farm subsector, on the other hand, are in transition from subsistence forms of agriculture to commercial agriculture. They market approximately 40 percent of what they produce and purchase 10 to 20 percent of their labor inputs. Their purchase of modern inputs (fertilizers, improved seeds, insecticides, herbicides, fungicides and machinery) is minimal [36].

This study focuses on this latter subsector. This is the sector that is supposed to bear the largest share of responsibility in Kenya's development. The government recognizes this role of the small farm subsector and states that the "key strategy will be to direct an increasing share of the total resources available to the nation towards developing the smallholder farming areas" [37].

Statement of the Problem

In many respects the smallholder is the key to Kenya's future. Smallholders' production will have to increase at an increasing rate if the nation is to grow. The capacity of the smallholder sector to meet the objectives of development, such as increasing farm income so as to improve the standard of living of the rural population as well as meeting the growing demand for food, will depend on how fast this sector grows. Already, rising prices of food and other agricultural products indicate that supply is lagging behind demand.

The problem of increasing output and productivity is aggravated by complex ecology, rapid population growth, complex institutional structures and shortage of good arable land. Of the total land area of 57 million hectares (ha), only 6.84 million are classified as high potential agricultural land. This is only 12 percent of the total land area. Given that the population of Kenya is approximately 14 million, this implies that at present Kenya has about 0.49 ha of high potential land equivalents per capita. If the present high population growth rate of about 3.5 percent per year is to continue, then at the turn of the century, the per capita high potential land equivalents will be no more than 0.2 to 0.3 ha.

It is estimated that there are approximately 1.2 million small holdings in Kenya, of which 25 percent are under one hectare and 50 percent under two hectares. These support the 90 percent of the population living in the rural areas [21].

All this reflects land scarcity, which means that more will have to be produced per hectare of farm land. But this does not seem to be happening. From 1967 through 1975, agricultural production at constant prices increased about 3.9 percent a year, on the average. But food production rose only about 2.5 percent while the population increased about 3.3 percent a year [43].

This means that ways must be found to increase production, given the scarcity of land. We have to turn to technologies that are land saving or are substitutes for land. Growth of agricultural productivity can be achieved in many ways. These include investments in rural economic overheads such as feeder roads, marketing and storage facilities, agricultural research, extension services and increased water supplies. These are necessary but not sufficient in themselves. Perhaps the most important means of increasing agricultural productivity, however, is increased use of high quality farm inputs such as pesticides, higher yielding seeds, and fertilizers. The important advantage of this method of increased agricultural production is that these inputs are often complementary with labor inputs. This is important in a situation like that of Kenya, where labor is not scarce. The role of these inputs in increasing productivity is well recognized by the government. In 1970, the government set up a working party to look into the use and the distribution of these inputs. The Working Party Report, known as the Havelock Report, expressed doubt as to whether increasing agricultural productivity by small farmers could continue due to insufficient use of appropriate agricultural inputs [36].

Although these inputs are usually recommended as a package, fertilizer has been shown to be a prime mover of agricultural development in a number of densely populated countries and at the same stage of development as Kenya. Fertilizer is also well known as a substitute for land.

Goldsworthy [10] and Watson [45] in Nigeria contend that the use of fertilizer is one of the most important factors capable of bringing about a significant short-run increase in agricultural production. In the Unites States, Heady et al. estimated that 45 percent of the average annual increase in yields for all crops over the past several decades came from fertilizers. Of the remainder, 6 percent came from irrigation, 10 percent from the introduction of hybrid maize, and the remainder from improved seeds, improved cropping practices and other innovations [15].

Ibach [20] concluded that from the mid-fifties to the early sixties about 36 percent of the change in crop production per acre could be attributed solely to the increased rates of fertilizer application.

In Kenya the government realizes the significance of fertilizer use in contributing to farmer's income and to the total value of the agricultural output. The government is using fertilizer subsidy to encourage its use. Fertilizer subsidy schemes have been in operation since 1963 and they are bound to continue. Fertilizers are also the single most important purchased agricultural input. Of a total purchased input bill of K Ł 21.7 million in 1973, fertilizers were responsible for 27 percent, machinery and fuel 22 percent, agricultural chemicals 14 percent, manufactured feeds 13 percent, livestock and medicines 7 percent, and seeds 6 percent. Using estimated figures for 1975, the shares are 38 percent, 19 percent, 12 percent, 13 percent, 5 percent and 5 percent respectively.[2]

The role of fertilizer was further reiterated by the International Labor Organization report to Kenya, which noted that the use of fertilizers is likely to be in general employment augmenting since they increase the yield of existing crops and thereby either increase output or release land for other uses. It further contended that given the population pressure on land and the increasing demand for foodstuffs, fertilizer use should be encouraged [21].

Farming with fertilizer is advantageous in many other ways. It is usually connected with much additional labor, in particular if fertilizer use induces a change in cropping pattern. Fertilizer is usually a foreign exchange saving type of input, because the costs in terms of foreign exchange are lower than the foreign exchange value of the increased output.

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[2]Calculated from Republic of Kenya, Statistical Abstract, 1975 (Government Printer, 1975).

Given that increased agricultural productivity is likely to become more crucial for continued economic development in Kenya, and that fertilizer is likely to play an important part of any successful strategy to improve agricultural productivity, there is a need for studies of the factors that affect its demand by the small farmers. The identification of the relative contribution of the various factors affecting the fertilizer demand will provide some guide to public resource allocation.

Input-output price relationships have been viewed as the major vehicle through which the use of modern inputs can be expanded, so as to increase output in the rural areas. This would appear to be the rationale behind the fertilizer subsidy program in Kenya. However, public policy makers' abilities to determine input-output price relationships is seriously handicapped by lack of quantitative information at the farm level on demand for these inputs. The primary purpose of this research is to provide this needed information with respect to fertilizers.

There is a wide gap between the knowledge of the farmer and that of the public policy makers, who fix product price as well as fertilizer subsidy. A similar gap exists between the farmer, fertilizer companies, and credit institutions.

This study, by attempting to derive fertilizer demand at the farm level, hopes to contribute some of the quantitative information needed to close this gap. Ogunfowora and Norman [35], using data collected in 1966 from Northern Nigeria, have provided similar information. However, the lack of information on fertilizer demand at the farm level is not unique to Kenya. Dalrymple [6] has observed that astonishingly little seems to have been written about the nature of demand for fertilizer at the farm level.

Objectives of the Study

1. To identify the major constraints for fertilizer use on farm level as perceived by farmers.
2. To generate farm plans for a set of representative farms which will maximize net farm income within a set of objective and subjective restraints.
3. To assess the impact of increased fertilizer prices, product prices and capital on enterprise combination and net farm income.
4. To derive a series of demand responses for fertilizer under various levels of fertilizer prices, product prices and capital.
5. To estimate demand elasticities for fertilizer prices, product prices, capital and to assess their policy implications.

The Organization of the Study

In Chapter II, a detailed discussion of the various aspects of the fertilizer industry is undertaken. These include past trends of fertilizer consumption, market structure, fertilizer prices, fertilizer subsidies, transport costs, research on fertilizer use, promotional activities and seasonal credit for fertilizer. Chapter III is devoted to the methodology and analytical techniques used in the study. The analytical techniques consist of static and parametric linear programming and regression analysis.

A brief review of the literature pertaining to the empirical estimation of fertilizer demand is presented. The application of linear programming techniques in African agriculture is reviewed. The sources of the various data sets are described. In Chapter IV, the structure of agricultural production in the study area is examined, representative farms are constructed, and the factors influencing the use of fertilizers, as perceived by the farmers, are analyzed. Chapter V presents the linear programming model. This chapter discusses the model activities, technical coefficients, prices, and resource restrictions used in the study area. Chapter VI is devoted to the examination of optimum farm plans in terms of net farm income, cropping patterns and resource use. The impact of varying fertilizer prices, product prices and capital on net farm income, cropping pattern and resource use is examined. Chapter VII presents the estimated fertilizer demand equations, their interpretation and policy implications. Chapter VIII presents the summary, policy implications and suggestions for future research.

CHAPTER II

FERTILIZER INDUSTRY IN KENYA

Kenya does not produce its own fertilizers. All its needs are met through imports. At one time, sodium phosphate (24 percent P_2O_5) was manufactured at Turbo by the East African Fertilizer Co. Ltd. However, the company ran into financial difficulties and ceased production. A mixing plant exists in Nakuru which is run by Windmill Fertilizers East Africa, Ltd.

Past Trend in Consumption

The past trend of fertilizer consumption is shown in Table 2.1. It can be observed from Table 2.1 that fertilizer consumption increased rapidly from 38,700 tons in 1963 to 95,000 tons in 1966. There was a temporary decline in consumption of fertilizer in 1967 and 1968, possibly due to coffee berry diseases in these years. Complex fertilizers have experienced a very rapid growth since 1968 and are responsible for the decline or stagnation of the consumption of single fertilizers. Reductions in fertilizer consumption occurred in 1971 and 1973-74. This decline in consumption can be attributed to the oil crisis culminating in very high fertilizer prices in the world market, supply shortages and the drought conditions that prevailed in the same period in the country, especially in 1973. In this period from 1963 to 1974, the average annual growth rate in consumption of total fertilizers, single nitrogen fertilizers, single phosphate fertilizers, single

TABLE 2.1
FERTILIZER CONSUMPTION IN KENYA, 1963-74

Quantity (Tons '000)

Year	Single Nitrogen Fertilizers	Single Phosphate Fertilizers	Single Postassium Fertilizers	Complex Fertilizers	Total
1963	17.9	14.2	0.4	6.2	38.7
1964	32.2	12.7	0.2	10.6	55.7
1965	48.0	28.0	0.3	10.5	86.8
1966	30.1	46.1	0.8	18.0	95.0
1967	29.3	32.3	0.8	18.8	81.2
1968	37.3	31.5	2.2	11.1	82.1
1969	31.1	37.0	2.5	32.0	102.6
1970	50.2	42.0	4.8	41.9	138.9
1971	41.0	42.2	3.1	42.7	128.0
1972	54.7	34.3	7.3	52.3	148.6
1973	79.0	32.0	2.0	30.0	143.0
1974	65.6	41.7	5.5	85.5	198.3

SOURCE: Crop Production Division, Ministry of Agriculture.

potassium fertilizers and complex fertilizers was 15 percent, 11.5 percent, 9.5 percent, 24.5 percent, and 24.5 percent respectively.

In terms of nutrient consumption, phosphatic fertilizers are the most important in Kenya. Compounds have become the most important source of phosphatic pentoxide, their P_2O_5 nutrient content having increased rapidly recently. Similarly, about 50 percent of all nitrogen nutrients consumed in Kenya are supplied by mixes and compounds. The situation is well depicted by Table 2.2.

The consumption breakdown of fertilizers by regions and on per hectare basis is not available. Estimates of consumption by crop and by the two farm sectors were made by the Working Party on Agricultural Inputs. These estimates showed that the bulk of fertilizers were consumed by the large farm sector and used mainly on cash crops (tea, coffee, maize and pyrethrum). The use by the small farm sector and on food crops that could be estimated was negligible. Table 2.3 depicts this situation clearly.

This situation has not changed significantly despite the fact that the small farm sector is now producing as much if not more of the major cash crops and the bulk of the food for the nation. In 1973, the Ministry of Agriculture estimated that 143,000 tons of fertilizer was used in Kenya. Thirty-four percent of this went to maize, twenty-two percent to coffee, fifteen percent to tea and ten percent to wheat. Again, the bulk of this was consumed by large-scale farmers. This has led to criticism of the government fertilizer subsidy, which, based on these fertilizer uses, tends to favor the large-scale farmers. This will be discussed below.

TABLE 2.2
FERTILIZER NUTRIENTS CONSUMPTION IN KENYA,
1971-72 - 1973-74

Quantity (Tons)

Nutrients	1971-72	1972-73	1973-74
N	18,000	25,000	23,000
P_2O_5	28,000	28,000	21,350
K_2O	5,000	6,000	3,350
Total	51,000	59,000	47,700

SOURCE: Ministry of Agriculture.

TABLE 2.3
ESTIMATED UTILIZATION OF FERTILIZERS BY CROP AND FARM TYPE IN 1969

(Metric Tons)

Crop	Total Tonnage	Total N Nutrient			Total P_2O_5 Nutrient		
		Large Farms	Small Farms	Total	Large Farms	Small Farms	Total
Tea	15,845	3,669	275	3,944	953	55	1,008
Coffee	11,256	1,688	862	2,550	825	--	825
Wheat	19,923	2,284	a	2,284	9,223	a	9,223
Maize	41,706	3,373	a	3,373	5,966	3,784	9,750
Rice	1,265	--	214	214	--	105	105
Other cereals	1,500	--	--	--	645	--	645
Sugar	6,383	1,264	--	1,264	216	--	216
Pineapples	750	216	--	216	86	--	86
Other horticulture	810	43	42	85	45	45	90
Pyrethrum	919	--	--	--	--	248	248
Mixtures exported	2,327	n.a.	n.a.	354	n.a.	n.a.	781
Other and unaccounted for	2,288	n.a.	n.a.	456	n.a.	n.a.	430
Total[b]	104,972	12,537	1,393	14,740	17,959	4,237	23,407

SOURCE: Republic of Kenya, Report of the Working Party on Agricultural Inputs, Government Printer, Nairobi, 1971.

[a]According to evidence received by the working party it appears that a number of small-scale farmers especially in the settlement schemes used a moderate quantity of fertilizer in 1969 but we have been unable to obtain a precise estimate of the quantities involved.

[b]These are column totals only. The total of columns 2 and 3 is less than the total of column 4 by the amount of fertilizer exported or unaccounted for.

Future Consumption of Fertilizer in Kenya

The reliability of projections made about the future demand for fertilizers depends critically on the realism of the assumptions made about several important variables that have affected demand in the past and those expected to affect demand in the future.

The Ministry of Agriculture has made fairly elaborate projections of future fertilizer consumption up to 1980. The variables considered in these projections include the areas of different crops to be grown; the prices which the farmers receive for their products and have to pay for fertilizers; the response of crops to different fertilizer combinations under different conditions; the farmers' awareness of these factors; farmers' applications of recommended fertilizer levels; credit availability and the government policy with respect to fertilizer promotion.

Table 2.4 indicates the projections made with respect to various nutrients.

The projections made for N, P_2O_5 and K_2O by 1980, imply annual growth rates of 8 percent, 10 percent, and 19.5 percent respectively. These growth rates are below those recorded for the preceding period of 1963-74.

Although some of the factors considered by the Ministry in projecting future demand are policy variables which can easily be manipulated, others are exogenous to the Ministry. The prices of coffee and tea, which consume a high proportion of fertilizers in Kenya, are determined by the forces of supply and demand in the world market. Their fate in the world market will affect the amount of foreign exchange which can be allocated to the purchase of fertilizers.

TABLE 2.4
FUTURE NUTRIENT DEMAND IN KENYA

Nutrients	1975	1980
Nitrogen (N)	33,000	48,000
Phosphates (P_2O_5)	32,700	52,400
Potassic (K_2O)	3,700	9,000
Total	69,400	109,400

SOURCE: Ministry of Agriculture.

Foreign exchange in a country like Kenya is a scarce commodity, with many competing uses, and hence a very high opportunity cost. Fertilizer prices are also determined in the world market, a market that has proved difficult to predict in the wake of the energy crisis. This illustration only goes to show how cautiously any projected future demand for fertilizers should be treated.

Sources of Fertilizer

Most fertilizers consumed in Kenya are imported from Europe and East Africa. The European countries supplying fertilizers to Kenya are members of the powerful European Complex and Nitrex Cartel.

Table 2.5 gives a breakdown of fertilizer imports in 1973 per type and country of origin. The table shows that Holland and West Germany each supplied one-third of Kenya's total fertilizer requirements in 1973. Imports from Uganda and Tanzania made up for 10 percent and 7 percent respectively and the balance, 16 percent, was imported from various other countries, with Italy and Sweden together supplying 8 percent. Imports from sources other than European or East African countries amounted to only 0.5 percent of total imports in 1973.

West Germany and Holland supplied about 80 percent of all nitrogenous fertilizers (53 percent and 29 percent respectively) in 1973. Most phosphatic fertilizers were imported from Uganda (44 percent), Holland (28 percent), and Tanzania (16 percent). Compound fertilizers were purchased mainly from Holland (53 percent), West Germany (23 percent), and Italy (17 percent).

TABLE 2.5
FERTILIZER IMPORTS PER TYPE AND COUNTRY OF ORIGIN

Types of Fertilizer (Tons)

Country of Origin	N		P		K		NPK		Total	
	Quantity	%	Quantity	%	Quantity	%	Quantity	%	Quantity	%
Holland	23,000	(29)	9,000	(28)	--	--	16,000	(53)	48,000	(34)
West Germany	42,000	(53)	--	--	--	--	7,000	(23)	49,000	(34)
Uganda	--	--	14,000	(44)	--	--	--	--	14,000	(10)
Tanzania	3,000	(4)	5,000	(16)	--	--	2,000	(7)	10,000	(7)
Italy	2,000	(3)	--	--	--	--	5,000	(17)	7,000	(5)
Sweden	4,000	(5)	--	--	--	--	--	--	4,000	(3)
Other countries	5,000	(6)	4,000	(13)	2,000	(100)	--	--	11,000	(8)
Total	79,000	(100)	32,000	(100)	2,000	(100)	30,000	(100)	143,000	(100)

SOURCE: Annual Trade Report, 1973 (East African Community).

Recent developments, however, since 1973 are bound to change this picture drastically. Kenya has decided to build its own fertilizer factory at Mombasa, which went into production early in 1978. The East African Community has collapsed, and trade between the partner states has almost ceased. This eliminates Uganda and Tanzania as sources of fertilizer.

Domestic Fertilizer Production

Kenya has entertained the idea of producing fertilizers domestically for a long time. In 1967, the Triangle Fertilizer Ltd. was launched with a capital outlay of K Ł 5 million, with Albatros of Holland and Imperial Chemical Company each contributing 40 percent of the total, and Development Finance Company of Kenya 20 percent. The project never got underway because it is claimed that serious errors were made in the feasibility study.

Consequently, Kenya has only had a mixing plant at Nakuru--Windmill Fertilizers East Africa Ltd.--which produces mixtures from imported bulk fertilizer. The company is jointly owned by Windmill Holland B.V.--a subsidiary of Central Resources Corporation of New York (60 percent), Development Finance Company of Kenya (25.7 percent), and Mackenzie Kenya Ltd. (14.3 percent). The latter is at present the company's sole distributor in Kenya. The sales of mixed fertilizers from the Nakuru plant have averaged about 40,000 tons per year over the last few years, of which about 30 percent is re-exported to neighboring countries.[1]

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[1] Unpublished mimeo from fertilizer distributors.

Until 1974, the importation and distribution of fertilizer was left in the hands of private firms, usually local branches of large international concerns, and mainly subsidiaries of the powerful European-based Complex and Nitrex cartel. This situation creates uncertainty in the timing of fertilizer imports. In many instances scarcity of fertilizer has existed in the country and the blame has been placed on these private importers mainly controlled from Europe.

An expected shortage of fertilizers in the long rainy season of 1974 prompted the government to import directly. Established firms were denied import licenses except for minor amounts of special varieties. In 1975, the Kenya government agreed with the N-Ren Corporation of Cincinnati, Ohio, U.S.A., to build and operate a fertilizer blending plant in Mombasa, using mainly imported components at a cost of K Shs 418 million, with an annual capacity of 240,000 tons of NPK compounds. The company, to be known as KEN-REN, also received a monopoly for fertilizer imports after 1976.[2]

The proposed capacity of 240,000 tons a year of various nitrogenous and complex fertilizers will be spread as follows:

Calcium ammonium nitrate (CAN)	60,000 tons per year
NPK compounds	
17-17-17	10,000 tons per year
20-10-10	80,000 tons per year
20-20-0	10,000 tons per year
16-48-9 (Diammonium Sulphate - DAP)	80,000 tons per year
Total	240,000 tons per year

[2]Unpublished mimeo from fertilizer distributors.

Thus the complex is designed to produce all NP and NPK fertilizers currently used in Kenya.[3]

Theoretically the question of whether to meet the domestic demand for fertilizer by domestic production or through reliance on fertilizer imports will depend upon a number of factors:

1. The effectiveness of the investment in fertilizer industry in saving or earning foreign exchange.
2. The availability of local or imported cheaper raw materials for feeding a domestic fertilizer industry.
3. Existence of a local market or export market to allow establishment of an optimal size plant.

Foreign exchange saving or earning is the most important variable in deciding whether or not to invest in a fertilizer industry. As a scarce resource, foreign exchange is critical to the development of Kenya's economy because of its multiple alternative uses and very high opportunity cost. It is one of the major constraints in optimal utilization of resources in Kenya. A continuous dependence on fertilizer imports would imply a recurring expenditure of high opportunity resources.

The ability of investment in domestic fertilizer production to save foreign exchange will depend on the availability of raw materials within the country, the amount of foreign exchange required to finance the capital costs of a fertilizer plant, and the foreign exchange needed to finance the recurring costs.

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[3]Unpublished mimeo from fertilizer distributors.

The capital costs of erecting a fertilizer industry and its operation costs will depend on whether economies of size and scale can be exploited, the ability to take advantage of the most recent technological changes, and the intensity of demand and size of the market.

The other objective of investing in a fertilizer industry in a country like Kenya is the transfer of technical skills and the creation of employment for the local labor.

In justifying this undertaking in Kenya, the above economic factors were used. It was argued that the undertaking would have substantial economic benefits in terms of foreign exchange savings, employment, utilization of local resources and would also go a long way in shielding the local farmer from the vagaries of the international fertilizer markets. This was also viewed as an import substitution project which would enable the country to replace existing fertilizer imports on an economic basis.

The scale of operations, the inexpensive technical know-how available from N-Ren Corporation, the local availability of all packaging materials and the basic feedstock for the ammonia plant, limestone and diatomite and the low cost of labor in Kenya would ensure low costs of production.

It was further argued that the project would go a long way in facilitating realization of higher agricultural production in the rural areas where these are now constrained by lack of further agricultural land, the high world market prices for fertilizers and sometimes supply shortages on the world market. It would create employment for 136 Kenyans and indirectly generate more employment within the agricultural sector, and within the distributive system, especially at the stockist level and within the agro-processing sector.[4]

But despite this argument, it is still doubtful that the project will be able to achieve all this. Its ability to save foreign exchange will depend on the prices of raw materials to be imported, which include phosphate rock and/or phosphoric acid, potassium and other chemical catalysts. This still involves a high foreign exchange component.

The viability of the plant based on the Kenyan and export market is another area which creates a lot of pessimism. The current consumption of fertilizers in Kenya is estimated to be about 150,000 tons a year. It was argued that Ken-Ren's reduced prices would result in an increase in consumption to about 200,000 tons a year by 1978, and the balance of 40,000 tons would be exported to other countries of Eastern Africa. Thus, the plant is designed for this capacity, i.e., 240,000 tons a year. But export to these other countries is limited. Uganda and Tanzania produce their own fertilizers, and in any case, with the collapse of the East African Community, the trade between these partner states is non-existent. Fertilizer use in surrounding African countries like eastern Zaire, southern Sudan, Ethiopia, Rwanda, Burundi and Somalia is very small and transport links are very bad. No great optimism seems warranted therefore with respect to the export market. This means that the plant may end up being underutilized, culminating with high prices to the Kenyan farmer.

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[4]Unpublished mimeo from fertilizer distributors.

Further, one doubts whether domestic production of fertilizer will culminate in lower prices to Kenyan farmers. This is because even if the plant is large enough to take advantage of the economies of scale and hence produce fertilizer at low cost, this cost advantage might be partly or wholly offset by the high transport cost required, particularly in a geographically dispersed market in which roads are inaccessible at critical times of the year when fertilizer is needed.

Thus, given that raw materials have to be imported and the scale of operations might be too small to reap economies of scale, and the domestic market not being big enough, one would still place a caveat as to the viability of the plant.

Market Structure and Distribution Channels

From a theoretical point of view, the process of fertilizer distribution essentially involves the process of transfer of ownership and creation of time and place utilities through the physical flow of fertilizers from importers to the farm-consumer end of the channel. This process creates three economic markets. First, there is the exchange mechanism between the importer as a seller and wholesaler (distributor). In Kenya some groups are importers as well as wholesalers or distributors.

Secondly, there is the exchange between the wholesaler (distributor) as a seller, and the retailer as a buyer.

Thirdly, there is the exchange between the retailer as a seller, and the farmer as a buyer.

Before 1974, the importation and distribution of fertilizers in Kenya was mainly done by two local importing companies, and local subsidiaries of the European-based Complex and Nitrex cartel. In 1970, the Kenya Farmers' Association (KFA), representing Albatros-Holland the Ruhrstickstoff-Germany, imported and distributed 34 percent of the fertilizer. Mackenzie Kenya Ltd. distributed about 24 percent of the market and represents Windmill Ltd. Sapa Chemicals, representing Montecalini-Edison, the Italian chemical giants, distributed 5 percent. Other companies--Hoechst and BASF of Germany and Twiga--distributed 37 percent of the total fertilizer consumed [46].

The KFA has thirty-two branches. From these branches sales are either made directly to large-scale farmers, government organizations and nearby small-scale farmers, or through Cooperative Unions and societies to members of cooperative societies, and through its 1,500 registered stockists. Mackenzie Kenya Ltd. has five branches and several smaller shops all over the country. In addition, KFA uses the stores of the Maize and Produce Board as storage depots. From these branches, KFA and Mackenzie Kenya Ltd. sell some fertilizers directly to farmers, although most of it goes to local stockists appointed by them. Both firms have established a network of local stockists in the country to channel fertilizers to small-scale farmers. SAPA has started to establish depots in selected areas. The other companies are not so well established, and sell directly to farmers and cooperatives, or compete for tenders in cases of large requirements.

The Cooperative Unions usually order fertilizer from private distributors for the societies which sell them to their members.

The number of stockists varies from district to district, but it goes into hundreds in densely populated parts of the country. In total, the number of stockists is estimated at 1,500. Most of them handle an average of 10 to 15 kg bags of fertilizer per season; however, a few have achieved sales of more than 100 bags. The importance of stockists is high in areas where the Cooperative Unions are weak and where the average farm size is small [30].

This market structure and the distribution channels described above have been highly criticized in Kenya, especially by the Report of the Working Party on Agricultural Inputs of 1971. The report pointed out and documented that the private firms operating in importation and distribution of fertilizers tended to select types of fertilizers and sources of supply that were not in the country's best interest, and that confusion among them resulted in unwarranted high prices, due to their oligopolistic network. The report further indicated two constraints operating against obtaining supplies from the cheapest source:

> First, the majority of importers at the moment are members of the European-based Nitrex Cartel of nitrogenous fertiliser manufacturers. This organisation sets a common f.o.b. price for all straight nitrogenous fertilisers sold by members of the cartel. Second, until recently it appears to have been a deliberate policy of the Ministry of Agriculture acting on the advice of the Fertiliser Advisory Committee (whose active members have been existing fertiliser distributors). This policy has prevented firms which would have imported fertiliser from non-European sources, e.g., the Middle East, from entering the market and making it more competitive than it is at the moment [36].

Thus, what we observe here is that the marketing and distribution of fertilizers in Kenya is highly concentrated. This may end up in collusion on prices, market sharing and through established marketing organization and outlets, the possibility of excluding potential new entrants into the fertilizer industry. It could also result in less emphasis being placed on the introduction of new ranges of fertilizers, or in making them more difficult to obtain than if the industry was highly competitive.

The report recommended that measures be taken to remedy these practices and to increase competition in the industry. It was also noted that the network was hopelessly inadequate for the task of providing all small farmers with easy access to fertilizer supplies. The report further noted its failure to provide supplies in suitable packages, and its failure to provide adequate advice on different fertilizers and their use to small farmers. The report recommended that the role of cooperatives in supplying fertilizer to farmers be strengthened as one of the ways in which the constraints of the distribution system can be removed.

Regretably, recent measures have moved in the opposite direction. In 1974, the government entered into the fertilizer market. It imported 174,000 tons of fertilizer. At the end of 1974 stocks were estimated at about 40,000 tons [44]. This was because the government, through the Kenya National Federation of Cooperatives which had no previous experience in fertilizer distribution, was unable to distribute all the fertilizers. The established and experienced firms which were denied import licenses in that year were reluctant to undertake distribution of government fertilizer.

In 1976-77, import licenses were issued to four new importers who had just come into the fertilizer business with little experience behind them. These were accused of collusion by the former importers. This goes a long way in showing that the Working Party Report had some substance when it alleged that there was collusion among the former importers.

The new importers' lack of experience in the international fertilizer market could have also caused the shortage in fertilizer in that year.

In 1977-78, the import licenses have been issued to ten importers, including KFA and Windmill representing former importers.

The method of issuing these licenses leaves a lot to be desired. The criteria seem to be more on political influence than on experience in the fertilizer business, ability to distribute fertilizers all over the country, or the ownership of warehouses. During the author's interviewing with distributors it was alleged that licenses issued to certain individuals who lacked experience and know-how in fertilizer had passed hands for handsome profit. This will then culminate in inefficiency in purchasing of fertilizers overseas, which will then result in shortages, and higher prices for farmers.

Thus, the new policy of import licenses and a single fertilizer company empowered to produce and import all fertilizers, hardly increases competitiveness, and fertilizers will be supplied at relatively high cost for a long time.

Fertilizer Prices and Margins

The price of fertilizer constitutes an important variable in so far as it influences the level and pattern of production and market resource allocation. Changes in fertilizer price can lead to shifts in the profitability of fertilizer and farmers' economic motivation towards production of various crops as well as input-output price ratio.

During 1971-74, the price of fertilizers skyrocketed in Kenya as illustrated by Table 2.6. This table shows that using 1971-72 as a base (100 percent), the weighted index of fertilizer prices had increased to 209 percent by March 1974, indicating that prices for the most commonly used fertilizers had more than doubled in price during this short period. In fact, increases were even greater between 1973 and 1975.

These price increases are the result of four major factors, viz. increased prices in producing countries, changes in exchange rates, increased sea freight charges and increased distribution costs within Kenya. The estimate of the contribution of these factors to the price increase between March 1973 and March 1974 for the average popular type of fertilizer is indicated below:[5]

	K Shs Per Ton	Percentage
Increased producer prices approximately	72	15%
Changes in exchange rates approximately	111	23%
Increased freight costs approximately	199	41%
Increased local distribution costs approximately	103	21%
Total	485	100%

The effect due to exchange rate was a result of the Kenyan shilling decreased in value against most European currencies by 15 percent, as a result of the decreasing value of the 1972-73 U.S. dollar to which it was tied. This also had a major impact on increased freight

[5]Estimates--Ministry of Agriculture.

TABLE 2.6
F.O.B. MOMBASA PRICES PER TON (INCLUDING SUBSIDY)
FOR MOST POPULAR FERTILIZERS IN KENYA BETWEEN
1971-72 - MARCH 1974

(K Shs per Metric Ton)

Type of Fertilizer	1971-72	March 1973	Oct. 1973	March 1974	Increase March 1973-March 1974	
CAN/ASN	537	660	766	978	318	(48%)
S.A.	369	489	618	788	299	(61%)
T.S.P.	631	868	1,103	1,518	650	(75%)
D.A.P.	856	1,157	1,473	1,942	785	(68%)
25-5-5	608	842	1,050	1,231	389	(68%)
11-55-0	901	1,167	1,486	2,005	838	(72%)
15-45-0	857	1,106	1,406	1,861	755	(68%)
Weighted average price	617	806	997	1,291	485	(60%)
Weighted index	100	131	162	209		

SOURCE: Ministry of Agriculture.

costs. The other factor contributing to increased freight cost was the Kenyan importers' increased reliance on charter ships. Increased local distribution costs were mainly attributed to higher financing costs and higher costs for unloading and handling in Kilindini harbor. This leaves only 15 percent attributed to increased producer prices, mainly to the oil crisis in Europe. But perhaps the full impact of increased producer prices had not been felt in Kenya by March 1974.

These increased fertilizer prices have contributed substantially to the production costs in Kenya. Their impact on production costs can be illustrated by the case of maize and wheat production in the Trans Nzoia District in Table 2.7.

The table shows that increased fertilizer prices accounted for 81 percent of the increased maize production costs and 28 percent of the increased production costs for wheat between April 1973 and April 1974. These increased fertilizer prices and their impact on production costs led the government to increase the price of maize and wheat by K Shs 4/85 per 90 Kg bag and K Shs 5/30 per 90 Kg bag respectively, to compensate farmers.

The price of fertilizer and the determination of profit margins on subsequent channel-levels are fixed by the government on the basis of a yearly price list that is prepared by the Fertilizer Association, the members of which are importing companies as well as government representatives. The price controller (Ministry of Finance and Planning) mainly determines the margins on the subsequent channel-levels. The development of prices from Mombasa to an up-country farmer at Eldoret, 800 km away, is illustrated in Table 2.8 for two fertilizer types distributed by the KFA.

TABLE 2.7
EFFECTS OF INCREASED FERTILIZER PRICES ON MAIZE
WHEAT PRODUCTION COSTS, 1973-74[a]

Crop	Prod. Cost April 1973 (Shs/Acre)	Prod. Cost April 1974 (Shs/Acre)	Increase (Shs/Acre)	% (Shs/Acre)
Maize (1,620 kg/acre)				
Fertilizer	150	237	87	58%
Other prod. costs	301	322	21	7%
Total	451	559	108	24%
Wheat (540 kg/acre)				
Fertilizer	58	90	32	55%
Other prod. costs	187	271	84	45%
Total	245	361	116	47%

SOURCE: Farm Management Information, Trans Nzoia District.

[a]Assumes the same amount of fertilizer will be applied.

TABLE 2.8
PRICES, COSTS AND MARGINS IN THE DISTRIBUTION OF SELECTED FERTILIZERS IN ELDORET, KENYA, 1972-73

	1972				1973			
	T.S.P.[a]		A.S.[b]		T.S.P.		A.S.	
	Price/ Ton	Share of Retail Price	Price/ Ton	Share of Retail Price	Price Ton	Share of Retail Price	Price/ Ton	Share of Retail Price
	K Shs	%	K Shs	%	K Shs	%	K Shs	%
Price CIF	600.00	110.0	256.70	73.1	1,050.82	90.0	531.36	77.6
+ Cost of labor charges	25.00	4.6	21.50	6.1	40.00	3.43	40.00	5.8
Price at port gate Mombasa	625.00	114.7	273.20	79.3	1,090.82	93.43	571.36	83.4
Less subsidy	-215.00	-39.5	-42.00	-12.0	-129.00	-11.00	-25.50	-3.7
FOB Mombasa (ex importer)	410.00	75.2	236.20	67.3	961.82	82.3	545.86	79.7
Transport costs rail - 800 km	46.00	8.4	46.00	13.1	46.50	4.0	46.50	6.8
Price delivered to railway station	456.00	83.7	282.20	80.4	1,008.32	86.3	592.36	86.5
Wholesale margin	44.00	8.1	24.50	7.0	85.65	7.3	37.14	5.4
Price ex wholesale store	500.00	91.8	306.70	87.4	1,093.97	93.6	629.50	92.0
Transport, average 20 miles	15.00	2.8	15.00	4.3	20.00	1.7	20.00	2.9
Price delivered to retailer's store	515.00	94.5	321.00	91.5	1,113.97	95.3	649.50	94.9
Retail margin	30.00	5.5	30.00	8.5	55.00	4.7	35.00	5.1
Price ex retailer's store = price to farmer	545.00	100	351.00	100	1,168.97	100	684.50	100

SOURCE: Price Controller, Ministry of Finance and Planning.

[a]Triple Super Phosphate, 43 percent P_2O_5.

[b]Ammonium Sulphate.

From the table we can observe that the relative share of the retailer's margin decreased as fertilizer prices increased. Similarly, that of the wholesaler decreased, but their absolute amounts increased. The retailer's absolute margin increased by 83 percent for the T.S.P. and 17 percent for Ammonium Sulphate. The absolute increase in wholesale margin went up by 52 percent for Ammonium Sulphate and 95 percent for T.S.P.

These margins have to be reviewed from time to time because they are vital if the system is going to function efficiently. They act as incentives to give the channel participants an adequate return on their time, their investment and their risks. They are payment for services that society needs.

However, sentiments have been expressed that those margins are excessive, as in the following statement:

> In Kenya fertilizer prices have decreased by 30 percent since the peak in 1974-75. On the other hand world market prices have come down by over 60 percent during the same period. What has gone wrong with our prices? Are the new importers taking too large a profit or are they not buying from the best and cheapest sources [23]?

Fertilizer Subsidy

The rational economic argument for subsidizing the price of fertilizer is that farmers, in effect, tend to over-discount returns to fertilizer as compared to society, due to a number of risks like price risk, weather risk and yield risk. Subsidized price, therefore, provides a compensatory discount that leads to a new, but higher level of optimal fertilizer use. Thus, in order to ensure low fertilizer prices to farmers, the government of Kenya provides for a relatively high fertilizer subsidy. Its main objective is to induce small farmers to use fertilizer for raising farm productivity. The program was begun in 1963 and the pattern of expenditure is illustrated by Table 2.9.

The role that fertilizer subsidies have played as promoters of fertilizer consumption is unclear. From Table 2.1 it can be observed that despite the introduction of a subsidy of Shs 375 per long ton of water soluble in the middle of 1963, it was not until 1965 and 1966 that a notable increase in phosphatic fertilizer consumption occurred. Furthermore, during the years 1964 and 1965, the consumption of nitrogenous fertilizers (and mixes and compounds) increased rapidly as well, although a subsidy on nitrogenous fertilizer was introduced in 1969. The latter subsidy, amounting to Shs 200 per long ton of nitrogenous nutrient, did not stop the consumption of straight nitrogenous fertilizer from falling 17 percent below its 1968 level, although consumption of mixes and compounds tripled between these two years.

This fertilizer policy has been criticized mainly on welfare grounds. It has been found that 80 percent of the subsidy accrues to large-scale farmers, and small-scale farmers only get 20 percent [36]. In their review of the existing subsidies on agricultural input in Kenya, the ILO Mission [21] found that the policy was not coherent. Moreover, there was evidence that agricultural inputs continued to flow to the large farmers even where marginal returns were higher from small-scale farmers. This situation must be rectified if agricultural productivity is to be increased. Thus, if fertilizer services and prices have not been favorable to small farmers, then one finds it hard to make an economic case for the continuation of these subsidies.

TABLE 2.9
FERTILIZER SUBSIDIES, RATES AND TOTAL COSTS, 1964-73

Year	Type of Nutrient		Total Costs of Subsidy
	Shillings Per Long Ton		K Ł '000
	P_2O_5	N	
1963-64 (July 1963)	375	--	166
1964-65	375	--	189
1965-66 (March 1965)	410	--	325
1966-67	410	--	350
1967-68	410	--	356
1968-69 (July 1968)	387.5	--	563
(Jan. 1969)		200	
1969-70	500	200	809
1970-71	500	200	778
1971-72	500	200	973
1972-73 (Sept. 1973)	300	120	750

SOURCE: Ministry of Agriculture.

More economic arguments can be put forward on why the government should explore other ways of reducing the cost of fertilizer to the small farmer other than direct subsidy. It is generally accepted that price reduction will promote fertilizer consumption, but the extent to which the demand for fertilizer will increase in response to a given percentage reduction in price and at various levels of the demand curve would depend upon the elasticity of fertilizer demand at that particular level. The policy-maker in Kenya lacks these coefficients.

The single major objective of the fertilizer subsidy is fertilizer demand expansion by ensuring better returns to farmers which could also be achieved by various means. The unilateral emphasis of government policy on subsidized prices as the sole means of attaining the indicated objective leads to misallocation of high opportunity cost resources insofar as trade-off seems to exist between the means. In order to maximize the effectiveness of a given budget allocation in achieving the desired objective, the government can diffuse the use of resources by shifting them from fertilizer subsidy into increased supply of soil testing facilities, research on fertilizer response of food crops, extension of fertilizer credit and improvement of outlets and distribution services as may reduce the real cost of local delivery to the small farmer.

Moreover, even though individual farmers may view the effect of fertilizer subsidy as a generation of favorable returns, the aggregate behavior of farmers may yield differential results. But all in all, one must bear in mind that in such issues as fertilizer subsidy, political expediency might replace sound economic analysis.

Transport Cost of Fertilizer

Fertilizer is mainly transported by rail and road in Kenya. The cost of both modes of transportation can form a large percentage of the retail prices of fertilizer to farmers. Table 2.8 shows that in 1973 railway transport costs formed 6.8 percent and 4 percent of the retail price of sulphate of ammonia and triple superphosphate respectively. On the other hand, transport costs formed 2.9 percent and 1.7 percent of sulphate of ammonia and TSP respectively. The costs depend on distances from Mombasa and the distances from depots to the farms.

Fertilizer transported by rail is charged according to two scales, depending on total quantity of shipment. These scales can be linearized as follows:

$$TC_1 = 1.00 + 0.029\ L_{K,j} \qquad (< 13 \text{ ton})$$

$$TC_2 = 0.08 + 0.007\ L_{K,j} \qquad (> 13 \text{ ton})$$

Where TC_1 is the transport cost in K Shs per 100 Kg for quantities under 13 tons, and TC_2 is the transport cost in K Shs per 100 Kg for quantities over 13 tons, $L_{K,j}$ represents the distance in miles between K and j. This shows that large quantities are heavily favored by the railways. To transport 100 tons in small separate shipments over 100 miles would cost in total K Shs 3,900, while the same quantity in one shipment over the same distance would cost K Shs 780.

Road transport costs vary from place to place. The range is from Shs 0.75 to Shs 1.00 per ton per mile. However for single bags, the costs are higher [30]. In both modes of transportation, costs progressively rise as we move further away from the coast. Since railways tend to enjoy greater economies of scale than road transport, the former as a low-priced mode of shipment gets preference over the latter for fertilizer haulage over longer distances. Both modes, however, are plagued by problems at the critical times of the year when fertilizer is needed at the farms. The railways are usually short of rolling stock, either due to peak demand or general lack of proper planning. The roads are mainly earth roads and are impassable during the wet seasons. This problem can only be alleviated in the long run by bitumenizing these roads.

Fertilizer Research and Promotion

Fertilizer research in Kenya is carried out by a variety of organizations: the Ministry of Agriculture, other parastatal research institutions, the FAO, and private fertilizer distributor firms. Research institutions within the Ministry of Agriculture may be divided into three groups although in practice there may be a certain amount of functional overlapping among them: national, crop specific and regional or district. The purely national institutions comprise the National Agricultural Laboratories, Kabete, and the National Agricultural Research Station at Kitale. The former undertakes the analysis of soil samples submitted by government agricultural extension staff. Fertilizer recommendations from these stations tend to be of a generalized nature, but regional differences in fertilizer application rates are given for widely grown crops such as maize.

The National Agricultural Research Station at Kitale has been conducting an intensive program of research into maize agronomy since 1963. It is this station, supported by Rockefeller funds which has made the major contribution to the breeding of improved hybrid and synthetic maize varieties in Kenya. Research stations under the Ministry of Agriculture which are specific to a particular crop are listed as follows: (1) Horticultural Research Station, Thika; (2) Potato Research Farm, Limuru; (3) High Level Sisal Research Station, Thika; (4) Msabala Cotton Research Station, Malindi; (5) Kibos Cotton Research Station, Kibos; (6) Wheat Plant Breeding Research Station, Njoro; (7) Pyrethrum Research Station, Molo; and (8) Marindas Agricultural Research Station, Molo (Pasture).

To this list of specialized institutes which are responsible to the Ministry of Agriculture, one may add two independent bodies: (1) Coffee Research Foundation at Ruiru and (2) Tea Research Institute at Kericho. Research findings on these and the national stations are extended on a district level at the following stations: (1) Coast Agricultural Research Station, Kikambala; (2) Nyanza Agricultural Research Station, Kisii; (3) Katumani Research Station, Machakos; (4) Eldoret Agricultural Research Station, Eldoret; (5) Western Agricultural Research Station, Kakamega; and (6) Nyandarua Agricultural Research Station, Ol Joro Orok. Thus, there is a fairly extensive network of stations within the Ministry of Agriculture, which enables fertilizer recommendations for a wide range of crops to be made down to at least the regional level. But the quantity of fertilizer research work undertaken at these stations depends both on the importance attached to it by the Ministry and the capability of the stations themselves.

The FAO Fertilizer Program is undertaken in conjunction with the Ministry of Agriculture. This program is demonstrating to farmers in the field what fertilizers can do. It is further performing two useful roles in the area of basic research into fertilizer use in Kenya. First, it is covering a large number of districts so that recommendations on the economic use of fertilizer can be made at the local level; and second, it is paying attention to food crops' responses to fertilizers, which have hitherto been ignored. They have collected a lot of data showing crop response to various fertilizers. They have further attempted to show the economic justification for using fertilizers by calculating net returns and value cost ratio (VCR). Table 2.10 shows the responses on hybrid maize resulting from various fertilizer combinations, the resulting net return and VCR.

However, despite these results having been obtained from farmers' fields, they should be used with caution. The cultural practices of farmers might differ substantially from those of researchers, resulting in significant differences in yields. Furthermore, although the amount of fertilizer used is not indicated in the table, the cost of fertilizer indicates that only purchase price was taken into consideration. Other costs, such as application cost, capital cost and transportation cost, seem to have been ignored. Inclusion of these costs in the calculation of VCR would have resulted in different VCRs from those indicated in the table.

As far as private firms go, Windmill Fertilizers E.A. Ltd. and Albatros Association (Co-op) Ltd., undertake soil sampling down to the individual field level. The University of Nairobi also does some useful work in the field of fertilizer research.

Kenya conducts a fair amount of fertilizer research, particularly on major crops, viz. coffee, tea, pyrethrum, sisal, maize and wheat,

TABLE 2.10
EFFECT OF FERTILIZER ON MAIZE YIELD FROM DEMONSTRATION
IN TWELVE DISTRICTS OF KENYA, 1972

District	No. of Demon-strations	Average Yield		Increase in Yield	Value[a] of Increase	Cost[b] of Fert.	Net Re-turn	VCR
		Control Kg/Ha	Treated Kg/Ha		K Shillings			
Kakamega	38	3,779	6,099	2,320	902	197	705	4.7
Bungoma	45	3,159	4,976	1,817	767	197	570	3.9
Homa Bay	50	2,532	4,538	2,006	780	197	583	4.0
Siaya	29	3,158	4,929	1,771	689	197	492	3.5
Murang'a	54	2,672	4,659	1,987	773	150	623	5.2
Nyeri	51	3,635	5,721	2,086	150	150	661	5.4
Embu	20	2,586	4,312	1,726	671	150	521	4.5
Machakos	6	1,524	2,247	723	281	150	131	1.9
Kericho	25	2,920	4,798	1,878	731	197	534	3.7
Baringo	8	3,765	5,506	1,741	677	197	480	3.4
Narok	8	3,167	4,827	1,660	646	197	449	3.4
Taita	29	3,478	5,498	2,020	786	150	636	5.2

SOURCE: Compiled from FAO Fertilizer Program (Kenya) Report No. 4, 1972.

[a]This is calculated using the 1972 price of maize which was K Shs 35 per 90 kg bag.

[b]The fertilizer used was 60-60-0 and 40-40-0 costed at K Shs 197 and K Shs 150 per 100 kgs.

which reflects the bias of policy makers towards cash crops, and negligence of food crops. But if the growing Kenyan population is to be fed without resorting to food imports, which is already constrained by scarce foreign exchange, then resource allocation must be shifted to fertilizer research on food crops. In fact, given the amount of work that has been undertaken for cash crops, it can be argued that further research in this area will only result in diminishing marginal productivities of these resources. Given that research resources are limited in both personnel and finances, then resources must be allocated where they have the highest returns. These high returns might be in food crops.

The role of promotion of fertilizer is to help the farmer identify his need for fertilizer, estimate the gains he will get from it, identify what type he needs and how to apply it, and where to buy it and how to finance it.

The government tries to do this through provision of extension services. The private firms advertise, and others like the KFA and Mackenzie Kenya Ltd. have field representatives. However, the promotion of fertilizer use in Kenya leaves much to be desired, demonstrated by the enormous gap between recommended fertilizer use and actual consumption levels. Given the predominance of small farmers in Kenya, effective fertilizer promotion and demonstration is difficult to organize, and is costly. Perhaps the cost might be reduced by relying more on group demonstrations, cooperatives and stockists. As it stands, extension service is inadequate and is available for only a few farmers.

Fertilizer Credit

The farmer in Kenya is exposed to three main types of agricultural credit, viz. long-term credit for land purchase; medium-term credit for development such as fencing and purchase of livestock; and short-term credit for purchase of inputs such as fertilizers and seeds--seasonal credit. This is the type of credit that will concern us here.

Table 2.11 shows the amounts extended by different sources of credit in Kenya, distinguished as to involvement with small or large farms.

Table 2.11 shows that the Agricultural Settlement Fund dominates the agricultural credit structure. Credit is also provided by commercial banks, the Agricultural Finance Corporation (AFC), traders (particularly input suppliers), the Cereals and Sugar Finance Corporation, the Cooperatives, and a little to smallholders by the Kenya Tea Development Authority (KTDA) and the Pyrethrum Board. The AFC gives a little long-term, but much more medium-term credit. The commercial banks give mostly short-term, but a little long and medium-term credit as well. All the other sources give only short-term credit.

These credit institutions tend to operate independently and consequently credit provision is highly fragmented. The Agricultural Settlement Fund, although dominating agricultural credit structure, provides little fertilizer credit. It concentrated on long-term and medium-term credit, which is only extended to small holdings on settlement schemes. The AFC credit is concentrated in medium-term credit. The Guaranteed Minimum Return (GMR) scheme is a short-term credit and insurance scheme through which seasonal inputs into

TABLE 2.11
ESTIMATED AGRICULTURAL CREDIT PROVIDED IN KENYA, 1972

('000 Shs)

	Small Farms	Large Farms	Total	%
Agricultural Settlement Fund	240,000	63,000	303,000	33
Agricultural Finance Corporation	32,000	186,000	218,000	24
Other government schemes	15,000	--	15,000	2
Guaranteed minimum return	15,000	15,000	30,000	3
Commercial banks	50,000	205,000	255,000	28
Cooperative societies	6,000	--	6,000	1
Kenya Tea Development Authority	2,000	--	2,000	1
Pyrethrum Board	600	--	600	1
Trade credit	20,000	65,450	85,450	9
Other sources	300	3,450	3,750	1
Total	381,000	538,000	919,000	

SOURCE: Donaldson, G.F. and Von Pischke, J.D., "Small Farmer Credit in Kenya" (AID Spring Review, Washington, 1973).

large-scale maize and wheat production are financed. The AFC is the agent of the Cereals and Sugar Finance Corporation as far as the GMR scheme is concerned. The scheme advances credit to farmers owning a minimum of six hectares of wheat or maize. This criterion alone eliminates the majority of smallholders, and so the fertilizer credit that is extended through this scheme goes to large farmers. This is the main criticism raised against this scheme, not to mention the large losses incurred through the scheme and borne by the Treasury as it taxes the public at large. This culminates in subsidizing large-scale maize and wheat growers. Commerical bank credit and trade credit are directed toward large-scale farmers.

In the present credit structure in Kenya, one observes a lack of fertilizer credit and little agricultural credit to small farmers in general. The government is trying to alleviate this situation through the Cooperative movement. The Kenya Cooperative Production Credit Scheme (CPCS) was started in 1970 to provide short-term credit through the Cooperative movement. The Cooperative movement seems to constitute an ideal base to organize credit for the purchase of production inputs such as fertilizers. This is so even when cooperatives are responsible for marketing part of the farmers' production and are thus certain to be able to recover without difficulty the value of the loan granted for fertilizer and other inputs. Nevertheless, this credit should not, as is the case at present, remain linked to one single speculation which happens to interest the cooperative. It is quite possible to imagine that credit granted to a member of a cooperative for fertilizer purchase for the production of food crops, such as maize, beans, and potatoes, could be linked to the marketing of that producer's coffee, pyrethrum, or tea. Unfortunately, such activities are not very developed among cooperatives. They only function in certain districts, particularly among the coffee growers. The scheme limits participation to members of qualifying cooperatives. But even if this were not the case, its effectiveness would still be limited, since the majority of small farmers are not yet ready to participate in cooperative movements.

Theoretically, the retailer or stockist at the local level would be the best placed to grant fertilizer credit, for he knows his clients. However, retailers have little capital to buy fertilizers and erect or hire storage space. Moreover, as noted earlier, their profit margins are very low, and the lower the margin, the more expensive the fertilizer. In these circumstances they fail to extend credit to farmers; they always sell their fertilizer for cash, while timely supplies are by no means always assured. The government is exploring ways of extending credit to retailers, especially those with storage.

The Kenya government maintains a policy of keeping interest rates on agricultural credit low. But experience in many developing countries suggests that a low interest rate policy tends to penalize the small farmers whom it was designed particularly to benefit [8]. It is argued that low interest rates tend to discourage the rate of saving and flow of funds into the agricultural sector. It discourages economizing in the use of funds, and it tends to be associated with the misallocation of funds among users. If the interest rate is not used to ration the available supply of funds, alternative means have to be found. These alternatives tend to result in the larger farmers with more influence getting a disproportionate share of funds. This tendency is reinforced by the fact that credit institutions operating low interest rate policies have to cut costs in every possible way, and thus favor large loans that are less costly [18].

However, despite the need for input credit, there exists some unwillingness among small farmers to borrow money that may be due to necessity of pledging title to their land as a collateral. This is a deterrent to those who run the risk of pledging their entire property for the purchase of fertilizers. Thus, any type of production credit envisaged should be tied to the farmer's performance or to the increased production potential of the input, rather than to the security of land or other assets. To facilitate loan recovery, the provision of credit may be tied up with marketing.

CHAPTER III

RESEARCH METHODOLOGY AND ANALYTICAL TECHNIQUES AND SOURCES OF DATA

A brief review of literature pertaining to the empirical estimation of fertilizer demand is presented in this chapter. The conceptual framework to be used in this study is outlined. The application of linear programming techniques in African agriculture is reviewed. The sources of various data needs are described.

There is a variety of estimation methods available for demand studies, but the two major estimation methods commonly used are: (1) the statistical regression approach based on time series data and (2) the intrafirm estimation technique using linear programming.

Regression Approach

Most empirical models of fertilizer demand have been based on the assumption of constant production technology. A common approach of estimating the price elasticity of demand for fertilizer is to derive it indirectly from the profit maximization conditions, given a particular agronomic fertilizer response function [14].

The theory of the firm assumes that the average farmer has perfect knowledge of the production function, the product and factor prices, and attempts to maximize profits. Given a Cobbs-Douglas production function with two inputs, $Y = aL^{\alpha}F^{\beta}$, the profit function is formulated as

$$\pi = (aL^{\alpha}F^{\beta})\ P_y - rL - P_f F$$

where π denotes profits, Y production, L land, F fertilizer, P_y product price, P_f fertilizer price, r land rental, a the intercept term, and α and β the production elasticities of land and fertilizer respectively. Maximizing profits by setting the marginal value product of fertilizer and land equal to their respective prices, we derive a fertilizer demand function that depends on its own price, product price, price of substitutable inputs, and the parameters of underlying production function. Assuming that land is a fixed input, this can be expressed as

$$F = \left(\frac{1}{a\beta}\right)^{\frac{1}{\beta-1}} \left(\frac{P_f}{P_y}\right)^{\frac{1}{\beta-1}} .$$

From the above equation, the parameters in the demand equation can be solved algebraically once the production elasticity of fertilizer (β) and the intercept (a) are known. This gives us a normative demand function which approximates reality only if all the assumptions previously mentioned hold true.

Timmer has pointed out two limitations of this approach [41]. First is the required assumption of farmers' maximizing behavior with no consideration of the risk perceived by the farmers. Second is the arbitrariness in the choice of the relevant fertilizer response function.

Timmer argued that there is a substantial amount of evidence in the United States as well as from the relatively few studies undertaken for less developed countries to show that the farmer's marginal revenue from additional fertilizer use substantially exceeds its marginal cost. This would indicate the importance of factors such as risks associated with yield and price variability, level of knowledge, and possibly other constraints which have been ignored in many other studies. Furthermore, this deviation between MR and MC of fertilizer might be due to the fact that all the costs are not considered, i.e., application cost, capital cost and transportation cost.

The choice of the appropriate fertilizer response function is a complicated one. There exist a diversity of response functions across farms in an area, and for a single farm at different points in time. Here one confronts the problems of omitted variables and lack of consideration for differences in the quality of inputs. The use of data from controlled experiments does not usually replicate actual farm conditions. Thus, our estimates are bound to be unrealistic.

Fertilizer demand functions have also been estimated directly, especially where aggregate time series data exist. Griliches' [11] partial adjustment model has been widely used both in developed and developing countries in estimating fertilizer demand [2, 19]. Griliches' model is formulated as follows:

$$Y_t^* = a_0 + a_1X_{1t} + a_2X_{2t} + U_t$$

$$\frac{Y_t}{Y_{t-1}} = \left(\frac{Y_t^*}{Y_{t-1}}\right)^b \text{ or } Y_t - Y_{t-1} = b\,(Y_t^* - Y_{t-1})$$

where

Y_t^* = the desired quantity for fertilizer

X_{1t} = the price of fertilizer relative to prices received for crops

X_{2t} = the price of fertilizer relative to prices paid for other factors of production

U_t = random disturbance term

t = time.

The adjustment equation above states that the percentage change in actual fertilizer consumption is a power function of the percentage difference between desired and actual consumption of fertilizer. Substituting the first equation into the second and solving for Y_t, we obtain the estimating equation:

$$Y_t = (1-b)Y_{t-1} + a_0b + a_1bX_{1t} + a_2bX_{2t} + bU_t \ .$$

The inclusion of the lagged dependent variable among the explanatory variables serves as a substitute for any omitted variable having a similar trend and thus provides a more fully specified model. Although a certain degree of correction for specification errors in the model is implied, important information regarding the independent effects of other variables is subsumed in the adjustment coefficient. Griliches, himself, has noted that this adjustment coefficient becomes a catch-all term that is difficult to interpret [11]. Furthermore, the partial adjustment model may lead to an unwarranted focus on price policy simply because the effects of changes in prices permit quantification.

The use of the regression method to estimate demand functions is criticized on many fronts. (1) It is difficult to use the regression approach for evaluating some anticipated changes or introduction of new variables when no historical data are available. (2) Lack of a single equation to correctly represent the true functional relationship between variables. Other problems with the method include measurement errors, model specification, multi-collinearity and identification.

However, the major problem in applying it to a country like Kenya (and the developing countries in general) is lack of sufficiently long term series data on fertilizer price and use.

Intrafirm Linear Programming Estimation Approach

The estimation of demand functions using the linear programming approach employs a modification of the standard simplex linear programming model as employed by Heady and Candler [12]. This model and its variants will provide the theoretical framework for the empirical section of this study.

Following Heady and Candler, the linear programming model which forms the basis of the estimation of resource demand and product supply functions can be formulated as follows:

$$\text{Max } Z = C'X$$

$$\text{subject to } AX \leq B$$

$$\text{and } X \geq 0$$

where

Z = the value to be maximized

C = n by 1 vector of prices

X = n by 1 vector of activity levels

A = m by n matrix of input-output coefficients

B = m by 1 vector of available factors or other restrictions.

In general, the idea is to generate the optimum pattern of farm production and resource demand for various price relationships, resource availability and technological coefficients. The parametric programming model is a modification of the standard simplex model presented above. It enables the researcher to study the effects of a wide range of costs or prices on the optimum solution to the standard simplex problem. The model thus modified has been used by many researchers to estimate product supply and resource demand. Ogunfowora et al. and Moore et al. [35, 29] have specifically applied parametric programming to estimate the demand for fertilizer and water respectively. The quantities of resource demanded are obtained by ranging the price (cost) of the given resource over an appropriate range through a resource buying activity introduced into the model.

Ogunfowora [34] conceptualizes such a linear programming problem with parametric objective function as follows:

$$\text{Max } Z_\alpha = \sum_{j=1}^{n} C_j X_j$$

$$\text{subject to } \sum_{i=1}^{m} a_{ij} \leq b_i$$

$$\text{and } X_j \geq 0$$

where

$$Z = Z\ (X_1,\ X_2, \text{---} X_j, \text{---}, X_n)$$

$$C'_j \leq C_j \leq C''_j$$

$$\frac{C''_j \leq C_j \leq C'_j}{\lambda} = k \text{ or } C''_j - C'_j = \lambda k$$

where

Z = the α^{th} objective function to be maximized for a given price level within the acceptable price range

b_i = the level of the i^{th} resource available

C'_j and C''_j = the lower and the upper limits of the price of the j^{th} activity

λ = constant increment in the price of the j^{th} activity k = the number of optimum solutions within the price range.

Krenz et al. [25] using the programming model, conceptualized supply function as follows:

$$QA = f(P_1, P_2, P_a, P_n; R_1, R_2---R_n; C_1, C_2---C_n).$$

Using this formulation demand function for a resource can be conceptualized as follows:

$$D_F = f(P_{r1}, P_{r2}, P_{rF},---P_{rn}; P_1, P_2---P_n; R_1, R_2, R_r---R_n; C_1, C_2---C_n)$$

where

QA = quantity A produced (P_A varied)

P_1 to P_n = net prices of the enterprises in the model

D_F = the quantity for factor F (fertilizer in our case)

P_{r1} to P_{rn} = the prices of factors of production

R_1 to R_n = the levels of fixed resources of the farm

C_1 to C_n = coefficients of production on the farm in all production alternatives considered.

In these formulations of supply and demand functions, the quantity of the product supplied and the quantity of resource demanded are not just a function of the prices of output and resource, but the model also considers the array of alternative production enterprises competing for limited factors of production.

This approach, however, is normative, indicating farmers' potential response under the assumptions of profit maximization motives, perfect knowledge about prices, technological changes and environmental factors. Under these circumstances some divergence, usually overestimation, between normative demand response and actual demand response can be expected [39, 40].

The object of this study is not to estimate regional or national fertilizer demand response, which requires that the results of benchmark farms be aggregated, but rather to estimate farm-firm fertilizer demand response. Thus, the delineation of an "average" or "representative" farm is considered appropriate. The discussion of its construction will be presented in Chapter IV.

This being the case then, the problems of aggregation bias and their possible solutions are not dealt with. For a regional or national response estimation, methods of benchmark construction which minimizes aggregation bias would be required. A few methods which are theoretically appropriate, but not necessarily the most practicable, have been discussed elsewhere [3, 7, 39].

Estimation of Elasticity from Step Functions

The linear programming formulation generates "step" demand functions. Figure 3.1 depicts such a "stepped" demand function for fertilizer.

The optimum solution and price ranges for all steps in the demand function can be presented as follows [24]:[1]

$$
\begin{aligned}
f\,(\text{M.V.P.}) &= 0 \text{ for } 0 \leq \text{M.V.P.} \leq MC_{1a} \\
&= X_{1a} \text{ for } MC_{1a} \leq \text{M.V.P.} \leq MC_{1b} \\
&= X_{1b} \text{ for } MC_{1b} \leq \text{M.V.P.} \leq MC_{1c} \\
&= X_{1c} \text{ for } MC_{1c} \leq \text{M.V.P.}
\end{aligned}
$$

---

[1]Modified from [24].

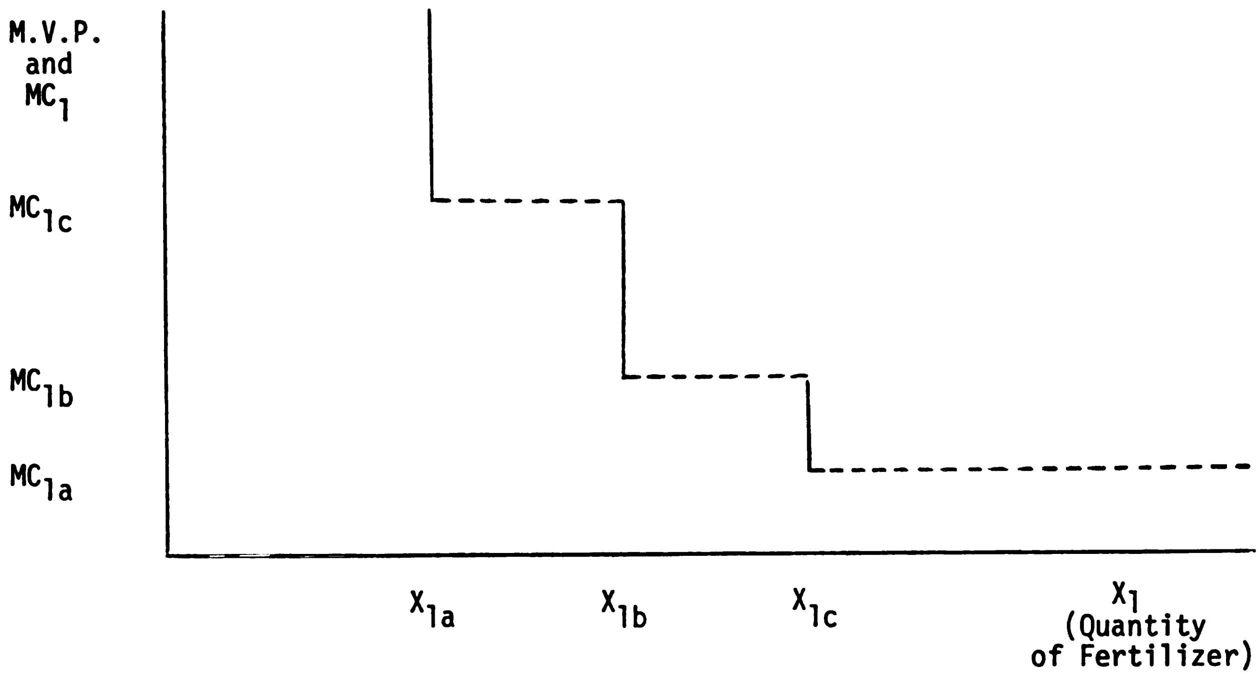

FIGURE 3.1
FARM-FIRM STEP DEMAND FUNCTION

M.V.P. is the marginal value productivity of X_1 (Fertilizer), and MC_1 is the price per unit of resource X_1, which is assumed to vary directly with price. The range of the vertical segments of the demand function is based on profit maximizing criteria, M.V.P. = MC_1.

The stepped demand function reflects the interaction of resource supplies and fixed production coefficients. The optimum cropping program, and therefore the quantity of resource, holds for all the prices included within the vertical portion of any one step [29].

Elasticity of demand is useful in formulation of agricultural policy. But in estimating quantitative measures of elasticity, step functions are not particularly useful. The degree of response over a range of prices can vary widely from no response to large jumps in response, and it is difficult to generalize such response into a single elasticity measure. Again, the magnitude of elasticity is highly dependent upon the segment of the curve for which the elasticity is computed and the range over which the demand or supply is perfectly elastic or inelastic cannot be determined a priori [4, 24]. In other words, we cannot derive any meaningful point elasticity from a step function.

Moore et al. [29] in estimating demand for irrigation water, used the solution quantities and their corresponding prices as the data for a least square regression analysis to estimate a continuous function.[2] It was assumed that the mid-points of the vertical portions of the steps are more stable with respect to price changes, and are therefore

---

[2]But this is because of using a single representative farm. The use of many representative farms for a region would lead to a continuous function when aggregated.

used as the observations for fitting the estimating equations. Since such data do not meet the assumptions of normality and independence used in regression analysis, statistical inference and probability statements cannot, therefore, be made.

On the other hand, although the smoothing process of the step function enables us to derive the precise measure of elasticity, much of the intrinsic behavior of the farmers would be obliterated. Accordingly, it would be advisable to retain the steps for the purpose of correct and practical decision making at the farm level [24]. The retaining of the steps will be very realistic especially if the representative farm is a real average from "sample". In practice, few if any farmers make adjustments in the sense of a continuous function.

The choice of an analytical technique depends upon the availability of data, the purpose for which the model is intended, and the nature of the structural coefficients being sought to elucidate a particular problem. Linear programming is the approach used in this study. Its most important advantage lies in the fact that it is highly suitable for estimating supply and demand functions and analyzing farm adjustment problems in an environment where no time series data exist.

The Use of Linear Programming Approach in African Agriculture

The usefulness of linear programming techniques in analyzing farm level operational problems in Africa was recognized in the 1950s. The application of the technique was limited to identifying combinations of resources which would maximize returns on the farm level.

McFarquhar and Evans [28] demonstrated this technique using a hypothetical tropical farm under various assumptions of land availability and cropping pattern. Clayton [5] generated similar optimizing farm plans for an actual smallholder farm in Kenya, with sets of assumptions regarding soil fertility maintenance, the extent of mechanization, and cropping patterns incorporating cash and subsistence crops to varying extents. The study, however, is devoid of policy prescriptions since no policy questions were addressed.

Clayton and Ogwel [32] have explored the efficiency of a regional aggregative model as a planning tool for Kenyan agriculture, using data from Nyeri district, Central Kenya. Clayton's earlier study used data from the same district.

Heyer [17] discusses several broader macro uses to which linear programming micro-analysis can be put, including the shadow pricing of agricultural resources, the evaluation of new variety profitability and research priorities, and the assessment of employment and mechanization programs. Using Kenyan data, she describes the changing pattern of constraints limiting output under alternative mixtures as the land/labor ratio is varied. Non-farm allocations of labor time were not incorporated in the model. The analysis has been extended, however, to include uncertainty restrictions.

Norman [31] uses linear programming techniques to assess the profitability of several adjustments in farm models based on data obtained in Northern Nigeria. These adjustments include reallocation of existing resources, increasing the input of labor on a year-round basis, increasing prices of crops purchased by the marketing board, and introducing currently available new technologies for groundnuts, sorghum and cotton. These adjustments tended to increase farm income.

Ogunfowora and Norman [35] have used linear programming techniques, not only to assess profitability of adjustment but to specifically estimate farm-firm fertilizer demand and its elasticities with respect to own price, product price, and capital, making it useful for policy prescription. The study also shows that linear programming technique can be used to estimate resource demand in an environment lacking time series data.

Ogunfowora [33] using Nigerian data again has undertaken an analysis of the constraint posed by period specific capital shortages and by quality of management (a proxy for scale) as well as by labor. Subjective limitations reflecting management differences and risk aversion behavior distinguish two farm models which represent different levels of commercialization. Shadow prices for labor and capital suggest the types of government policies which most efficiently increase income potential in these respective farm types. Ogunfowora has also used a poly-period dynamic programming model to plan operations for a farm settlement scheme which would assure both an adequate income and short-period repayment capability.

Johnson [22], using Rhodesian data, has demonstrated the power of linear programming techniques in identifying some potential labor and income effects of alternative wage and price assumptions.

The limitations of the technique in analyzing African farm-level operational problems have been well summarized by Heyer [16]:

> The linear programming model is well suited to an examination of constraints on production in a situation in which the objective function is unambiguous and risk considerations do not dominate production decisions. Neither of these conditions is easily fulfilled, however, in semi-subsistence peasant farming. The objective function is difficult to determine. Cultural and institutional factors such as an attachment to livestock, or a

> taboo against planting maize before millet, can be viewed as further constraining the production environment and can be incorporated as constraints in the model. But there is still the difficulty of deciding what it is that subsistence farmers aim for, subject to many constraints. Alternatives that can be considered include insuring an adequate food supply in drought years, producing a suitably varied diet maximizing the number of people fed, maximizing the market value of output and so on.

But we have to bear in mind that, to a large extent, the methodological problems encountered are a function of the purpose for which the analysis is intended.

Sources of Data

The selection of a model to use in an analysis of a study like this is highly influenced by data availability. The data available in Kenya for such a model can be obtained from many sources. Thus, the data used in this study were obtained from various sources, viz., Central Bureau of Statistics (CBS), District Farm Guidelines from the Ministry of Agriculture, fertilizer yield response from FAO/Ministry of Agriculture Project, fertilizer distributors, publications, and a farm survey conducted by the author. Data collection by CBS and the farm survey undertaken by the researcher are discussed below.

The CBS undertook a national survey of the smallholder agricultural sector in 1974-75 [38]. The pilot survey was conducted in three districts from March to May 1974. After effecting the necessary adjustments, data collection began in October 1974 and was carried on through October 1975.

A two-stage stratified sample was used to select the final list of respondents. The primary sampling unit (PSU) was the sub-location--the basic administrative unit in the country. Prior to the selection of PSUs, all sub-locations were classified into agro-ecological zones.

This exercise was undertaken by the Farm Management Division of the Ministry of Agriculture. Sub-locations were aggregated into zones on the basis of the main cash crop grown in their areas. The purpose of introducing the concept of agro-ecological zoning was to facilitate stratification which would improve the efficiency of the sample by grouping the sample population into more homogeneous units than would otherwise have been possible. Since the agricultural population was the primary focus of interest of the survey, a criterion of stratification associated with land use, either actual or potential, was considered the most appropriate for the purpose. In those areas of the country where "predominant cash crop" criteria could not be applied, stratification was effected on an alternative basis using either a "special area" criterion or a rainfall criterion as in the Coast Province.

Each province had an equal number of PSUs in the sample. A total of 139 sub-locations altogether were selected. The probability of selection for a PSU was based on the product of the square root of the rural population and the cultivated area as estimated from the 1969 population census and the 1969 Small Farms Census Survey. Within each PSU, twelve smallholder households were selected as respondents for inclusion in the sample, adding up to a total sample size of 1,668 households. The method of selection of smallholder households within the PSUs varied according to whether the land in each sub-location was registered or not. In the registered areas, the land registration lists in the District Land Offices were used to provide a list of farms within the sub-location, and the twelve farms were then randomly selected from these lists. Enumerators in these areas were subsequently instructed to visit the selected farms to determine whether they had been informally subdivided into two or more independently managed holdings. If no subdivision had taken place, the farm was considered to be a single holding, and retained in its entirety in the sample. In those cases where the farm had been subdivided, only one of the holdings was randomly selected for enumeration and the household weight adjusted according to this last stage probability selection. In the non-registered PSUs, the 1969 Population Census Enumeration Areas (EA) were used for sample selection. Two EAs were selected with equal probability from each selected sample sub-location. A complete listing of households was then undertaken within each of these two EAs by the field staff and a final random selection made of six households within each EA. Once the final selection of households had been made, each household was assigned its individual household weight based on the reciprocal of the household's probability of selection. Only eighteen households in the entire survey were discarded for non-response. Allowance for these was made at the end of the survey by an adjustment of the weights of the other households within the non-respondents' PSU.

The survey year was divided into thirteen four-week cycles. The four-week lunar cycle was found to have a number of bias-eliminating and administrative advantages over the more traditional calendar month:

1. Each cycle was exactly the same length.
2. Each cycle always started on exactly the same day of the week.
3. A simple work program could be worked out for enumerators detailing households to be visited on specific days, which would

remain constant for all the cycles.

4. Possible biases that might be introduced by an enumerator always visiting a household at the beginning or end of a month were automatically removed by the fact that cycles were evenly spread across all the months in the course of one year.

During any enumeration week, an enumerator was required to visit his respondents assigned to that week twice, with a maximum gap of four days between visits. In the field, data collected were checked by the supervisors and provincial statistical officers before final transmission to Nairobi. Data processing was done in Nairobi. The data from this survey, published in the CBS Basic Report, will form a substantial part of the empirical analysis of this study.

The second farm survey was undertaken by the researcher from October 1976 to May 1977. The purpose of this survey was to collect more information on fertilizer use in Central Province of Kenya. Consequently, the sample of this second survey was a complete enumeration of the 254 household sub-sample of the national CBS sample representing Central Province.

The primary reasons for choosing Central Province of Kenya for a study on fertilizer use include:

1. Acute land shortage and high population densities, thus reflecting the problems confronting smallholders and indicating the need for land-saving technology.
2. The land holdings are consolidated and individually owned.
3. Smallholder development has been undertaken for over twenty years.
4. The researcher comes from this area, knows it well, and would have no language problem.

The data collected in this study were mainly attitudinal, pertaining to farmers' perceptions of or level of understanding of the profitability of fertilizer use, reliability of fertilizer sources and delivery system, sources of information on fertilizer use, availability of credit and farmers' technical knowledge.

In collecting the data, the researcher was assisted by two senior enumerators provided by the Institute for Development Studies of the University of Nairobi. After the survey, the data were coded, punched and put on tape for analysis at Michigan State University.

These data will be used mainly to analyze socio-economic and institutional factors influencing fertilizer use in Central Kenya, and to identify general farming constraints in the area. Results are reported in the next chapter.

CHAPTER IV

THE STRUCTURE OF AGRICULTURAL PRODUCTION AND FACTORS INFLUENCING FERTILIZER USE IN THE STUDY AREA

The sample survey was carried out in the five districts that comprise the Central Province of Kenya, viz., Kiambu, Kirinyaga, Murang'a, Nyandarua and Nyeri. These were classified into three main agro-ecological zones, namely, Coffee East of Rift, Tea East of Rift, and High Altitude Grasslands Zone. In this study these three agro-ecological zones will be referred to as the Coffee Zone, the Tea Zone, and the Grassland Zone. In each zone, climatic and soil conditions can be assumed to be roughly constant. All the farms within each agro-ecological zone, then, can grow the same variety of crops and have the same available technology.

Physical and Climatic Factors

The average annual rainfall in Central Province of Kenya varies from as little as 750 mm in the lower parts of Kiambu, Kirinyaga and Murang'a districts to over 1,500 mm in the higher areas adjoining the eastern side of the Aberdares and the southern side of Mt. Kenya. Most of the agricultural land of the province receives 1,200 to 1,500 mm per year in a bimodal distribution.

The altitudes of agricultural land in the province drop to less than 1,550 meters in the east and rise to over 2,150 meters in some areas adjoining the Aberdares and Mt. Kenya. A large proportion of the province is hilly, becoming more undulating in the lower south-eastern areas and in the central parts of Nyandarua district. This rugged terrain and high population densities limit the effective size of the farm in the province.

Representative Farm Characteristics

In a study like this, the cost of programming every farm would be prohibitive. Consequently, in carrying out the linear programming analysis, it is essential to set up a representative farm. The farms in our sample were classified into coffee, tea and grassland zones. The farms in each agro-ecological zone are assumed to be sufficiently homogeneous with respect to the key variables that affect farm adjustment. The levels of the initial resources in each case are based on farm averages of those making up an agro-ecological zone. Thus, the arithmetic mean was used for most of the analysis. For the analysis only one average farm was used for each agro-ecological zone. This offers an opportunity for more detailed analysis using parametric techniques.

Land Use

The average size of holdings in the study area was 8.23 hectares in the grassland zone, 3.39 hectares in the tea zone and 2.35 hectares in the coffee zone. The cultivated areas were 4.26 hectares in the grassland zone, 2.20 hectares in the tea zone and 1.54 hectares in the coffee zone. The farmers in the area did not report any rented land. This would imply that they can only expand their operations on the family-owned holdings.

Farm Labor Force

Family farms predominate in the study area and consequently the family is the major source of the farm labor force. The average size of the family in the study area consists of nine persons in the tea zone and seven persons in both the coffee and the grassland zones. The composition of the average farm family by zone is shown in Table 4.1.

The family labor is allocated among various enterprises on the farm. Table 4.2 shows average family labor allocation by zone and enterprise.

In terms of man-hours the average size of the farm family in the study area ranged from 1,160 in the coffee zone to 1,573 in the grassland zone for crops. Compared on a per hectare and a per cultivated hectare basis, the coffee zone uses more family labor than the tea and grassland zones, but uses less family labor for cattle than the tea and grassland zones.

In addition to the family labor on the farm, hired labor is used to supplement it. This is especially true during peak labor demand. The hired labor comprises casual and regular labor. The allocation of average hired labor in the study area is tabulated in Table 4.3. As Table 4.3 indicates, the tea zone used more hired labor on the average than the coffee and grassland zones.

Farm Capital

Capital is regarded as the most limiting resource in the study area. The main source of capital in the area is personal savings, which are generally low due to low incomes. The farmers in the area

TABLE 4.1
COMPOSITION OF THE AVERAGE FAMILY IN THE STUDY AREA

Family Members	Conversion Factor to Man Equivalents	Coffee Zone Number in Family	Tea Zone Number in Family	Grassland Zone Number in Family
Male adults (15 yrs. or more)	1.00	1	2	1
Female adults (15 yrs. or more)	0.75	2	2	2
Large children (7 - 14 yrs.)	0.50	2	3	2
Small children (less than 7 yrs.)	0.00	2	2	2
Total (in persons)		7	9	7

SOURCE: Compiled from survey data.

TABLE 4.2
AVERAGE FAMILY LABOR ALLOCATION (MAN-HOURS)
BY ENTERPRISES AND ZONES

Enterprises	Coffee Zone	Tea Zone	Grassland Zone
Crops			
Family labor per holding	1,160	1,490	1,573
Family labor per hectare	494	439	191
Family labor per cultivated hectare	753	677	369
Cattle			
Family labor per holding	815	1,340	1,086
Other livestock			
Family labor per holding	408	493	257
Farm general			
Family labor per holding	237	461	440

SOURCE: Compiled from survey data.

TABLE 4.3
AVERAGE HIRED LABOR ALLOCATION (MAN-HOURS)
BY ENTERPRISES AND ZONES

Enterprises	Coffee Zone	Tea Zone	Grassland Zone
Crops			
Hired labor per holding	169	414	290
Hired labor per hectare	72	122	35
Hired labor per cultivated hectare	110	188	68
Cattle			
Hired labor per holding	85	95	47
Other livestock			
Hired labor per holding	24	21	3
Farm general			
Hired labor per holding	36	99	54

SOURCE: Compiled from survey data.

tend to be debt averse and this militates against the use of the little institutional credit that is available. Money lenders as a source of credit are non-existent in the area. The average value of operating capital by zone in the study area is shown in Table 4.4. This shows that the coffee zone had the least operating capital in aggregate, while on a per hectare basis it was in the grassland zone.

Cropping Pattern

The crops grown in the study area were grouped into major categories, viz., specified crops and non-specified crops. The specified category included hybrid maize, beans, English potatoes, pyrethrum, coffee and tea. The non-specified category included all other crops, such as bananas and sweet potatoes. Except for coffee and tea, crops were grown as pure stands (sole) or mixtures.

The common mixtures were maize and beans, maize and potatoes, beans and potatoes, and maize, beans and potatoes. This system of growing two or more crops together at the same time and on the same piece of land is termed mixed cropping (intercropping).

Physical and socio-economic considerations interact to determine the types of crops and mixtures to be grown in the study area. Among the physical factors are rainfall, vegetation, soil and temperature. The socio-economic factors include the need to maximize returns to the limiting factors, especially land and labor, the need to obtain higher output and the need for security. This last factor indicates that mixed cropping, used as a means of increasing returns to land, is also used as a form of crop diversification, which is a strategy against risk.

TABLE 4.4
AVERAGE VALUE OF OPERATING COSTS BY ZONE

(K Shillings)

Costs	Coffee Zone	Tea Zone	Grassland Zone
Non-capital inputs[a]	657	1,063	792
Wages to regular labor	168	185	257
Wages to casual labor	7	18	7
Operating costs per holding	832	1,266	1,056
Operating costs per hectare	354.04	373.45	128.31

SOURCE: Compiled from survey data.

[a]Includes purchased seeds, fertilizers, machinery contract, sprays and livestock feed.

Mixed cropping as a practice is generally discouraged on the grounds that the average yields of crops are depressed when grown in mixtures rather than in pure stands. Norman has cited two reasons why yields are usually depressed: (1) lower plant density of individual crops and (2) competition for nutrients, space and light [31]. However, the depressed yields of individual crops are overcompensated by the aggregate yield per acre of all the crops.

Table 4.5 shows the average hectares devoted to different crop enterprises by zone. From Table 4.5, it can be observed that mixed cropping dominates average hectares devoted to maize, beans and English potatoes in all the zones. The same holds true for non-specified crops in all the zones.

The purpose of this section was to delineate the characteristics of a representative farm for each of the agro-ecological zones. Several variables, such as the age of the holder, his literacy level, size of farm labor force, net worth size of holding as indexed by hectarage cultivated, are important when defining a representative farm. But as we pointed out in our third chapter, the rigor employed in defining a representative farm depends upon the purpose of the particular study. If the objective of the study is not the derivation of aggregate supply functions, but rather the identification of the direction of the farm adjustment or expansion path and/or the estimation of responses to varying resource and price levels in an area, a less rigorous method of benchmark farm construction may be used. The objective of this study falls squarely in this category.

TABLE 4.5
AVERAGE HECTARES DEVOTED TO DIFFERENT CROP ENTERPRISES BY ZONE

Crop	Coffee Zone	Tea Zone	Grassland Zone	Total
Local maize				
Pure	0.03	0.07	0.14	0.24
Mixed	0.39	0.19	1.11	1.69
Hybrid maize				
Pure	0.02	0.09	0.46	0.57
Mixed	0.05	0.26	0.86	1.17
Beans				
Pure	0.01	0.00	0.03	0.04
Mixed	0.39	0.16	0.08	0.63
English potatoes				
Pure	0.03	0.02	0.03	0.08
Mixed	0.16	0.18	0.48	0.82
Pyrethrum				
Pure	0.03	0.08	0.31	0.42
Mixed	0.00	0.09	0.06	0.15
Coffee	0.23	0.00	0.00	0.23
Tea	0.00	0.70	0.00	0.70
Non-specified crops				
Pure	0.02	0.14	0.09	0.25
Mixed	0.18	0.22	0.61	1.01
Total	1.54	2.20	4.26	

SOURCE: Compiled from survey data.

Socio-Economic and Institutional Factors Influencing Fertilizer Use in the Study Area

Fertilizer use has been an important factor in increasing crop productivity in the developed countries and in those developing countries which have shown high rates of growth in the agricultural sector.

The potential role of fertilizer in increasing agricultural productivity is well recognized in Kenya. However, despite the promotional efforts undertaken by the Ministry of Agriculture, the use of fertilizer in Kenya remains very low, even when compared with fertilizer use in other countries in Africa. In 1974, fertilizer use per hectare of arable land in Kenya was 9.5 nutrient kilograms, while in Rhodesia, Egypt and Mauritania it was 21.1, 150.7 and 238.2 nutrient kilograms respectively [9].

This situation, then, calls for determination of the factors influencing fertilizer use so that light can be thrown on the appropriate policy variables which should be manipulated to increase the rate of fertilizer use in Kenya. So far, the government has tended to pursue price policy more than any other policy. But this has not resulted in high levels of fertilizer use. This would imply that other factors as well as price are important in influencing fertilizer use.

The use of any innovation by farmers is the combined result of the research to develop information on various aspects relating to the innovation, dissemination of the information, profitability of the innovation and its availability at the right time and place in the accepted form. The ability of the farmers to finance the investment is also important. Knowledge on these aspects of fertilizer innovation in Kenya is lacking. One of the objectives of this study is to attempt to contribute to the state of this knowledge.

The following section is based solely on a farm survey undertaken by the author in the five districts of Central Kenya from October 1976 to May 1977. In all, 254 farmers were interviewed.

Use of Chemical Fertilizer and Animal Manure

Out of the 254 farmers interviewed, 73 percent used chemical fertilizers, while 89 percent used animal manure. The use of animal manure remains quite popular with the farmers. The farmers' continued use of animal manure is based on their awareness that it maintains soil fertility for a long time and improves structure and water-holding capacity of the soil. This might also be due to the fact that animal manure is cheaper relative to chemical fertilizer.

Sources of Fertilizer Supply and Reasons for Their Preference

The main suppliers of fertilizers in the study area are the dealer/stockist and the cooperatives, especially in the coffee zone. These two sources supplied fertilizer materials to about 75 percent of the fertilizer users in the sample. Information regarding the sources from which the sample farmers purchased their fertilizer supplies is tabulated in Table 4.6.

Table 4.7 shows that, according to the farmers in the sample, the major reasons for preferring the fertilizer supply sources were convenience and provisions of credit.

TABLE 4.6
SOURCES OF FERTILIZER SUPPLY

Supply Source	Number of Farmers Served	Farmers Served as a Percentage of All Fertilizer Users
Kenya Farmers' Association	25	14
Dealer/stockist	55	30
Cooperative	84	45
Other	21	11
All sources	185	100

SOURCE: Compiled from the author's survey data.

TABLE 4.7
REASONS FOR PREFERENCE OF VARIOUS FERTILIZER SUPPLY SOURCES

Reasons for Preferring Supply Source	Number of Farmers	Farmers as a Percentage of All Fertilizer Users
Likes service	7	4
Convenience	126	68
Provision of credit	34	18
Other reasons	18	10
Total	185	100

SOURCE: Compiled from the author's survey data.

Availability of Fertilizers in the Study Area

The availability of fertilizer at the appropriate times is important in determining their use level. Nonavailability of fertilizer at the appropriate times is a limiting factor. In response to the questions relating to the availability of fertilizers, 63 percent of the farmers reported that fertilizer supplies were not available when they needed them most.

Modes of Transporting Fertilizer

The average distance traveled by farmers in the sample to buy fertilizers was eight miles. Forty-two percent of all farmers using fertilizers transported their fertilizer by means of a public transport (matatu), while 38 percent transported their fertilizer on foot. The average return fare for farmers was K Shs 2.50 and average transport cost for a 50 kilogram bag was K Shs 1.45. These costs raised the price of fertilizer substantially, not including the opportunity cost of the time spent in going to buy fertilizers.

Sources of Financing Fertilizer Use

Personal savings and cooperative credit were the most important sources of financing fertilizer purchase. Other institutional sources, such as commercial banks and the Agricultural Finance Corporation, played a relatively insignificant role in financing the farmers' investment in fertilizers. The cooperative credit was concentrated in the coffee zone and was mainly available to coffee growers.

TABLE 4.8
AVAILABILITY OF FERTILIZER IN THE STUDY AREA

Status of Fertilizer Availability	Number of Farmers	Farmers as Percentage of All Fertilizer Users
Available when needed	68	37
Not available when needed	117	63
Total	185	100

SOURCE: Compiled from the author's survey data.

TABLE 4.9
MODES OF TRANSPORTING FERTILIZER

Mode	Number of Farmers	Farmers as Percentage of All Fertilizer Users
On foot	70	38
Matatu	78	42
On foot and matatu	15	8
Other	22	12
All modes	185	100

SOURCE: Compiled from the author's survey data.

TABLE 4.10
SOURCES OF FINANCING FERTILIZER USE

Source of Finance	Number of Farmers	Farmers as Percentage of All Fertilizer Users
Personal savings	87	47
Cooperative credit	80	43
Dealer/stockist credit	3	2
Other sources	15	8
All sources	185	100

SOURCES: Compiled from the author's survey data.

Reasons for Not Using Fertilizers

The 27 percent of our sample farmers who did not use fertilizers were asked their reasons for not using fertilizers. Their responses are tabulated in Table 4.11. Fifty-nine percent did not use fertilizer due to lack of funds, while twenty-two percent did not use it because they had no knowledge about fertilizer use.

Reasons for Inadequate Fertilizer Use

The 73 percent of the farmers using fertilizers were asked whether their fertilizer use was adequate or inadequate. Table 4.12 shows their responses. The main reason given for inadequate use of fertilizer was lack of funds. This was also the main reason given by fertilizer non-users in the sample. This would indicate that lack of funds is a limiting factor in fertilizer use.

Sources of Information About Fertilizer Use

The sample farmers were asked their source of information about fertilizer use or from whom they sought advice regarding the use of fertilizers. Table 4.13 gives their responses. Thirty-four percent of the respondents got their information from their friends, relatives, and/or neighbors, while twenty-six percent got their information or advice from the local extension agents. Fertilizer suppliers were not significant sources of information or advice on fertilizer use.

Farmers' Technical Knowledge of Chemical Fertilizers Recommended for Their Areas

The farmers in the sample were asked whether they knew the chemical fertilizer recommended for their areas. Their responses are tabulated in Table 4.14. The majority of the farmers did not know

TABLE 4.11
REASONS FOR NOT USING FERTILIZERS

Reason	Number of Farmers	Farmers as Percentage of All Fertilizer Non-Users
Lack of funds	41	59
Lack of knowledge	15	22
Use of animal manure	13	19
Total	69	100

SOURCE: Compiled from the author's survey data.

TABLE 4.12
REASONS FOR INADEQUATE FERTILIZER USE

Reason	Number of Farmers	Farmers as a Percentage of All Fertilizer Users
Lack of fund	126	68
Use of animal manure	26	14
Lack of knowledge	15	8
High price	7	4
Adequate use	11	6
Total	185	100

SOURCE: Compiled from the author's survey data.

TABLE 4.13
SOURCES OF INFORMATION ABOUT FERTILIZER USE

Sources of Information	Number of Farmers	Farmers as Percentage of All Respondents
Friend/relative/neighbor	87	34
Cooperative	49	19
Extension agents	67	26
Dealer/stockist	12	5
Farmers' Training Centers	14	6
No source	25	10
All sources	254	100

SOURCE: Compiled from the author's survey data.

TABLE 4.14
FARMERS' TECHNICAL KNOWLEDGE OF CHEMICAL FERTILIZERS

Status of Technical Knowledge	Number of Farmers	Farmers as Percentage of All Respondents
Correct	61	24
Almost correct	38	15
Do not know	155	61
Total	254	100

SOURCE: Compiled from the author's survey data.

what type of fertilizers were recommended for their areas. This lack of knowledge leads to farmers applying the inappropriate type of fertilizers. The farmers might also be sold the wrong type of fertilizers. This culminates with the farmers discrediting the role of chemical fertilizers and consequent reduction in their use.

In conclusion, our observations have shown that such factors as lack of funds, lack of fertilizer supplies at the needed time, transport costs, lack of fertilizer credit and low literacy level act as constraints in increasing fertilizer use in Central Kenya.

This, then, calls for consideration of various policies. The prices of farmers' products should be fixed at a level which guarantees a reasonable level of profit. Institutional credit sources need to be encouraged to provide short-term credit to purchase fertilizers. Special attention should be paid to cooperatives as a source of fertilizer credit, not only to farmers growing cash crops such as coffee, but to all the farmers irrespective of what they grow. The extension of credit to the emerging dealer/stockist should also be given serious consideration. Proximity of these supply sources to local markets would substantially reduce the transport costs incurred by the farmers.

CHAPTER V

THE STRUCTURE OF THE LINEAR PROGRAMMING MODELS FOR THE STUDY AREA

The mathematical representation of the linear programming models used in this study was outlined in Chapter III. In Chapter IV, the characteristics of the representative farms for the three agro-ecological zones were spelled out. The empirical analysis of this study is performed in two phases. The first phase is a linear programming analysis of the three representative farms used to derive quantities of fertilizers demanded by the farm-firm for different fertilizer and product prices and capital availability levels. The second phase is a statistical analysis of the results obtained in phase one, which is used to fit regression equations defining fertilizer demand functions for the farm-firm.

The major objective of this study is to develop fertilizer demand functions for each representative farm in the three zones. The linear programming models are therefore especially formulated to provide the quantities needed to meet this objective. In addition, an attempt was made to simulate as closely as possible actual farm conditions.

In formulating the linear programming models certain assumptions were made. It was assumed that the farmers have perfect knowledge of input, output prices and technology. Technology is assumed to be constant. Farmers' operating capital is the limiting factor to the amount of fertilizer that can be purchased. No fertilizer credit exists for the farmers in the study area. The government fertilizer price subsidy will continue at the 1975-76 level (25 to 40 percent). It was further assumed that the input-output coefficients used in the linear programming models reflect average managerial ability.

Product, input prices and technology, the most risky components of production functions, are highly influenced and determined by the government. This substantially reduces the risk component to the farmers. However, the risk factor has to some extent been implicitly considered in our models by including a subsistence activity in each model as well as incorporating the minimum consumption constraints which have to be produced by the farmers.

This chapter is devoted to the description of the linear programming models. Each model has the following three elements: (1) the objective function, (2) the activity set and (3) the constraint structure.

The submatrices for the tea zone are presented in Tables 5.1 to 5.3. The structures are the same for coffee and high altitude grass zones, so they are not duplicated here. The only minor difference, however, is that the tea activity is replaced by coffee activity in the coffee zone. The two do not exist in the high altitude grass zone.

Objective Function

The objective function maximizes the net farm income on fixed factors, subject to the satisfaction of household food consumption.

TABLE 5.1
CROP AND MILK PRODUCTION ACTIVITIES[a]

Row No.	Resources: Obj. Function	Units Shs	Crop Production Activities: A_1 PLM -68.25	A_2 PHM -88.20	A_3 PHMPF -88.20	A_4 PHMNPF -88.20	A_5 PB -141.75	A_6 PBPF -141.75	A_7 PBNPF -141.75	A_8 PEP -840
1	LAND	HA	1	1	1	1	1	1	1	1
2	$FLCY_2$	HRS	68.85	165.94	165.94	165.94	248.69	248.69	248.69	246.75
3	$FLCY_3$	HRS	71.00	216.03	216.03	216.03	165.81	165.81	165.81	122.60
4	$FLCY_4$	HRS	129.81	196.00	196.00	196.00	142.94	142.94	142.94	82.30
5	$FLCY_5$	HRS	134.19	165.31	165.31	165.31	235.25	235.25	235.25	139.05
6	$FLCY_6$	HRS	210.62	115.71	115.71	115.71	62.50	62.50	62.50	282.05
7	$FLCY_7$	HRS	187.19	102.49	102.49	102.49	243.75	243.75	243.75	298.75
8	$FLCY_8$	HRS	245.77	123.49	123.49	123.49	289.44	289.44	289.44	222.15
9	$FLCY_9$	HRS	261.54	154.66	154.66	154.66	254.19	254.19	254.19	205.35
10	$FLCY_{10}$	HRS	181.50	148.17	148.17	148.17	128.13	128.13	128.13	100.95
11	$FLCY_{11}$	HRS	215.65	203.26	203.26	203.26	160.44	160.44	160.44	174.45
12	$FLCY_{12}$	HRS	214.54	197.31	197.31	197.31	402.69	402.69	402.69	450.90
13	$FLCY_{13}$	HRS	200.31	109.23	109.23	109.23	192.19	192.19	192.19	270.00
14	$FLCY_{14}$	HRS	188.58	154.71	154.71	154.71	213.00	213.00	213.00	240.00
15	LMS	KG	-1,093							
16	HMS	KG		-3,278	-4,100	-4,989				
17	BS	KG					-897	-1,184	-1,422	
18	EPS	KG								-9,094
19	PMS	KG								
20	TS	KG								
21	SCS	KG								
22	MKS	KG								
28	BP_2O_5F	KG			50			50		
29	BNPF	KG				250			250	
30	BNPKF	KG								
31	OC	SHS	68.25	88.20	88.20	88.20	141.75	141.75	141.75	840

[a]The explanation of abbreviations used in the above and following tables are given in Appendix A, Table A-1.

TABLE 5.1 - CONTINUED
CROP AND MILK PRODUCTION ACTIVITIES[a]

Row No.	Re-sources	Units Shs	Crop Production Activities							Milk Production Activity	SIGN	RHS
	Obj. Func-tion		A_9 PEPNPF -840	A_{10} PEPNPKF -840	A_{11} PPM -201.66	A_{12} PT -182.08	A_{13} PTNPKF -182.08	A_{14} PTNPKF -182.08	A_{15} PSC 0	A_{16} PMK -517.36		
1	LAND	HA	1	1	1	1	1	1	1	0.40	≤	3.39
2	$FLCY_2$	HRS	246.75	246.75	172.53	118.27	118.27	118.27		45.46	≤	356
3	$FLCY_3$	HRS	122.60	122.60		113.99	113.99	113.99		54.52	≤	321
4	$FLCY_4$	HRS	82.30	82.30	182.35	146.40	146.40	146.40		55.43	≤	373
5	$FLCY_5$	HRS	139.05	139.05		110.20	110.20	110.20		60.90	≤	343
6	$FLCY_6$	HRS	282.05	282.05	117.65	90.59	90.59	90.59		65.11	≤	360
7	$FLCY_7$	HRS	298.75	298.75	285.29	101.03	101.03	101.03		62.64	≤	413
8	$FLCY_8$	HRS	222.15	222.15	317.65	105.39	105.39	105.39		61.24	≤	434
9	$FLCY_9$	HRS	205.35	205.35		119.09	119.09	119.09		61.47	≤	396
10	$FLCY_{10}$	HRS	100.95	100.95	294.12	102.81	102.81	102.81		60.45	≤	369
11	$FLCY_{11}$	HRS	174.45	174.45	127.47	95.87	95.87	95.87		61.66	≤	386
12	$FLCY_{12}$	HRS	450.90	450.90	192.18	98.90	98.90	98.90		62.69	≤	492
13	$FLCY_{13}$	HRS	270.00	270.00	400.00	130.00	130.00	130.00		63.30	≤	446
14	$FLCY_{14}$	HRS	240.00	240.00	188.24	176.34	176.34	176.34		49.86	≤	429
15	LMS	KG									=	0
16	HMS	KG									=	0
17	BS	KG									=	0
18	EPS	KG	-12,732	-14,803							=	0
19	PMS	KG			-478						=	0
20	TS	KG				-2,000	-4,000	-7,000			=	0
21	SCS	KG							1		=	0.36
22	MKS	KG								-1,090	=	0
28	BP_2O_5F	KG									≤	0
29	BNPF	KG	430								≤	0
30	BNPKF	KG		530			375	750			≤	0
31	OC	SHS	840	840	201.66	182.08	182.08	182.08		517.36	≤	1,266

[a]The explanation of abbreviations used in the above and following tables are given in Appendix A, Table A-1

TABLE 5.2
CROP, MILK, SELLING AND CONSUMPTION ACTIVITIES

Row No.	Re-sources	Units Shs	Crop Selling Activities						Milk Selling Activity	Consumption Activities					Sign	RHS
	Obj. Func-tion		A_{17} SLM 0.83	A_{18} SHM 0.91	A_{19} SB 2.54	A_{20} SEP 0.87	A_{21} SPM 3.29	A_{22} ST 0.72	A_{23} SMK 0.84	A_{24} CLM 0.83	A_{25} CHM 0.91	A_{26} CB 2.54	A_{27} CEP 0.87	A_{28} CMK 0.84		
15	LMS	KG	1							1					=	0
16	HMS	KG		1							1				=	0
17	BS	KG			1							1			=	0
18	EPS	KG				1							1		=	0
19	PMS	KG					1							1	=	0
20	TS	KG						1							=	0
22	MKS	KG							1						=	0
23	CLM	KG								1					$\geq$	540
24	CHM	KG									1				$\geq$	385
25	CB	KG										1			$\geq$	64
26	CEP	KG											1		$\geq$	372
27	CMK	KG												1	$\geq$	866

TABLE 5.3
FERTILIZER BUYING AND LABOR HIRING ACTIVITIES

Row No.	Re-sources / Obj. Func-tion	Units Shs	Fertilizer Buying Activities			Labor Hiring Activities					
			A_{29} $BP_{205}F$ -1.92	A_{30} BNPF -2.19	A_{31} BNPKF -2.38	A_{32} $HLCY_2$ -0.32	A_{33} $HLCY_3$ -0.97	A_{34} $HLCY_4$ -0.48	A_{35} $HLCY_5$ -0.60	A_{36} $HLCY_6$ -1.08	A_{37} $HLCY_7$ -1.12
2	$FLCY_2$	HRS				-1					
3	$FLCY_3$	HRS					-1				
4	$FLCY_4$	HRS						-1			
5	$FLCY_5$	HRS							-1		
6	$FLCY_6$	HRS								-1	
7	$FLCY_7$	HRS									-1
8	$FLCY_8$	HRS									
9	$FLCY_9$	HRS									
10	$FLCY_{10}$	HRS									
11	$FLCY_{11}$	HRS									
12	$FLCY_{12}$	HRS									
13	$FLCY_{13}$	HRS									
14	$FLCY_{14}$	HRS									
28	BP_2O_5F	KG	-1								
29	BNPF	KG		-1							
30	BNPKF	KG			-1						
31	OC	SHS	1.92	2.19	2.38	0.32	0.97	0.48	0.60	1.08	1.12

TABLE 5.3 - CONTINUED
FERTILIZER BUYING AND LABOR HIRING ACTIVITIES

Row No.	Re-sources / Obj. Func-tion	Units Shs	Labor Hiring Activities							Sign	RHS
			A_{38} $HLCY_8$ -0.88	A_{39} $HLCY_9$ -0.42	A_{40} $HLCY_{10}$ -0.98	A_{41} $HLCY_{11}$ -1.85	A_{42} $HLCY_{12}$ -0.79	A_{43} $HLCY_{13}$ -0.63	A_{44} $HLCY_{14}$ -1.01		
2	$FLCY_2$	HRS								$\leq$	356
3	$FLCY_3$	HRS								$\leq$	321
4	$FLCY_4$	HRS								$\leq$	373
5	$FLCY_5$	HRS								$\leq$	343
6	$FLCY_6$	HRS								$\leq$	360
7	$FLCY_7$	HRS								$\leq$	413
8	$FLCY_8$	HRS	-1							$\leq$	434
9	$FLCY_9$	HRS		-1						$\leq$	396
10	$FLCY_{10}$	HRS			-1					$\leq$	369
11	$FLCY_{11}$	HRS				-1				$\leq$	386
12	$FLCY_{12}$	HRS					-1			$\leq$	492
13	$FLCY_{13}$	HRS						-1		$\leq$	446
14	$FLCY_{14}$	HRS							-1	$\leq$	429
28	BP_2O_5F	KG								$\leq$	0
29	BNPF	KG								$\leq$	0
30	BNPKF	KG								$\leq$	0
31	OC	SHS	0.88	0.42	0.98	1.85	0.79	0.63	1.01	$\leq$	1,266

In the subsistence farming of the type covered in this study, the provision of food to the members of the farm household is generally given top priority. Norman refers to this type of goal-seeking as security and profit maximization [31].

Crop Production Activities

The crop production activities are outlined in Table 5.1, columns A_1 to A_{15}. Column A_{15} represents the production of non-specified subsistence crops. This is one of the activities incorporated in the model to realistically reflect what the farmers are doing. The specified crop activities in the model include local maize, hybrid maize, beans, English potatoes, pyrethrum and tea. Since the data were for sole crops, activities in the model are sole crops. This differs substantially from the common practice in the area which tends to be mixed cropping, especially for the food crops--maize, beans and English potatoes. Perennial crops such as tea, pyrethrum and coffee are considered mature.

The input-output coefficients of the crop producing activities are derived from the farm survey data, the Ministry of Agriculture and FAO Fertilizer Programme data for Central Kenya collected from 1969 to 1973, and the Ministry of Agriculture District Farm Guidelines.

Except for local maize, pyrethrum and subsistence crop enterprises, all the other crop enterprises comprise three activities each. Two of the activities are fertilization levels for each crop. Each column of Table 5.1 defines an activity with its respective input-output coefficients. If a coefficient has a positive sign, it indicates using the resource; if a coefficient has a negative sign, it indicates adding to the resource.

The objective function coefficients (C_j) value include the costs of establishing that particular crop, and interest foregone. The coefficient of each crop activity is negative by the amount of allocable costs. The costs of establishing perennial crops were discounted over a period of their economic life. This was taken as fifteen years for tea and coffee and three years for pyrethrum.

Milk Production Activity

Although our main interest is in fertilizer demand, milk production activity was included in the models to reflect what the farmers are doing in our representative farms.

The input-output coefficients were derived from the farm survey data. Table 5.1, column A_{16} reflects this activity. A negative coefficient reflects an addition to the supply of milk, while a positive coefficient indicates the use of a resource. The negative C_j value indicates the cost associated with this activity. This includes the cost of a milking cow discounted over the seven year economic life of a cow, the cost of feed, dip, veterinary services and the interest foregone.

Crop Selling Activities

Table 5.2, columns A_{17} to A_{22}, indicate crop selling activities. The model is set up in such a way that the selling of food crops takes place only after consumption needs have been satisfied. Non-food crops are sold without any constraint. The prices of food crops (C_j values) are those prevailing in the local market in 1974-75.

Those markets are assumed to be competitive and prices usually differ from the government controlled prices. Tea, coffee and pyrethrum prices were those offered by the Kenya Tea Development Authority (KTDA), Coffee Cooperatives and the Pyrethrum Board of Kenya in 1974-75. The objective function coefficient is positive because selling adds to the value of the objective function, while the row coefficient of the selling activity has a positive coefficient indicating that selling reduces the stock of the output.

Milk Selling Activity

Column A_{23} in Table 5.2 indicates milk selling activity. Surplus milk after home consumption is sold either to the local market or the Kenya Cooperative Creameries Ltd. (KCC). The KCC price is government controlled and it tends to deviate from the local market. The price used here is that prevailing in the local market in 1974-75.

The objective function coefficient is positive indicating that selling of milk adds to the value of the program. The positive row coefficient of the selling activity carries a positive sign because selling milk reduces milk stock.

Consumption Activities

In our model formulation we assumed that household food consumption will be satisfied before any sale activities can be undertaken. These consumption activities are shown in Table 5.2, columns A_{24} to A_{28}. Column A_{28} depicts household milk consumption. The minimum household consumption requirements were determined from the farm survey data. The positive coefficients attached to consumption activities indicate that one unit of the j^{th} commodity to be consumed depletes the corresponding output in the output row. The objective function coefficients are positive. Household consumption of own products adds to the program the value of products that would have been spent in the local market to buy similar products for household consumption.

Fertilizer Buying Activities

Fertilizer buying activities supply plant nutrients, nitrogen, phosphorus and potassium to our linear programming model. The input-output coefficients for our fertilizer activities in the model were obtained from the Ministry of Agriculture and the FAO Fertilizer Programme undertaken in our study area from 1969 to 1973.

Table 5.3, columns A_{29} to A_{31}, indicates fertilizer buying activities in the model. The prices of these activities reflect the cost associated with the purchase of these plant nutrients. The prices used are those prevailing in the study area in 1976. The C_j values of fertilizer activities are negative, as fertilizer buying reduces the value of the program. The fertilizer buying activities have negative coefficients in the row columns indicating that an increase of one unit of fertilizer in the basis will increase the stock (assumed initially at zero levels) of fertilizer. The positive coefficients in the operating capital row show that the purchase of fertilizer requires an expenditure of operating capital equal to the price of the fertilizer.

The prices of the individual elements were unavailable. Hence, the price of fertilizer materials is used to estimate the price of individual fertilizer elements.

The price of nitrogen is estimated from either the price of sulphate of ammonia (21 percent N) or calcium ammonium nitrate (26 percent N). The price of phosphate, P_2O_5, is derived from the price of single super-phosphate (20 percent P_2O_5), while the price of potassium K_2O is estimated from the price of muriate of potash (60 percent K_2O). These prices are indicated by our C_j values, which are prices of a particular fertilizer material per kilogram.

Other buying activities that could have been incorporated in our linear programming model include the purchase of quasi-fixed factors of production such as hoes, pangas, axes and forked hoes. However, it was assumed that farmers already own these factors.

Labor Hiring Activities

The representative farms in our study area hire labor to supplement the stock of the family labor available on the farm. In Table 5.3, columns A_{32} to A_{44} represent labor hiring activities. The prices used are the wage rates per man-hour prevailing in the study area during 1974-75 period. The labor hiring activities have a negative coefficient in the row column of labor supplied by the family by cycles (months). The sign indicates that an increase of one unit of hired labor in the basis will increase the stock of man-hours by one unit. Thus, hired labor relaxes the labor constraint. The wage rate of hired labor is positive in the operating capital row, meaning that an increase of one unit of hired labor depletes operating capital by its wage rate. This implies that the extent to which hired labor relaxes the labor constraint is a function of the operating capital available to the farm-firm.

The C_j values for labor hiring activities are negative because the labor hiring activities reduce the value of the program.

No provisions are made in the linear programming model for the farmers to sell their labor in the form of off-farm work since the average farm in the study area is a net buyer of labor.

The Constraint Structure

The representative farms in the study area are faced with certain constraints in their production activities. These constraints, which include land, farm labor, operating capital, the farm household consumption requirements, and non-negativity of activity levels are outlined in Tables 5.1, 5.2 and 5.3. They are all defined below.

Agricultural Land Constraint

The land available to the representative farms influences both the acreage allocated to various crops and the cropping patterns undertaken by the farm-firm. The cropping patterns and land allocation to various crops by the representative farms in the study area were outlined in Chapter IV. Land is assumed to possess homogeneous physical properties within each zone but heterogeneous between zones. There was little evidence of land selling or renting in the study area. Consequently our linear programming model does not allow for this flexibility.

Agricultural Labor Constraints

The amount of family labor available to each representative farm for each cycle (month) throughout the year was estimated from the farm survey data. The family labor stock could be supplemented by labor hiring. The amount of labor hired where family labor was not sufficient depended on the amount of operating capital available to the farm-firm. Labor is broken down into cycles. The key below helps convert cycles into months.

Cycle 2	December 1 - December 28, 1974
Cycle 3	December 29 - January 25, 1974/75
Cycle 4	January 26 - February 23, 1975
Cycle 5	February 24 - March 23, 1975
Cycle 6	March 24 - April 20, 1975
Cycle 7	April 21 - May 18, 1975
Cycle 8	May 19 - June 15, 1975
Cycle 9	June 16 - July 13, 1975
Cycle 10	July 14 - August 10, 1975
Cycle 11	August 11 - September 7, 1975
Cycle 12	September 8 - October 5, 1975
Cycle 13	October 6 - November 2, 1975
Cycle 14	November 3 - November 30, 1975.

In our estimation, the working day was assumed to be eight man-hours per day in each cycle.

Operating Capital Constraint

In this study cash expenses were used as an indication of the amount of operating capital. The restriction on funds available for cash expenses was set equal to the amount estimated to have been spent on crop and milk production activities during the 1974-75 period. These were expenses on such inputs as hired labor, seed, pesticides, fertilizer, livestock feed, dip and veterinary services. The data on short-term credit availability and savings were non-existent. Thus, no borrowing activity was included in the linear programming model to supplement operating capital. Hence the operating capital constraint used was the minimal estimate of capital availability. However, this constraint was relaxed in the analysis by the assumption that increases in farmers' incomes due to increased product prices would lead to an increase of 20 percent in operating capital.

Food Consumption Constraints

The amount of each product consumed was estimated from the survey data. These data were aggregated to obtain the average consumption of the household per year for a particular product. These averages were then used as constraints for the products produced by the farm-firm.

Non-Negative Constraints

None of the activities discussed above can be operated at negative levels.

This chapter has presented a detailed description of the structure of the linear programming models to be employed in this study. The application of the models as described in this chapter, as well as their variants, is undertaken in Chapters VI and VII.

CHAPTER VI

OPTIMUM ORGANIZATION OF REPRESENTATIVE FARMS UNDER EXISTING RESOURCES AND UNDER VARIABLE PRICES AND CAPITAL LEVEL

The structure of the linear programming model used in this study was presented in Chapter V. In this chapter the resulting optimal organization of the representative farms for the three agro-ecological zones is presented. In this analysis, the interest is in the possibilities of increasing farm income through (1) improved allocation of existing resources; (2) the determination of optimal cropping patterns under existing resource constraints, prices and technology; and (3) the extent of resource use.

In the next phase, we explore how farm income, cropping pattern and resource use are affected by changes in product prices, fertilizer prices and operating capital level.

These changes will be represented as Alternatives I, II and III. Product prices will be varied in Alternative I, while other resources, fertilizer prices and operating capital are unchanged. The prices of coffee, tea, hybrid maize, milk, beans and English potatoes will be increased by 50 percent, 50 percent, 20 percent, 20 percent, 10 percent and 5 percent respectively. These price increases are in keeping with recent government price increases, which ranged from 23 percent for maize to 43 percent for milk. The price increases for coffee and tea conservatively reflect recent world market prices which increased by as much as 400 percent for coffee. This trend will continue for some time, especially now that drought has struck Brazil again.

In Alternative II, fertilizer prices are reduced by 40 percent with existing resources, product prices and operating capital level unchanged. This 40 percent is the highest fertilizer price subsidy level announced by the government in 1975-76. In Alternative III, the operating capital level is increased by 20 percent, with existing resources, product and fertilizer prices unchanged. It was assumed that given favorable product prices, farmers' incomes will increase and in turn, farmers will increase their operating capital level.

The validity of the optimal solution in each situation will depend on the realism of the assumptions made with regard to prices, technical coefficients and yields. For instance, the yields obtained by the Ministry of Agriculture and the FAO Fertilizer Program in the study area, although obtained from farmers' plots, could deviate substantially from those obtained by the farmers. The proper cultural practices--such as weeding early, and weeding the right number of times--that result in higher fertilizer response might not be adhered to. Fertilizer might not be available, or if available, might not be applied at the right time. However, despite these considerations, the optimization solution points to the potential income obtainable with resources organized in the optimal way.

Optimal Organization with Existing Resources and Prices

Table 6.1 compares actual and optimal organization of representative farms in the three agro-ecological zones. The following economic measures are employed: net farm income to fixed resources, net farm income per hectare, net farm income per family man-hour and net farm income per operating capital.[1]

In the Tea Zone the optimum net farm income came to shillings (Shs) 7,392.72 as against Shs 5,801.16 from the actual average for the representative farm in the sample. This represents a 27 percent increase. The average per hectare income is Shs 3,067.52, a 79 percent increase. The return per family man-hour is Shs 1.56 as against Shs 1.13, a 38 percent increase, while that of a unit of operating capital is Shs 5.84 against Shs 4.58, a 28 percent increase.

The net farm income to fixed factors in the Coffee Zone came to Shs 5,395.97 against Shs 4,949.77, a 9 percent increase. The average per hectare income is Shs 2,296.16, a 9 percent increase. The return per family man-hour is Shs 1.40 as against Shs 0.93, a 51 percent increase, while that of a unit of operating capital is Shs 6.49 as against Shs 5.95, a 9 percent increase.

In the High Altitude Grass (HAG) Zone, the optimum net farm income came to Shs 10,812.16 as against Shs 5,219.72, a 107 percent increase. The net farm income per hectare was Shs 1,958.72 as against Shs 634.23, a 209 percent increase. The net farm income per family man-hour was Shs 2.49 as against 1.03, a 142 percent increase, while

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[1] In general, a fixed cost item is minimal or zero, so gross farm income is equated to net farm income.

TABLE 6.1
A COMPARISON OF ACTUAL AND OPTIMAL ORGANIZATIONS UNDER EXISTING RESOURCES AND PRICES FOR THE THREE AGRO ECOLOGICAL ZONES

Item	Unit	Tea Zone			Coffee Zone			Hag Zone		
		Actual	Optimal	Change Percent	Actual	Optimal	Change Percent	Actual	Optimal	Change Percent
Net farm income	SHS	5,801.16	7,392.72	+27	4,949.77	5,395.97	+9	5,219.72	10,812.16	+107
Land	HA	3.39	2.41	-29	2.35	2.35	0	8.32	5.52	-33
Family labor	HRS	5,148.00	4,742.31	-8	5,324.00	3,867.34	-27	5,068.00	4,348.80	-14
Operating capital	SHS	1,266.00	1,266.00	0	832.00	832.00	0	1,056.00	1,056.00	0
Net farm income/ha	SHS	1,711.39	3,067.52	+79	2,106.29	2,296.16	+9	634.23	1,058.72	+209
Net farm income/hr	SHS	1.13	1.56	+38	0.93	1.40	+51	1.03	2.49	+142
Net farm income/opera-ating capital	SHS	4.58	5.84	+28	5.95	6.49	+9	4.98	10.24	+106
Plan										
Local maize	HA	0.26	0.49	+88	0.42	0.29	-31	1.25	1.36	+9
Hybrid maize	HA	0.35	0.50	+43	0.07	1.11	+1,486	1.32	2.82	+114
Beans	HA	0.16	0.05	-69	0.40	0.07	-82	0.11	0.15	+36
E. potatoes	HA	0.20	0.69	+245	0.19	0.32	+68	0.51	0.06	-88
Pyrethrum	HA	0.17	0	-100	0.03	0	-100	0.37	0	-100
Coffee	HA	0	0	0	0.23		-100	0	0	0
Tea	HA	0.70	0	-100	0	0	0	0	0	0
Cows in milk	HEAD	2	2	0	2	2	0	3	0	-33

SOURCE: Computed.

that of a unit of operating capital was Shs 10.24 as against Shs 4.98, a 106 percent increase.

The optimum cropping pattern is also reflected in Table 6.1. The cropping pattern in the optimum base plan is the same for the three zones. The area under local maize in the Tea Zone increased by 88 percent, declined by 31 percent in the Coffee Zone, and increased by 9 percent in the HAG Zone. Hybrid maize hectarage increased by 43 percent in the Tea Zone, 1,486 percent in the Coffee Zone and 114 percent in the HAG Zone. The area under beans declined by 69 percent in the Tea Zone, 82 percent in the Coffee Zone, and increased by 38 percent in the HAG Zone. The English potatoes hectarage went up by 24 percent in the Tea Zone, 68 percent in the Coffee Zone and declined by 88 percent in the HAG Zone. Pyrethrum, coffee and tea were not included in the optimum plans. Their exlucison reflects either their high labor requirements or their low relative profitability. The inclusion of all food crops in the optimum plans reflects the minimum food consumption constraint which must be produced by the farm firm. The optimum cropping pattern might change substantially if this constraint is relaxed. The optimum plans also included a milk production activity which came in at the same level in the Tea and Coffee Zones, but declined by 33 percent in the HAG Zone. Again, if the consumption constraint had not been imposed by the model, this activity might not have been included in the optimal plans.

The resulting optimum cropping pattern as reflected in Table 6.1 deviates substantially from the farmers' current practices in the three zones. This reminds us that linear programming is an exercise in normative economics, hence it indicates for assumptions used and given constraints how the farmer's income would be maximized. In the resulting optimum cropping plans, no plans included pyrethrum, tea or coffee, although farmers in the three zones do grow these crops. Pyrethrum and tea are being grown in the Tea Zone, coffee and pyrethrum in the Coffee Zone, and pyrethrum in the HAG Zone. Their exclusion does not mean that there will be no increase in their production; rather, it means that at the given prices and technology, they are not competitive enough to be included in the income-maximizing plans. We should keep in mind, however, the omission of still other factors from the model may prevent the model from capturing all aspects of farmers' behaviors in the study area.

Utilization of Resources and Their Marginal Value Products (MVPs)

Table 6.2 contains the MVPs of resources used in production, by zone. The sufficiency of land supply is reflected by its zero MVPs in the Tea and HAG Zones. The high MVP of Shs 1,834.02 in the Coffee Zone reflects its scarcity. The MVP indicates the gains which are possible in income through the acquisition of scarce resources. Thus, if one more hectare is brought into cultivation in the Coffee Zone, income would increase by its MVP, and a reduction of land under cultivation by one hectare would decrease income by the same amount of MVP. The more limiting the resource, the higher the MVP. The positive MVP indicates that the farmer would find it profitable to acquire that scarce resource if MVP > MFC of that resource.

Operating capital is a limiting factor in production for all the zones as reflected by its positive MVP. It is more limiting in the Coffee and the HAG Zones as indicated by high MVPs. These MVPs

TABLE 6.2
MARGINAL VALUE PRODUCTS (MVPs) OF RESOURCES
BY AGRO ECOLOGICAL ZONES

Resources	Unit	Tea Zone MVP (Shs)	Coffee Zone MVP (Shs)	HAG Zone MVP (Shs)
Land	HA	0	1,834.02	0
Operating Capital	SHS	3.16	6.45	6.10
$FLCY_2$	HRS	0	0	0
$FLCY_3$	HRS	0	0	0
$FLCY_4$	HRS	0	0	2.10
$FLCY_5$	HRS	0	0	0
$FLCY_6$	HRS	4.49	0	0
$FLCY_7$	HRS	0	0	13.49
$FLCY_8$	HRS	0	0	0.55
$FLCY_9$	HRS	1.75	0	0
$FLCY_{10}$	HRS	0	0	0
$FLCY_{11}$	HRS	7.51	0	0
$FLCY_{12}$	HRS	3.29	0	0
$FLCY_{13}$	HRS	0	0	0
$FLCY_{14}$	HRS	0	0	0
P_2O_5F	KG	7.79	14.31	13.63
NPF	KG	7.36	7.53	13.29
NPKF	KG	9.90	17.74	15.55

SOURCE: Computed.

indicate that farmers could increase their incomes if more operating capital was made available. This shortage of operating capital points to the need for short term credit to break this constraint. It is evident by comparing Tables 6.1 and 6.2 that the return per unit of operating capital was higher than its MVP in all the zones. The opportunity cost of a unit of operating capital, as indicated by the current interest rates being charged by formal financial institutions in Kenya, was 10 percent in the study area. Thus, the rate of return on capital as indicated by its MVP appears to be substantially above the current rate of interest in the formal market.

The labor supply is not a constraint in any cycle in the Coffee Zone as reflected by zero MVPs in Table 6.2. In the Tea Zone, labor is a limiting factor in cycles 6, 9, 11 and 12. These are the peak labor periods in the zone, during which farmers are busy pruning and plucking tea, weeding, planting and harvesting. The MVP of labor is highest in cycle 11, when farmers are busy harvesting long-rain crops and weeding for short-rain crops. Although no allowance was made for the selling of family labor in our model, we can take the hiring labor wage rate in the zone to reflect the family labor opportunity cost. The wage rates in cycles 6, 9, 11 and 12 are Shs 1.08, 0.42, 1.85 and 0.79 per family man-hour respectively. The MVPs for man-hours in the same cycles are Shs 4.49, 1.75, 7.51 and 3.29 respectively. Thus, the MVPs of labor are too high in the zone during the peak periods compared with their opportunity costs. Given this situation, the farmers can increase their income either by working extra hours or hiring extra labor. This latter alternative might not be feasible if the farmers are already constrained by insufficient operating capital.

The peak periods in the HAG Zone are in cycles 4, 7, and 8, as reflected by their positive MVPs. These cycles coincide with land preparation, planting, weeding and harvesting operations in the zone. Cycle 7 is the greater constraint as reflected by its very high MVP. This is the period when weeding is being done in the area. The wage rates in cycles 4, 7, and 8 are Shs 0.36, 1.90 and 0.73 respectively. The MVPs are Shs 2.10, 13.49 and 0.55 respectively. Assuming that labor of uniform quality is available in peak season, this indicates it would be profitable for farmers to hire extra labor in cycles 4 and 7 since in these cycles the MVP of labor is greater than its MFC. However, it would be unprofitable to hire extra labor in cycle 8 since MVP < MFC of labor.

The MVPs of fertilizers are higher than their prices in all the zones. In the Tea Zone the MVPs ranged from Shs 7.39 for nitrogen-phosphate fertilizers to Shs 9.90 for NPK fertilizers. Their prices ranged from Shs 1.92 to Shs 2.38 per kilogram. The MVP ranged from Shs 7.53 to Shs 17.74 in the Coffee Zone and Shs 13.29 to Shs 15.55 in the HAG Zone. This indicates that with existing fertilizer prices and under existing output conditions, it would be profitable to use more fertilizers in all the zones. In this situation, then, lack of fertilizer use can only be attributed to farmers' inadequate knowledge of the role of fertilizer in increasing production, or to lack of operating capital for use in fertilizers, or to risk aversion.

In the above discussion, we have presented the MVPs of resources as if they were derived from a continuous function. Although the MVP of resources derived from linear programming is analogous to one derived from a continuous function, the two are not quite the same.

In programming, the MVP is evaluated at the margin with no other resource restricting [27]. Non-restricting resources are free and can combine with one more unit of the restricted resource to yield the MVP of the resource. The MVP from programming represents the rate of change in the objective function for one additional unit of the resource; its behavior for further additional units of the resource may be erratic, depending upon which factors become restricting as output changes. This erratic behavior is attributable to the corner solution of linear programming, i.e., the solution holds for a specific range until the other resources become limiting, at which point another organization becomes optimal and the MVPs of the resources change.

Linear programming also provides information about the excluded activities. It indicates the cost of forcing an extra unit of activity into the solution. The shadow prices of the excluded activities also provide information regarding the competitive position of these activities in the optimal solution. The lower the income penalty, the higher is the competitive position of that activity to enter into the optimum solution and vice-versa. If, for instance, the assumptions underlying the analysis are reasonable, then by growing a hectare of tea under current price and technological conditions, the farmer actually reduces his potentially obtainable income by Shs 1,381.69.

Optimal Organization of the Representative Farm with Variable Product, Fertilizer Prices and Capital Level for the Tea Zone

In the first part of this chapter we attempted to show to what extent the optimal allocation of existing representative farm resources under the present state of technology and prices would increase the net farm income, change existing cropping patterns and improve resource use. In the remainder of this chapter we shall explore the impact of variable product, fertilizer prices and capital level on (1) net farm income, (2) cropping pattern, and (3) resource use by zone. In the tables that follow, for all the zones and in the rest of this study, these changes are presented as Alternatives I, II and III, respectively. Alternative I represents increases in the prices of coffee, tea, hybrid maize, milk, beans and English potatoes by 50 percent, 50 percent, 20 percent, 20 percent, 10 percent and 5 percent, respectively. Alternative II represents the reduction of fertilizer prices by 40 percent while Alternative III represents the increase in the level of operating capital by 20 percent. As stated earlier, the increases in the prices of hybrid maize, milk, beans and English potatoes are based on recent price increases by the government. The increases in the price of coffee and tea are based on recent world market price increases. The fertilizer price changes are based on a 40 percent fertilizer price subsidy announced by the government in 1975-76. The increase in the level of operating capital was based on the assumption that as farmers' incomes increase, they will increase their operating capital.

Product prices are varied in Alternative I while fertilizer prices and capital level remain unchanged. Fertilizer prices are varied in Alternative II, while product prices and capital level are unchanged. In Alternative III, capital level is changed while product and fertilizer prices remain unchanged. In other words, if one variable is changed, the others take their base plan values.

The changes in net farm income for the Tea Zone are contained in Table 6.3. The estimated net income as a result of an increase in product prices is Shs 8,071.56 as against Shs 7,392.72 for the base plan, an increase of 9 percent. The net per hectare average return is Shs 3,281.12 as against Shs 3,067.52 under the base plan, an increase of 7 percent. Net farm income per man-hour is Shs 1.72 as against Shs 1.56, a 10 percent increase. The net return per unit of operating capital is Shs 6.38 as against Shs 5.84 for the base plan, an increase of 9 percent.

The fertilizer price decrease resulted in a substantial increase in net farm income. The net farm income is Shs 8,286.41 as against Shs 7,392.72, a 12 percent increase. The net farm income per hectare is Shs 3,481.68 as against 3,067.52, an increase of 14 percent. The net average return per family man-hour is Shs 1.74 as against Shs 1.56 for the base plan, an increase of 11 percent. The net return to a unit of operating capital is Shs 6.55 as against Shs 5.84 under the base plan, a 12 percent increase.

The change of operating capital level from Shs 1,266 in the base plan to Shs 1,520 in Alternative III resulted in a net farm income of Shs 8,146.13 as against Shs 7,392.72 under the base plan, an increase of 10 percent. The net farm income per hectare is Shs 3,169.70 as against 3,067.52 for the base plan, a 3 percent increase. The net average return per man-hour is Shs 1.60 as against Shs 1.56 under

TABLE 6.3
EFFICIENCY MEASURES FOR THE BASE PLAN AND ALTERNATIVES I - III
FOR THE TEA ZONE

Item	Unit	Base[a] Plan	Alternatives					
			I	Change Percent	II	Change Percent	III	Change Percent
Net farm income	SHS	7,392.72	8,071.56	+9	8,286.41	+12	8,146.13	+10
Land	HA	2.41	2.46	+2	2.38	-1	2.57	+7
Family labor	HRS	4,742.31	4,686.81	-1	4,773.39	+1	5,106.90	+8
Operating capital	SHS	1,266.00	1,266.00	0	1,266.00	0	1,520.00	+20
Net farm income/ha	SHS	3,067.52	3,281.12	+7	3,481.68	+14	3,169.70	+3
Net farm income/hr	SHS	1.56	1.72	+10	1.74	+11	1.60	+2
Net farm income/ operating capital	SHS	5.84	6.38	+9	6.55	+12	5.36	-8

SOURCE: Computed.

[a]Base plan is included to facilitate the comparison.

the base plan, an increase of only 2 percent. The net return per unit of operating capital is Shs 5.36 as against Shs 5.84, a decline of 8 percent. This would imply that as capital is increased, *ceteris paribus*, dimishing return to capital sets in.

The basic cropping pattern did not change in the three Alternatives as shown by Table 6.4. The only change occurring in all three of the Alternatives was in the level of hybrid maize and English potatoes. The increase in product prices resulted in an increase of 76 percent of the area under hybrid maize while the area under English potatoes declined by 49 percent. The decrease in fertilizer prices brought about a 44 percent increase of the area under hybrid maize, and a decline of 38 percent of the area under English potatoes. The change in operating capital level brought about a 48 percent increase of the area under hybrid maize and a decline of 12 percent in the area under English potatoes. Thus, changes in Alternatives I to III resulted in a larger net farm income compared with base plan net farm income. The largest increase, 12 percent, occurred in Alternative II and the smallest, 9 percent, occurred in Alternative I. This increased income in all Alternatives was a result of increased production in hybrid maize which, coupled with hybrid maize prices, more than offset the loss due to reduced production of English potatoes.

In spite of 50 percent increases in the prices of tea and coffee, they are still absent from these optimal plans. This would imply that, despite price increases, the relative profitability of these crops remains essentially unchanged; therefore coffee and tea are still excluded.

TABLE 6.4
LEVEL OF CROP ENTERPRISES UNDER VARIABLE PRODUCT PRICES, VARIABLE FERTILIZER PRICES AND VARIABLE CAPITAL LEVEL FOR THE TEA ZONE

Crop Enterprise	Unit	Base[a] Plan	Alternatives					
			I	Change Percent	II	Change Percent	III	Change Percent
Local maize	HA	0.49	0.49	0	0.49	0	0.49	0
Hybrid maize	HA	0.50	0.88	+76	0.72	+44	0.74	+48
Beans	HA	0.05	0.05	0	0.05	0	0.05	0
English potatoes	HA	0.69	0.35	-49	0.43	-38	0.61	-12
Pyrethrum	HA	0	0	0	0	0	0	0
Coffee	HA	0	0	0	0	0	0	0
Tea	HA	0	0	0	0	0	0	0

SOURCE: Computed.

[a]Base plan is included to facilitate the comparison.

Land is in excess supply as pointed out by its zero MVP in Table 6.5. The changes incorporated in Alternatives I to III do not bring enough land into use as to make it a constraint on production.

The MVP of operating capital in Alternative I is Shs 3.12 as against Shs 3.16 under the base plan. This implies that operating capital is still a constraint at the same level. The MVP for labor in cycle 3 is now positive as compared with zero MVP for the same cycle under the base plan. This would imply that increased product prices have resulted in increased employment of family labor in this cycle. The MVPs of labor in cycles 6, 9, 11 and 12 have declined compared with those under the base plan. This would indicate that as product prices are increased more family labor, as well as hired labor, is employed to relax the labor constraint. Thus, *ceteris paribus*, diminishing returns to labor sets in; hence, the lower MVPs of labor. The MVP for P_2O_5 fertilizers and NP fertilizers increase as product prices are increased. This points out that product price increases do not necessarily result in increased utilization of these fertilizers. The MVP for NPK fertilizers, however, declines as product prices are increased, implying that more NPK fertilizers are utilized.

The MVP of operating capital in Alternative II is Shs 4.11 compared to Shs 3.16 under the base plan. Thus, as fertilizer prices decrease, *ceteris paribus*, more fertilizer is bought; thus, operating capital is now a limiting factor as shown by its high MVP. The MVPs for labor in peak labor periods, cycles 6, 11 and 12, have increased substantially as compared with those under the base plan for the same cycles. This would indicate that as more fertilizer is utilized,

TABLE 6.5
MARGINAL VALUE PRODUCTS (MVPs) OF RESOURCES UNDER VARIABLE PRODUCT PRICES, VARIABLE FERTILIZER PRICES AND VARIABLE CAPITAL LEVEL FOR THE TEA ZONE

Resource	Unit	Base[a] Plan MVP (Shs)	Alternatives		
			I	II	III
Land	HA	0	0	0	0
Operating capital	SHS	3.16	3.12	4.11	2.94
$FLCY_2$	HRS	0	0	0	0
$FLCY_3$	HRS	0	3.44	0	0.17
$FLCY_4$	HRS	0	0	0	0
$FLCY_5$	HRS	0	0	0	0
$FLCY_6$	HRS	4.49	4.41	5.52	4.25
$FLCY_7$	HRS	0	0	0	1.24
$FLCY_8$	HRS	0	0	0	0
$FLCY_9$	HRS	1.75	1.73	0	1.65
$FLCY_{10}$	HRS	0	0	0	0
$FLCY_{11}$	HRS	7.51	7.62	7.63	7.28
$FLCY_{12}$	HRS	3.29	3.25	4.04	3.11
$FLCY_{13}$	HRS	0	0	0	0
$FLCY_{14}$	HRS	0	0	0	0
P_2O_5F	KG	7.79	7.91	5.88	7.56
NPF	KG	7.36	7.70	4.82	7.36
NPKF	KG	9.90	9.80	7.31	9.37

SOURCE: Computed.

[a]Base plan is included to facilitate the comparison.

labor becomes even more of a constraint because more labor is needed to harvest higher yields.

The MVPs for all fertilizers decline as compared with those under the base plan. This illustrates diminishing returns to fertilizer as its use is increased.

The MVP for operating capital in Alternative III is Shs 2.94 as compared with Shs 3.16 under the base plan. The decrease in MVP of operating capital in Alternative III illustrates diminishing returns to capital. The increase in operating capital results in more employment of family labor in cycles 3 and 7. The MVPs of labor in these cycles are now positive compared to zero MVPs under the base plan. In cycles 6, 9, 11 and 12, the MVPs of labor have declined compared with those under the base plan for the same cycles. This would imply that more operating capital results in more employment of family labor, as well as hired labor, to relax labor constraint in these peak labor periods. As more labor is employed, *ceteris paribus*, diminishing returns to labor sets in; hence the lower MVPs of labor. The MVPs of fertilizers decline as operating capital is increased. This indicates that as more operating capital is made available, then more fertilizers are utilized; but their lower MVPs indicate diminishing returns to fertilizers.

In all three Alternatives the average return per unit of capital was higher than its MVP while the MVP of capital in all three alternatives was higher than its opportunity cost. The average return per family man-hour was lower than its MVP in Alternatives I and II. The MVP of labor in both Alternatives was higher than its MFC. The average return per family man-hour in Alternative III was higher than its MVP in cycles 3 and 7. The MVP of labor in cycle 3 was less than its opportunity cost. The MVP of labor in other peak labor periods was higher than its opportunity cost. The MVPs of fertilizers in all the Alternatives were higher than their MFCs.

Optimal Organization of the Representative Farm with Variable Product, Fertilizer Prices and Capital Level for the Coffee Zone

The changes incorporated in Alternatives I to III resulted in increased net farm income compared with the base plan net farm income as shown in Table 6.6. The largest increment, 20 percent, occurred in Alternative III and the smallest, 5 percent, in Alternative II. The same changes held for net farm income per hectare. The return per family man-hour increased in all three Alternatives. Again, Alternative III had the largest increase, 17 percent; and the smallest, 7 percent, occurred in Alternative II. The return per unit of operating capital increased in Alternatives I and II by 12 and 5 percent respectively over the base plan return per unit of operating capital. The return per unit of operating capital was unchanged in Alternative III.

The cropping pattern remained basically the same as that in the base plan (Table 6.7). The only changes were at the levels of hybrid maize and English potatoes. Dramatic changes occurred in Alternative III where the area under hybrid maize was reduced by 20 percent, and the area under English potatoes was increased by 69 percent. The optimal plans in the three Alternatives did not include coffee or pyrethrum. Again, this reflects the fact that given current prices and technology, these crops are not competitive.

The MVP of land was Shs 2,403.45 in Alternative I as against Shs 1,834.02 under the base plan (Table 6.8). This implies that as

TABLE 6.6
EFFICIENCY MEASURES FOR THE BASE PLAN AND ALTERNATIVES I - III IN THE COFFEE ZONE

Item	Unit	Base[a] Plan	Alternatives					
			I	Change Percent	II	Change Percent	III	Change Percent
Net farm income	SHS	5,395.97	6,077.56	+13	5,650.55	+5	6,467.00	+20
Land	HA	2.35	2.35	0	2.35	0	2.35	0
Family labor	HRS	3,867.34	3,790.32	-2	3,825.58	-1	3,935.17	+2
Operating capital	SHS	832.00	832.00	0	832.00	0	998.00	+20
Net farm income/ha	SHS	2,296.16	2,586.20	+13	2,404.49	+5	2,751.91	+20
Net farm income/hr.	SHS	1.40	1.60	+14	1.48	+6	1.64	+17
Net farm income/ operating capital	SHS	6.49	7.30	+12	6.79	+5	6.48	0

SOURCE: Computed.

[a]Base plan is included to facilitate the comparison.

TABLE 6.7
LEVEL OF CROP ENTERPRISES UNDER VARIABLE PRODUCT PRICES, VARIABLE FERTILIZER PRICES AND VARIABLE CAPITAL LEVEL IN THE COFFEE ZONE

Crop Enterprise	Unit	Base[a] Plan	Alternatives					
			I	Change Percent	II	Change Percent	III	Change Percent
Local maize	HA	0.29	0.29	0	0.29	0	0.29	0
Hybrid maize	HA	1.11	1.27	+14	1.20	+8	0.89	-20
Beans	HA	0.07	0.07	0	0.07	0	0.07	0
English potatoes	HA	0.32	0.16	-50	0.23	-28	0.54	+69
Pyrethrum	HA	0	0	0	0	0	0	0
Coffee	HA	0	0	0	0	0	0	0
Tea	HA	0	0	0	0	0	0	0

SOURCE: Computed.

[a]Base plan is included to facilitate the comparison.

TABLE 6.8
MARGINAL VALUE PRODUCTS (MVPs) OF RESOURCES UNDER VARIABLE PRODUCT PRICES, VARIABLE FERTILIZER AND VARIABLE CAPITAL LEVEL IN THE COFFEE ZONE

Resource	Unit	Base[a] Plan MVP (Shs)	Alternatives		
			I	II	III
Land	HA	1,834.02	2,403.45	2,071.43	1,834.02
Operating capital	SHS	6.45	6.21	6.17	6.45
$FLCY_2$	HRS	0	0	0	0
$FLCY_3$	HRS	0	0	0	0
$FLCY_4$	HRS	0	0	0	0
$FLCY_5$	HRS	0	0	0	0
$FLCY_6$	HRS	0	0	0	0
$FLCY_7$	HRS	0	0	0	0
$FLCY_8$	HRS	0	0	0	0
$FLCY_9$	HRS	0	0	0	0
$FLCY_{10}$	HRS	0	0	0	0
$FLCY_{11}$	HRS	0	0	0	0
$FLCY_{12}$	HRS	0	0	0	0
$FLCY_{13}$	HRS	0	0	0	0
$FLCY_{14}$	HRS	0	0	0	0
P_2O_5F	KG	14.31	13.84	8.24	14.31
NPF	KG	7.53	7.89	7.53	7.53
NPKF	KG	17.74	17.15	10.25	17.74

SOURCE: Computed.

[a]Base plan is included to facilitate the comparison.

product prices are increased, land becomes more of a limiting factor to production. The MVP of operating capital is Shs 6.21 in Alternative I as against Shs 6.45 under the base plan, implying that operating capital is less of a constraint when product prices are increased. The MVP of labor is zero in all the Alternatives as well as in the base plan. This implies that labor is in excess supply in the Coffee Zone during all the cycles. The MVPs of P_2O_5 and NP fertilizers declined, implying that increased product prices have led to more fertilizer being utilized as compared with the base plan. The decline in MVP implies that diminishing returns to fertilizers is in operation.

The MVP of land in Alternative II is Shs 2,071.43 as against Shs 1,834.02 under that base plan, indicating that land is still more of a limiting factor to production. The MVP of operating capital is Shs 6.17 against Shs 6.45 under the base plan. Labor is still in excess in all the cycles as reflected by its zero MVP. The MVPs of fertilizers have declined compared with those of the base plan. This points out that a decrease in fertilizer prices results in more fertilizers being utilized. As more fertilizers are utilized, diminishing returns to fertilizer set in, culminating in decreased MVPs for fertilizers.

The change in the level of capital in Alternative III does not bring any changes to the MVPs of all the resources compared with the MVPs of the same resources under the base plan. This would imply that the MVP of operating capital is still within its range of stability.

The average return per unit of family man-hour and per unit of operating capital is greater than its MVP in all three of the Alternatives. The MVPs of operating capital and fertilizers are greater than their opportunity costs in all three Alternatives. The MVPs of labor in all the cycles are less than their opportunity costs in the three Alternatives.

Optimal Organizations of the Representative Farm with Variable Product, Fertilizer Prices and Capital Level for the HAG Zone

The changes brought about by Alternatives I to III on net farm income in the HAG Zone are depicted in Table 6.9. The net farm income increased in all three of the Alternatives compared with the base plan net farm income. The largest increase of 18 percent was in Alternative I, the smallest of 9 percent was in Alternative II. The net farm income per hectare increased by 18 percent in Alternative I and by 7 percent in Alternatives II and III. The return per family man-hour went up by 18 percent in Alternative I and by 7 percent and 11 percent respectively in Alternatives II and III. The return per unit of operating capital declined by 7 percent in Alternative III, indicating diminishing returns to operating capital. The increase in return per operating capital was 18 percent in Alternative I and 9 percent in Alternative II.

The cropping pattern did not change in mix from the base plan (Table 6.10). The changes were mainly on the levels of local maize, hybrid maize and beans. There was no change on the levels of these crops in Alternative I, compared with their levels under the base plan. In Alternative II the area under local maize declined by

TABLE 6.9
EFFICIENCY MEASURES FOR THE BASE PLAN AND ALTERNATIVES I - III IN THE HAG ZONE

Item	Unit	Base Plan[a]	Alternatives					
			I	Change Percent	II	Change Percent	III	Change Percent
Net farm income	SHS	10,812.16	12,762.58	+18	11,781.00	+9	12,038.66	+11
Land	HA	5.52	5.52	0	5.64	+2	5.74	+4
Family labor	HRS	4,348.80	4,348.80	0	4,438.58	+2	4,363.71	0
Operating capital	SHS	1,056.00	1,056.00	0	1,056.00	0	1,267.00	+20
Net farm income/ha	SHS	1,958.72	2,312.06	+18	2,088.83	+7	2,097.33	+7
Net farm income/hr	SHS	2.49	2.93	+18	2.65	+7	2.76	+11
Net farm income/ operating capital	SHS	10.24	12.09	+18	11.16	+9	9.50	-7

SOURCE: Computed.

[a]Base plan is included to facilitate the comparison.

TABLE 6.10
LEVEL OF CROP ENTERPRISES UNDER VARIABLE PRODUCT PRICES, VARIABLE FERTILIZER PRICES AND VARIABLE CAPITAL LEVEL IN THE HAG ZONE

Crop Enterprise	Unit	Base[a] Plan	Alternatives					
			I	Change Percent	II	Change Percent	III	Change Percent
Local maize	HA	1.36	1.36	0	1.20	-12	1.09	-20
Hybrid maize	HA	2.82	2.82	0	3.26	+12	3.36	+19
Beans	HA	0.15	0.15	0	0.13	-13	0.11	-27
English potatoes	HA	0.06	0.06	0	0.03	-50	0.06	0
Pyrethrum	HA	0	0	0	0	0	0	0
Coffee	HA	0	0	0	0	0	0	0
Tea	HA	0	0	0	0	0	0	0

SOURCE: Computed.

[a]Base plan is included to facilitate the comparison.

12 percent, while the area under hybrid maize increased by 12 percent. The areas under beans and English potatoes declined by 13 and 50 percent, respectively. The area under local maize declined by 20 percent while the area under hybrid maize increased by 19 percent in Alternative III. The area under beans in Alternative III declined by 27 percent while that under English potatoes remained unchanged. Pyrethrum is mainly grown in this area, but it is conspicuously absent in all the optimal cropping plans. This, again, reflects its high labor requirements coupled with relatively low returns per hectare.

Land in the HAG Zone is not a limiting factor as illustrated by its zero MVP in Table 6.11. The MVP of operating capital is Shs 7.56, Shs 6.90 and Shs 5.47 in Alternatives I, II and III respectively, against Shs 6.10 under the base plan. The increase in MVPs of operating capital in Alternatives I and II indicates that it has become more of a limiting resource to production. The decrease of the MVP of operating capital in Alternative III is due to diminishing returns to capital.

The MVPs of labor are positive in the peak labor periods in cycles 4, 6, 7 and 8. In cycle 4, the MVPs of labor are Shs 2.57, Shs 1.82 and Shs 0.48 in Alternatives I, II and III respectively, as against Shs 2.10 under the base plan. The MVPs of labor in cycle 6 is zero in Alternatives I and II, but it is Shs 4.85 in Alternative III. The MVPs of labor in cycle 7 are Shs 16.26, 15.00 and 12.29 in Alternatives I, II and III respectively as against Shs 13.49 under the base plan. This shows that labor is more of a limiting factor on production in cycle 7 than in the other cycles. The MVP of labor

TABLE 6.11
MARGINAL VALUE PRODUCTS (MVPs) OF RESOURCES UNDER VARIABLE PRODUCT PRICES, VARIABLE FERTILIZER PRICES AND VARIABLE CAPITAL LEVEL IN THE HAG ZONE

Resource	Unit	Base[a] Plan MVP (Shs)	Alternatives		
			I	II	III
Land	HA	0	0	0	0
Operating capital	SHS	6.10	7.56	6.90	5.47
$FLCY_2$	HRS	0	0	0	0
$FLCY_3$	HRS	0	0	0	0
$FLCY_4$	HRS	2.10	2.57	1.82	0.48
$FLCY_5$	HRS	0	0	0	0
$FLCY_6$	HRS	0	0	0	4.85
$FLCY_7$	HRS	13.49	16.26	15.00	12.29
$FLCY_8$	HRS	0.55	0.48	0.43	0.66
$FLCY_9$	HRS	0	0	0	0
$FLCY_{10}$	HRS	0	0	0	0
$FLCY_{11}$	HRS	0	0	0	0
$FLCY_{12}$	HRS	0	0	0	0
$FLCY_{13}$	HRS	0	0	0	0
$FLCY_{14}$	HRS	0	0	0	0
P_2O_5F	KG	13.63	16.43	9.08	12.42
NPF	KG	13.29	16.03	8.44	12.66
NPKF	KG	15.55	18.75	11.29	14.81

SOURCE: Computed.

[a]Base plan is included to facilitate the comparison.

in cycle 8 is lower in the three Alternatives than it is in cycle 7, implying that labor is not as limiting in cycle 8 as in cycle 7.

The MVPs of fertilizer are higher in Alternative I than they are under the base plan. This implies that an increase in product prices does not necessarily lead to increased utilization of fertilizers, although the MVPs indicate that fertilizer use would increase income substantially. Farmers might not utilize more fertilizers when product prices are increased because they base their decision on relative prices. Also, this might not follow in the case where operating capital is limiting, as it is in this case.

The MVPs of fertilizers in Alternatives II and III are lower than those under the base plan. This implies that under Alternatives II and III, more fertilizers are utilized, leading to diminishing returns to fertilizers, and hence the lower MVPs of fertilizers.

The results in this chapter indicate a substantial potential for increasing farm income and production with existing resource supplies and the present technological knowledge of the farmers. The empirical findings in this chapter are of value in suggesting economic adjustments in resource use. They are useful in promoting efficient agricultural production in the study area. They indicate that land is a limiting factor to production only in the Coffee Zone, contrary to the popular belief that land is a limiting factor to production in the whole of the study area. Thus, even though the available hectarages would appear to be insufficient for the household in the Tea Zone, resource proportions are such that maximizing net farm income requires land be fallowed. Operating capital is a limitation to production in all the zones. Labor is not a limitation to production in any period in the Coffee Zone, but it is in peak labor periods in the Tea and HAG Zones. The use of fertilizers in all the zones would result in substantial increases in income. Thus, the information provided in this chapter can be utilized by policy makers to improve agricultural policy with respect to resource use and cropping pattern in the three agro-ecological zones.

CHAPTER VII

FERTILIZER DEMAND FUNCTIONS UNDER VARYING LEVELS OF PRICES AND OPERATING CAPITAL

In an environment where time series data on resource use and product supply are lacking, the strategy has been to resort to linear programming techniques to estimate resource demand functions and/or product supply functions. Unfortunately, the *a priori* knowledge available for characterizing resource demand functions by this technique is very limited. The review of previous studies in Chapter III showed that quite a number of studies have derived supply functions for the farm-firm. Ogunfowora et al. [35] and Moore et al. [29] derived demand functions for fertilizer and irrigation water respectively by drawing heavily on the techniques used in deriving supply functions. This study will adopt the same strategy. Parametric linear programming and regression analysis techniques will be applied in this study.

The conventional method of parametric linear programming used to derive normative resource demand and product supply functions is modified in this study. The conventional method is thoroughly treated by Heady et al. [12]. It involves determining the range of a resource (or product) price over which the optimum farm will not be altered and, hence, the price range over which the quantity of resource use (or product produced) does not change. In contrast to the conventional method, in this study fertilizer price, product prices and capital level are set at a particular level and an optimum farm plan is obtained. These variables are again set at different levels and optimum farm plans are obtained. Associated with each plan is a quantity of fertilizer demanded. These parametric programming results are treated as though they were independent observations. The solution quantities of capital, fertilizer and the prices of fertilizer and products are then used in a regression analysis to estimate continuous fertilizer demand functions for the farm-firm. Given that the objective is to quantify farm-level fertilizer demand elasticities, then since the estimated functions are continuous regression equations, they can be used to derive point elasticities. However, the data generated by this method do not meet the assumptions of normality and independence used in regression analysis; statistical inference and probability statements, therefore, cannot be made [29]. Consequently, the statistical tests presented in this study should be interpreted as a measure of goodness of fit. This approach is also normative, indicating farmers' potential responses under the assumptions of farm income maximization, perfect knowledge about prices, technological changes, institutions and environmental factors. To the extent that these assumptions fail, farmers' actual decisions may sometimes differ markedly from those indicated as optimum. Anderson et al. and Sheehy et al. [1, 39] indicate that the normative approach may lead to an upward biased estimate of commodity supply and elasticities, and it is not yet clear to what extent normative quantities should be adjusted to closely approximate the actual supply and demand responses. Aware of this possiblity, an attempt was made to simulate as closely as possible actual farm conditions. Furthermore, fertilizer and product prices are largely fixed by the government and this reduces price risk substantially. But there are still technological and yield risks to contend with. Thus, the fertilizer quantities generated by this approach might deviate markedly from the quantities purchased in the market.

The fertilizer demand responses estimated in this study are for a representative farm in each agro-ecological zone and hence we do not encounter the problem of aggregation bias which we would have to contend with if we were estimating fertilizer demand functions for a region.

With no *a priori* knowledge of the functional form of the fertilizer demand function, various functional forms--linear, quadratic, exponential--were fitted to the data. Next, the square root transformation of the independent variables was applied. It has proved very successful in fertilizer studies [13]. To avoid multicollinearity, each independent variable was transformed by substracting its mean.

The criteria for assessing the adequacy of the fitted functions and for selecting the best regression equation follow the traditional procedure, namely (1) conformation with accepted theory and logic, (2) the size of the coefficient of multiple determination, R^2, and (3) statistically significant F-values for the regression mean squares. However, it must be remembered that generating data with linear programming may result in the data violating the assumptions which must be made in using these statistical tests. Nevertheless, the selection of a function is more of an art than a science [13]. The function with square root transformation of the product price index was selected to represent the demand for fertilizer, due to the overall desirability of the function based on the above three criteria.

The Kenyan government, realizing the potential role fertilizer can play in increasing agricultural production, uses price policy to influence its use. However, the impact and magnitude of the various variables on fertilizer use have not been estimated. In this study, then an attempt was made to test the hypothesis that substantial use of fertilizer could come about in response to (1) an increase in the price of farm products, (2) a fall in the price of fertilizer relative to the prices of products and (3) an increase in the level of available operating capital. The test of this hypothesis would also provide evidence for or against the assumption that the combination of these variables as a package would lead to substantial increases in fertilizer use.

Fertilizer Demand Model

The functional relationship in fertilizer demand can be stated as follows:

$$D_F = f\ (P_I,\ P_F,\ K,\ T,\ U) \qquad (1)$$

where

D_F = quantity for fertilizer in kilograms

P_I = price index of farm products[1]

P_F = price of fertilizer in K shillings

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[1]The method used for calculating product price index is presented in Appendix B.

K = the level of operating capital in K shillings

T = the level of technology

U = error term.

The specification of the above model could have included prices of other inputs that are either substitutes for or complements to fertilizer. However, the inclusion of the variables in the models was dictated by the data that could be generated by using parametric linear programming technique.

The identification problem is usually encountered in demand estimation. However, this problem is not encountered in this estimation of demand for fertilizer because of the way the data was generated.

A constant level of technology was assumed for this study. If technology is eliminated from the model, then the estimating model reduces to the following functional form:

$$D_F = b_0 + b_1 P_I + b_2 P_F + b_3 K + U. \qquad (2)$$

From economic theory, we would expect b_1 and b_3 to be positive while b_2 should be negative, implying that the demand for fertilizer should increase *ceteris paribus* as the product price index and operating capital level increase while the demand for fertilizer should decrease as the price of fertilizer increases.

Four crops in the Tea Zone, four in the Coffee Zone, and three in the HAG Zone were assumed to be the main fertilizer users. To generate data for estimating the demand functions, seven levels of product price were used, the magnitude of each being raised by equal proportions. However, the magnitudes varied among different products. They were based on past price movements (as pointed out in Chapter VI) as well as future price expectations for the different products. Table 7.1 shows the expected range and magnitudes of price increases for individual products for the Tea Zone. Table 7.2 shows the expected range and magnitude of price increases for individual products for the Coffee Zone. Table 7.3 shows the expected range and magnitudes of price increases for individual products for the HAG Zone.

Given the above increases in product prices it was assumed that farmers' incomes in the area would increase. Thus, we raised the level of operating capital by 20 percent. Table 7.4 shows the levels of operating capital by zone.

In the 1975-76 period, the government announced that the fertilizer price subsidy would be reduced from 40 to 25 percent. With this in mind, fertilizer prices were reduced by 40 percent and 25 percent respectively. Table 7.5 shows fertilizer types and their initial prices and subsidized prices.

The fertilizer price subsidy of 25 percent was tantamount to raising fertilizer prices from the 40 percent subsidy level. Two fertilizer price levels represented the two subsidy rates for each fertilizer type, i.e., P_{f_1} for the 40 percent subsidy rate and P_{f_2} for the 25 percent subsidy rate. Two levels of operating capital availability were specified. K_1 represented the initial operating capital level, while K_2 represented operating capital level after a 20 percent increase. These various levels of operating capital and fertilizer price were combined with the seven levels of product price and programming solutions obtained for each combination. Each optimum solution provided the data needed for estimating the demand functions

TABLE 7.1
EXPECTED RANGE AND MAGNITUDE OF PRICE INCREASE FOR THE TEA ZONE

Products	Price Range (Shs per Kg)								Percentage Increase
	1[a]	2	3	4	5	6	7	8	
Hybrid maize	0.91	1.09	1.31	1.57	1.88	2.26	2.71	3.25	20
Beans	2.54	2.79	3.07	3.38	3.72	4.09	4.50	4.95	10
E. potatoes	0.87	0.91	0.96	1.01	1.06	1.11	1.17	1.23	5
Tea	0.72	1.08	1.62	2.43	3.65	5.48	5.48	12.33	50

[a]Prevailing prices in the survey area during 1974-75 period.

TABLE 7.2
EXPECTED RANGE AND MAGNITUDE OF PRICE INCREASE FOR COFFEE ZONE

Products	Price Range (Shs per Kg)								Percentage Increase
	1[a]	2	3	4	5	6	7	8	
Hybrid maize	0.76	0.91	1.09	1.31	1.57	1.88	2.26	2.71	20
Beans	2.48	2.73	3.00	3.30	3.63	3.99	4.39	4.83	10
E. potatoes	0.89	0.93	0.98	1.03	1.08	1.13	1.19	1.25	5
Coffee	0.97	1.46	2.19	3.28	4.92	7.38	11.07	16.61	50

[a]Prevailing prices in the survey area during 1974-74 period.

TABLE 7.3
EXPECTED RANGE AND MAGNITUDE OF PRICE INCREASE FOR HAG ZONE

Products	Price Range (Shs per Kg)								Percentage Increase
	1[a]	2	3	4	5	6	7	8	
Hybrid maize	0.89	1.07	1.28	1.54	1.85	2.22	2.66	3.19	20
Beans	1.63	1.79	1.97	2.17	2.39	2.63	2.89	3.18	10
E. potatoes	0.60	0.63	0.66	0.69	0.72	0.76	0.81	0.85	5

[a]Prevailing prices in the survey area during 1974-75 period.

TABLE 7.4
LEVEL OF OPERATING CAPITAL BY ZONE (SHS)

Zone	Initial Level	Current Level	Percentage (Increase)
Tea	1,266[a]	1,520	20
Coffee	832	998	20
HAG	1,054	1,267	20

SOURCE: Survey data.

[1]Prevailing operating capital level during the survey.

TABLE 7.5
FERTILIZER TYPES, THEIR INITIAL PRICES AND SUBSIDIZED PRICES (Shs/Kg)

Fertilizer Type	Initial Price	Price at 40 Percent Subsidy	Price at 25 Percent Subsidy
P_2O_5	1.92[a]	1.15	1.44
NP	2.19	1.31	1.64
NPK	2.38	1.43	1.79

SOURCE: Survey data.

[1]Prevailing fertilizer prices during the survey.

for fertilizer. These resulted in twenty-eight observations each for the three zones. The data used for deriving the demand functions for the representative farms in the three zones are presented in Appendix C_1, C_2 and C_3 for the Tea, Coffee and HAG Zones, respectively.

Fertilizer Demand Estimates for the Tea Zone

From the discrete observations, the following equation and statistics were obtained for the fertilizer demand function in the Tea Zone:

$$D_F = 67.61 + \underset{(0.98)}{26.92 P_I^{1/2}} - \underset{(-5.18)}{344.38^{**} P_F} + \underset{(5.93)}{0.56^{**} K}$$

$$R^2 = 0.73 \text{ and } F\ (3,\ 24) = 21.37^{**}\ . \qquad (3)$$

In this and other equations to be presented later, the figures in parentheses are the t-values. The significance of the β-coefficients and F-values at 5 and 1 percent levels is indicated by one and two asterisks, respectively.

The explanatory variables displayed the expected signs. The coefficient of multiple determination, R^2, is high, 0.73, implying that the explanatory variables accounted for a substantial amount of the variability in the quantity of fertilizer demanded by the farm-firm in the Tea Zone. The F-test of the regression mean square was significant at the 1 percent level, implying that the regression model fitted the data adequately. If the observations had been independent then the β-coefficients of fertilizer price and capital are significant at the 1 percent level while that of product price is not significant even at the 10 percent level. The lack of independence in observations should also be borne in mind in interpreting the results of Coffee and HAG Zones equations.

The elasticities of the fertilizer demand with respect to its own price, product price and capital level were calculated at their mean values of observations as follows:

$$\varepsilon\overline{P}_f = \frac{\partial Q}{\partial P_f} \cdot \frac{\overline{P}_f}{Q} \tag{4}$$

$$\varepsilon\overline{P}_f = \frac{\partial Q}{\partial P_I} \cdot \frac{\overline{P}_I}{Q} \tag{5}$$

$$\varepsilon\overline{K} = \frac{\partial Q}{\partial K} \cdot \frac{\overline{K}}{\overline{Q}} \tag{6}$$

where

Q = quantity of fertilizer demanded. Table 7.6 shows the mean values used in the calculation of elasticities by zone.

The elasticity of the fertilizer demand was -1.65 with respect to its own price, 2.32 with respect to operating capital and 0.27 with respect to the product price index. The magnitudes of the elasticities show that the demand for fertilizer would be most responsive to changes in the operating capital level, followed by fertilizer price and product price, in that order. These elasticities imply that a 1 percent increase in fertilizer price *ceteris paribus* is predicted to reduce fertilizer consumption by 1.65 percent. Similarly, a 1 percent increase in operating capital is predicted to increase fertilizer consumption by 2.32 percent and 1 percent increase in product price is predicted to increase fertilizer consumption by 0.27 percent. The plausible explanation of a low elasticity of product price index is that with a limitation on capital, the use of fertilizer cannot be extended beyond a certain point (capital limitation) regardless of how far prices of products are increased.

TABLE 7.6
MEAN VALUES USED IN THE CALCULATION OF ELASTICITIES

Zone	$\overline{Q}$ (Kgs)	$\overline{P}_I$	$\overline{P}_F$ (Shs)	$\overline{K}$ (Shs)
Tea	335.79	2.79	1.61	1,393
Coffee	125.64	2.28	1.61	915
HAG	172.09	2.18	1.30	1,161.50

SOURCE: Calculated.

The results of our analysis are depicted in graphs of Figure 7.1, in which the quantity of fertilizer is graphed against output price index. In this figure, fertilizer and capital variables are assumed to be shift parameters. Given the initial demand function for fertilizer as $K_1P_{f_1}$, the fertilizer demand curve shifts to the left, $K_1P_{f_1}$ as the price of fertilizer increases. The increase of capital level to K_2 shifts the demand curve to $K_2P_{f_1}$. The demand curve $K_2P_{f_2}$ reflects an increase in both capital level and fertilizer price. The magnitudes of the shifts reflect the relative influence of fertilizer price and capital level on fertilizer demand response, while the slopes of the curves reflect the influence of product price index on fertilizer demand response.

Fertilizer Demand Estimates for the Coffee Zone

The following equation and statistics were obtained for the fertilizer demand function in the Coffee Zone:

$$D_F = -264.15 + \underset{(5.16)}{17.79^{**}}P_I^{1/2} - \underset{(-3.80)}{55.70^{**}}P_F + \underset{(5.64)}{0.48^{**}}K$$

$$R^2 = 0.92 \text{ and } F\ (3,\ 24) = 88.73^{**}\ . \qquad (7)$$

The three explanatory variables had the expected signs. They explain 92 percent of the variation in fertilizer demand for the farm-firm in the Coffee Zone. The F-test of the regression mean square was significant at the 1 percent level implying that the regression model fitted the data adequately. The β-coefficients of fertilizer price, product price and capital are significant at the 1 percent level.

The elasticities of fertilizer demand with respect to its own price, product price and capital level were obtained as demonstrated

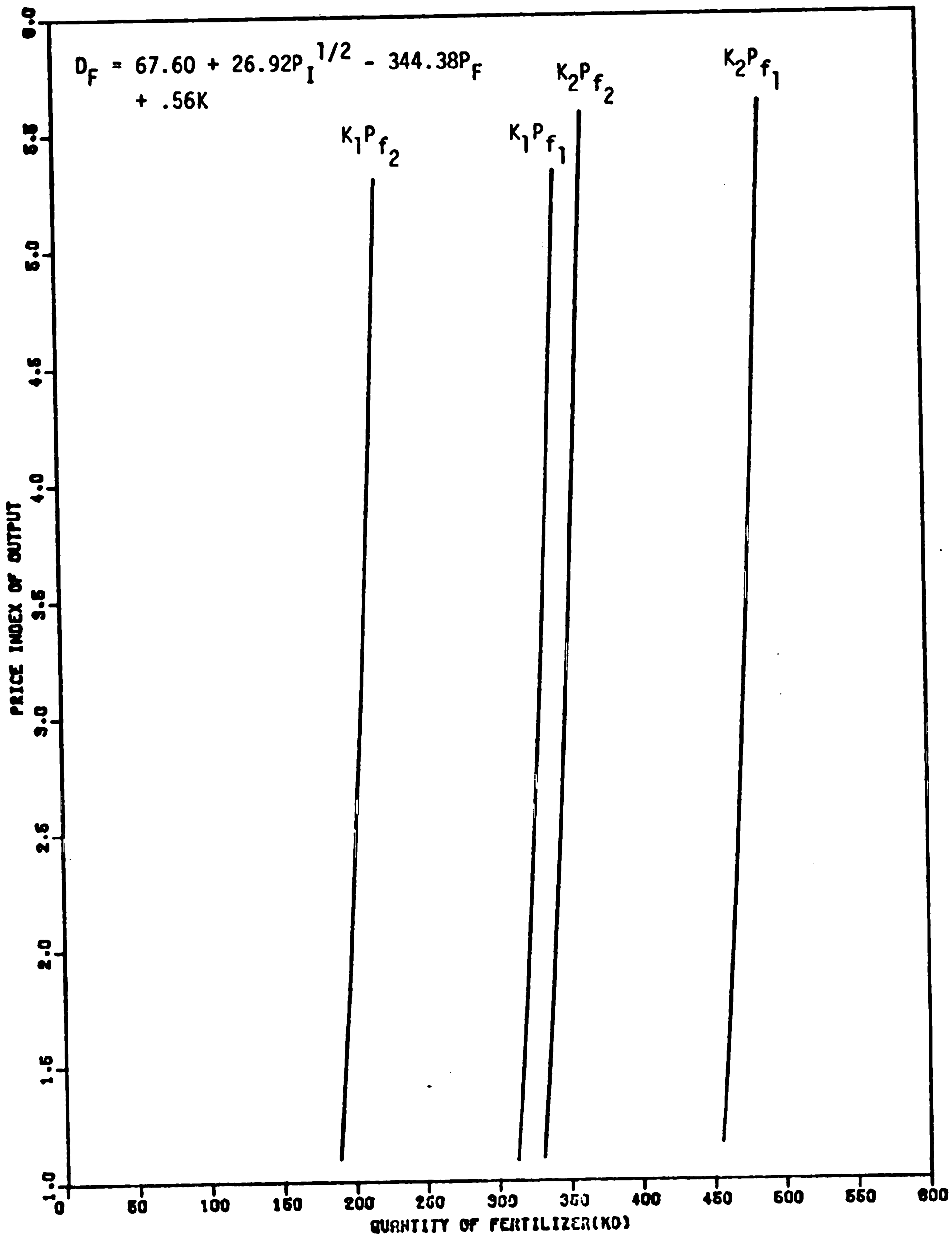

FIGURE 7.1
FERTILIZER DEMAND FUNCTIONS FOR VARIOUS LEVELS OF OUTPUT AND FERTILIZER PRICE LEVELS AND CAPITAL AVAILABILITY FOR THE TEA ZONE

in equations (4) to (6) above. The elasticity of fertilizer demand was -0.71 with respect to its own price, 3.49 with respect to operating capital, and 0.32 with respect to product price index. The magnitudes of the estimated elasticities indicate once again that the demand for fertilizer is product price inelastic. Thus, large product price changes are necessary to significantly affect demand. The demand for fertilizer is fertilizer price inelastic, but less inelastic compared to product price index. The capital elasticity of demand for fertilizer is highly elastic. Based on the estimated elasticities, a 1 percent increase in fertilizer price will decrease the quantity demanded by 0.71 percent. On the other hand, a 1 percent increase in product price and capital level will increase the quantity of fertilizer demanded by 0.32 percent and 3.49 percent, respectively. The estimated equation for fertilizer in the Coffee Zone is quite satisfactory from both an economic and statistical viewpoint. The impacts of fertilizer prices, product prices and capital on fertilizer demand are as hypothesized.

Figure 7.2 shows that if we again assume fertilizer and capital variables as shift parameters, then an increase of fertilizer price shifts the initial fertilizer demand curve to the left from $K_1P_{f_1}$ to $K_1P_{f_2}$. The increase of capital level shifts demand curve to the right, $K_2P_{f_1}$. The demand curve $K_2P_{f_2}$ reflects an increase in both capital level and fertilizer price. The magnitudes of these shifts reflect the relative influence of fertilizer price and capital level on fertilizer demand responses, while the slopes of the curves reflect the influence of product price on fertilizer demand response.

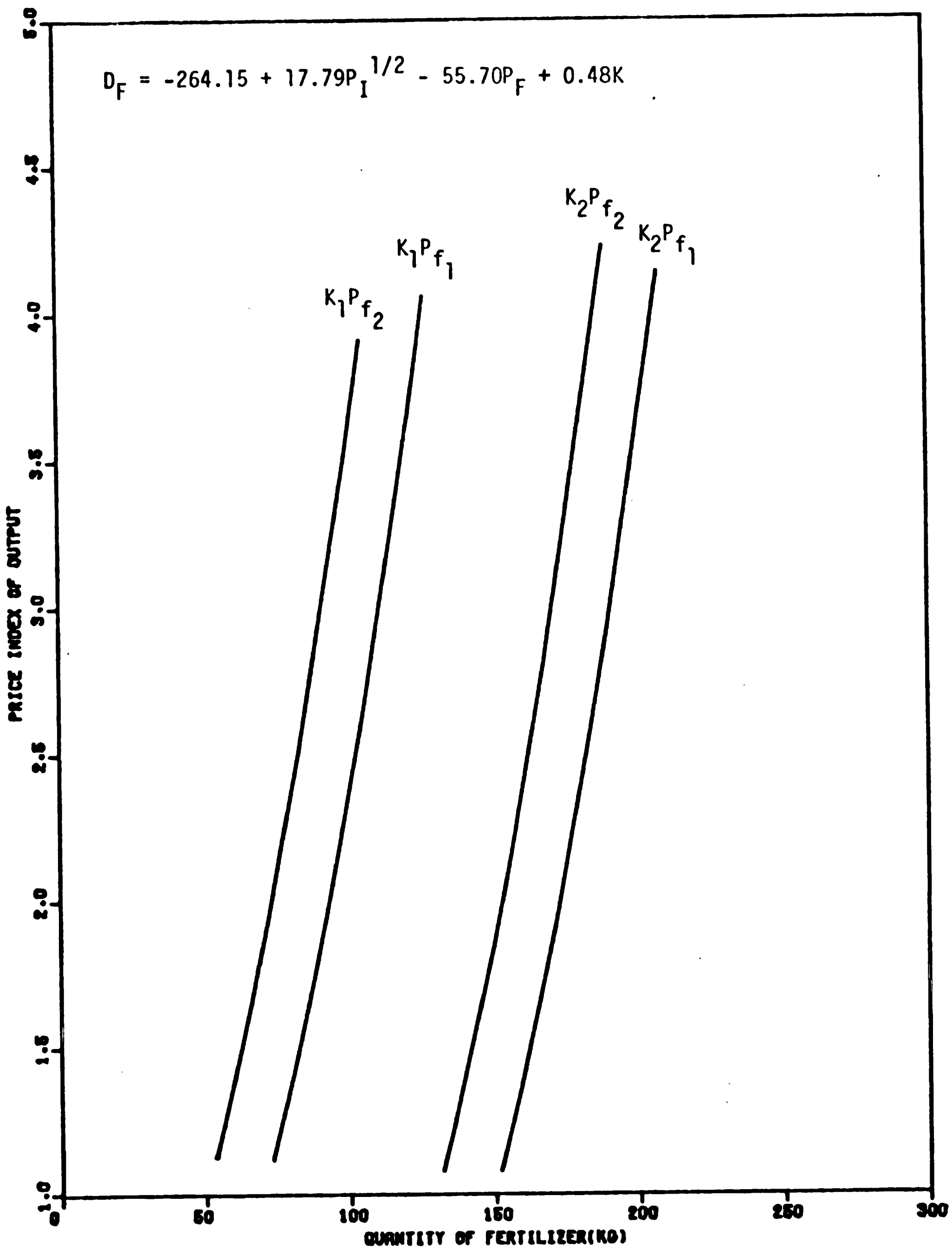

FIGURE 7.2
FERTILIZER DEMAND FUNCTIONS FOR VARIOUS LEVELS OF OUTPUT AND FERTILIZER PRICE LEVELS AND CAPITAL AVAILABILITY FOR THE COFFEE ZONE

Fertilizer Demand Estimates for the High Altitude Grass Zone

The equation and statistics obtained for the fertilizer demand function in the High Altitude Grass Zone are presented below:

$$D_F = \underset{}{51.69} + \underset{(2.51)}{3.05^{*}P_I^{1/2}} - \underset{(-11.21)}{24.44^{**}P_F} + \underset{(41.74)}{0.13^{**}K} \qquad (8)$$

$R^2 = 0.98$ and $F\ (3,\ 24) = 652.02$.

The explanatory variables had the expected signs. They explain almost all--98 percent--of the variation in the fertilizer demand for the farm-firm in the High Altitude Grass Zone. The F-test of the regression mean square was significant at the 1 percent level, indicating that the regression model fitted the data.

The β-coefficient of fertilizer price and capital are significant at the 1 percent level, while that of product price is significant at the 5 percent level.

The elasticities of fertilizer demand with respect to its own price, product price and capital level were -0.24, 0.04 and 0.87, respectively. The magnitude of these elasticities indicate that the demand for fertilizer is almost perfectly inelastic with respect to product price, inelastic with respect to fertilizer price and less inelastic with respect to capital level. Thus, according to these estimates, a 1 percent increase in product price will bring about only a 0.04 percent increase in fertilizer demand, tantamount to no response. The same decrease in fertilizer price would lead to an increase of 0.24 percent in fertilizer demand, and a 1 percent increase in the level of capital would lead to an 0.87 percent increase in fertilizer demand.

These results are depicted in Figure 7.3. The slopes of the curves reflect the influence of product price on fertilizer demand response. Their slopes are almost zero, implying an almost perfectly inelastic demand for fertilizer with respect to product price. The curves also show that an increase in fertilizer price shifts the demand curve to the left and an increase in capital level shifts the fertilizer demand curve to the right. The shift to the left is indicated by the curve labeled $K_1P_{f_2}$, and a shift to the right is indicated by the curve labeled $K_2P_{f_1}$.

After the estimation of the above elasticities for product price index, fertilizer price and capital for the three zones, an attempt was made to see how the product price index elasticity for fertilizer demand would change if there was a policy decision to increase product prices. If we assume that product price increases lead to an increase of the mean product price index by 50 percent in all the zones, then we proceed to calculate the new product price index elasticity for each zone. The new mean product price indexes are 4.19, 3.42, and 3.27 for the Tea, Coffee and HAG Zones, respectively. The mean fertilizer quantity remains the same for all the zones. The new product price index elasticities for fertilizer demand are 0.34, 0.48 and 0.06 for the Tea, Coffee and HAG Zones. The original elasticities were 0.27, 0.32 and 0.04 for the Tea, Coffee and HAG Zones, respectively. This indicates that even with a substantial increase in product price index, the product price index elasticity for fertilizer demand does not change substantially.

The results presented in this study compare favorably with results obtained from other studies which have attempted to estimate

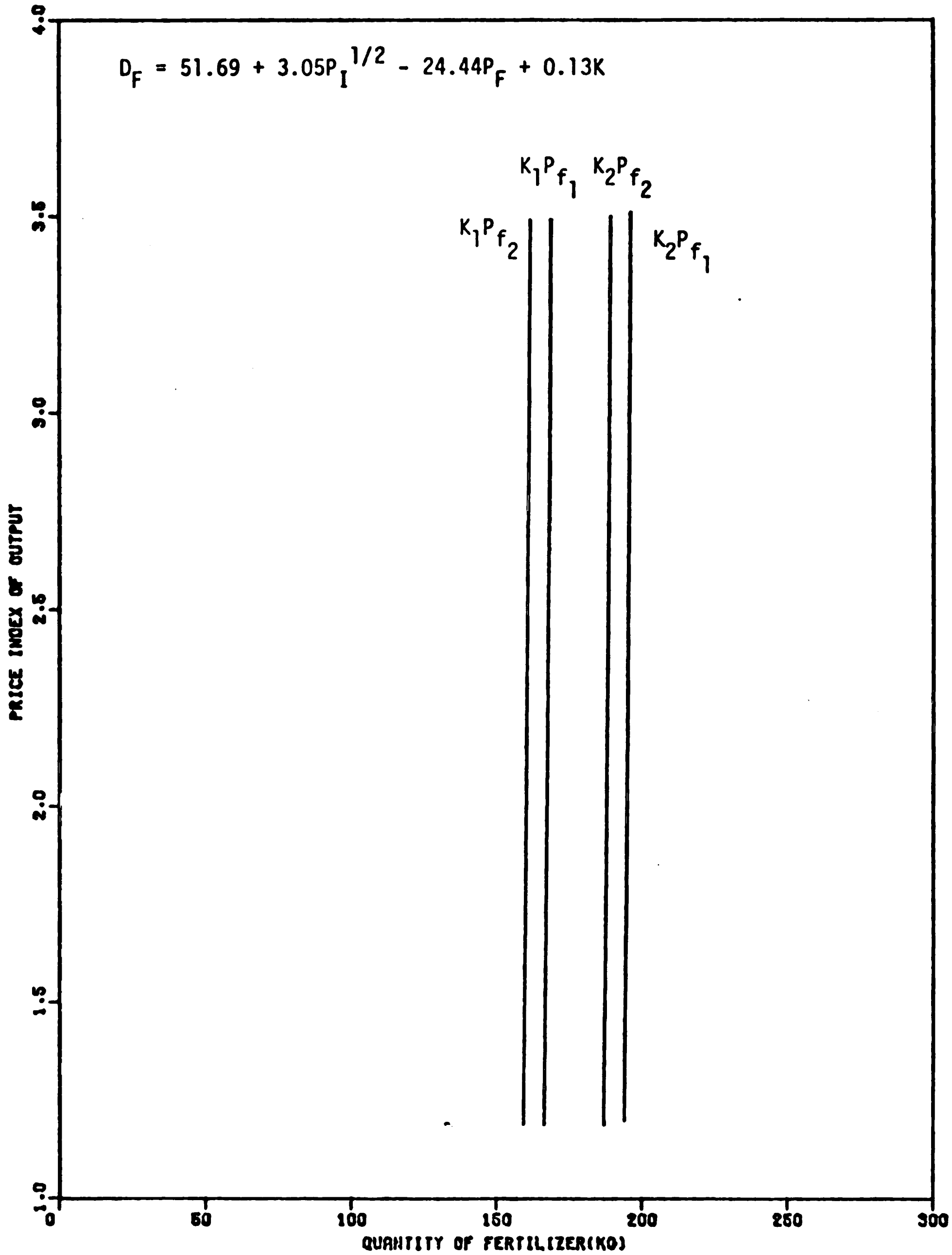

FIGURE 7.3
FERTILIZER DEMAND FUNCTIONS FOR VARIOUS LEVELS OF OUTPUT AND FERTILIZER PRICE LEVELS AND CAPITAL AVAILABILITY FOR THE HIGH ALTITUDE GRASS ZONE

farm level fertilizer demand for small farmers in developing countries.

Ogunfowora et al. [9], using the same technique in Northern Nigeria as the one employed in this study, estimated that the elasticity of fertilizer demand was -0.79 with respect to its own price, 1.63 with respect to capital, and 0.32 with respect to the product price index. Timmer has reported that the few studies that have used time-series data to estimate price elasticity for demand in developing countries have obtained a short term price elasticity of about -0.5 to -0.1, and the long term elasticity is in the range of -1.5 to about -3.0 [10]. Thus, the values obtained in our study can be interpreted as reasonable estimates of elasticities of farmer response to changes in fertilizer price, product price and capital level in the study area.

The results obtained in this study have important implications to both researchers and policy makers. The estimated price elasticity with respect to a change in fertilizer price is much higher than the price elasticity with respect to a change in the product price index in all three of the zones. This, then, would tend to indicate that the zero homogeneity condition for fertilizer demand functions might not hold in developing countries. That is, the effect of raising product price by 1 percent is not symmetric with the effect of lowering the fertilizer price by 1 percent. Many research workers as well as policy makers who have to choose the appropriate policy instrument--fertilizer subsidies or product price support--tend to rely on the symmetry assumption. Our results, just like those reported from developing countries by Timmer, Ogunfowora et al. and Raj

Krishna, tend to refute this assumption [42, 35, 26]. But Heady and Tweeten's estimates for the United States seem to confirm it [14]. Krishna, however, suggests that product price support might work better than input subsidies for a variety of reasons. Peasants tend to be more familiar with product prices and will probably be more sensitive to their variation. The critical factor for peasants is not insurance against high input prices, but guarantees that product prices will not collapse, leaving the cultivator helplessly in debt. Some input prices are difficult to subsidize--especially land and labor, which frequently form a large proportion of total costs--and only product price supports can be fully effective in stimulating the output of particular crops.

The results have also indicated that increase in capital has a high potential for increasing demand for fertilizer. This has important policy bearing in Kenya, where both product price support and fertilizer price subsidies are employed. Thus, even if fertilizer price subsidy and product price support can induce a substantial use of fertilizer, and hence increased output, their impact can be reduced tremendously if capital is limiting. That capital is limiting in the three zones has been established in this study. Further, it was shown that capital elasticities were higher than fertilizer price and product price index elasticities in all the zones. This would imply that any policy designed to increase fertilizer demand in the study area must provide for adequate fertilizer credit. Thus, just like one might argue that two policy instruments are more effective than one, one can also argue that three instruments employed simultaneously will result in greatest response. The response by farmers to these policy instruments takes time, and consequently the results obtained in this study might not approximate farmers' behaviors in the short run but it is hoped that they will predict their behavior in the long run.

These results do not tell the policy maker what the income distribution effect of product price support, fertilizer price subsidy and fertilizer credit policies are going to be on various groups. They only indicate how farmers would adjust their fertilizer use when either one of them is changed. The current fertilizer price subsidy in Kenya has been criticized on the grounds that it tends to favor those large-scale farmers (who use a lot of fertilizer) over the small farmers. The same argument can be applied to product price support. In favoring large-scale farmers, these two policy instruments have tended to worsen the income distribution between the two groups. Fertilizer credit is almost non-existent. A fertilizer credit policy, channelled specifically to small farmers might help to narrow the current widening income gap between large and small-scale farmers. In short, any policy instrument, be it fertilizer price subsidy or product price support, to be realistic, must consider the income distribution variable.

The issue of the relevance of results obtained in a study like this can be raised by policy makers and justifiably so. But Timmer [41] has summarized the situation well, when he observed that no policy maker would dare use these numbers if better ones were available. But this is the disturbing reality; little is known about factors affecting fertilizer use which is relevant at a policy level. Further fertilizer policy making, like many agricultural policies, might be placed in the realm of judgment, experience and politics, in addition to the realm of analysis.

CHAPTER VIII

SUMMARY, POLICY IMPLICATIONS, LIMITATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Summary

The objectives of this study were achieved through a combination of various techniques. The analysis of the survey data collected from 254 households pointed out the socio-economic factors influencing fertilizer use as perceived by farmers in the study area. The factors constraining fertilizer use included lack of funds, lack of fertilizer supplies at the needed time, high transport costs, lack of fertilizer credit and low literacy level.

Static linear programming and parametric linear programming were used to determine the organization that would maximize net farm income under existing resources, prices, technology, varying levels of fertilizer, product prices and capital. The objective function to be maximized in the model was net farm income. Further parametric linear programming and multiple regression analysis were used to estimate representative farms' demand functions for fertilizer.

Data concerning resources, enterprise organizations and technology were accumulated from the survey data. Data related to input-output coefficients, yields and prices had to be assembled and synthesized from the survey, CBS data, Ministry of Agriculture/FAO Fertilizer

Program Data and Ministry of Agriculture District Farm Guidelines. For the purpose of estimating optimum plans, an average farm was selected from each agro-ecological zone and assumed to be representative of farms in that zone.

The linear programming models were constructed to include crop production activities, selling activities, milk production activities, consumption activities, subsistence crop production activities, fertilizer buying activities and labor hiring activities.

The optimal allocation under existing resources and prices would result in substantial increases in net farm income. The increases were 9 percent, 27 percent, and 107 percent for the Coffee, Tea, and HAG Zones, respectively, against actual incomes. On all the farms, the MVPs of operating capital were high, suggesting that increasing the use of this resource would lead to income gains. A great income-raising possibility was also indicated by the MVPs of labor during peak labor periods in the Tea and HAG Zones, and high MVPs of fertilizer in all the zones. The MVPs of these resources also tended to be higher than their prices. The pressure for increase in farm size was indicated by the high MVP per hectare of land in the Coffee Zone. There was no land pressure in the Tea and HAG Zones as indicated by the zero MVP per hectare of land in these zones.

The cropping patterns under the optimum plans were not diversified, but were specialized in the production of four crops: local maize, hybrid maize, beans and English potatoes. This specialization was mainly due to their higher relative net returns, but also due to the minimum food consumption, which had to be produced by the farm-firm imposed on the model. This increased specialization reduced the number of crops from seven in the actual plan to four in the Coffee and Tea Zones and from five to four in the HAG Zone.

In the three Alternatives the variation of levels of product, fertilizer prices and capital led to an increase in net farm income of 9 percent, 12 percent, and 10 percent, respectively, against the base plan income for the Tea Zone. The increases were 13 percent, 5 percent and 20 percent, respectively, for the Coffee Zone. For the HAG Zone, the increases were 18 percent, 9 percent, and 11 percent respectively. This would indicate that net farm income is influenced by product prices and capital to a much greater extent than it is by fertilizer prices.

These changes in levels of product and fertilizer prices, and capital, did not change the cropping patterns for the representative farms in the three zones. The only change that occurred was in the variation of the levels of the crops in the plans.

The parametric linear programming analysis generated data on quantities of fertilizer demanded for different levels of product, fertilizer prices and capital. These quantities along with product price index, fertilizer prices and capital were used in a regression analysis to derive continuous fertilizer demand functions for the representative farm. Further, point elasticities with respect to product price index, fertilizer price and capital were derived from the continuous function. The overall fit of the fertilizer demand equations was good, and the predetermined variables explained a high percentage of the variation in the quantity of fertilizer demanded. In the Tea Zone, the results of the analysis show a positive, although not small, fertilizer demand response to changes in the product price index. A fall in the price of fertilizer and an increase in the level of capital bring larger demand responses for fertilizer. The demand for fertilizer is most responsive to increases in the capital level, with capital elasticity of 2.32 followed by fertilizer price changes with price elasticity of -1.65 and product price index elasticity of 0.27. In the Coffee Zone the elasticities were 3.49, -0.71, and 0.32 for capital, fertilizer price and product price index, respectively. This shows again that the demand for fertilizer is most responsive to increases in capital level.

In the HAG Zone, the capital elasticity was 0.87, followed by fertilizer price changes with a price elasticity of -0.24 and a product price index elasticity of 0.04. Here again, despite the fact that the elasticities were fairly low, the demand for fertilizer was still reasonably inelastic with respect to capital, followed by fertilizer price and product price index. All the elasticities were calculated at the mean value of observations.

The assumption that farmers respond symmetrically to a 1 percent increase in product price and a 1 percent decrease in fertilizer price is refuted by the results of this study. These results support similar findings that have been reported for developing countries. But studies in developed agricultural economies have tended to confirm it.

Policy Implications

The results obtained from the linear programming analysis point out that farmers in all three zones suffer from inadequacy of capital. Further, farm income is influenced by product price and capital to a much greater extent than it is by fertilizer prices. The computed elasticities in all three zones show quite clearly that capital has a much greater influence on the farm-firm's demand for fertilizer than do fertilizer and product prices. Part of this might be due to the fact that the capital constraint used in the model was that of the actual operating capital instead of the available capital. However, this operating capital constraint was relaxed by an assumption that farmers would increase their operating capital by 20 percent as their incomes increased. Lack of capital was also mentioned by farmers themselves as one of their major inhibiting factors in increasing fertilizer use. This then would imply that any policy aimed at increasing fertilizer use, and the consequent increase in output and farm income, must provide for more capital to the farmers. This calls for a formulation of credit policy based on the productivity of capital rather than on security of loans. This policy should strengthen cooperatives as the sources of short-term credit to all farmers, and not just to coffee growers. Cooperatives are especially suited to play this role because they can easily involve a large number of rural people. Their involvement in the rural economy is deeper than the mere provision of credit and this will help in loan recovery.

Nonavailability of fertilizer when needed was also isolated as an important factor constraining fertilizer use. This problem can be attacked from various fronts. Investment in bituminized feeder roads will enable fertilizer to be delivered in the rural areas even during the rainy seasons when these roads are now impassable. Credit should be provided to local dealer/stockists situated in local markets both for purchase of stock and erection of permanent stores. The proximity of available fertilizer will reduce the already substantial transport costs and save farmers' time. Investments in these infrastructures will definitely have high payoffs in the long run. The erection of a fertilizer factory at Mombasa if coupled with timely import of raw material may alleviate the problem of national fertilizer shortages, due either to late purchases by major fertilizer importers or to shortages of fertilizer in the world market.

However, although the results of this study indicate that credit supply will increase demand for fertilizer more significantly than fertilizer and product prices, we would reiterate that the three policy instruments are not mutually exclusive, consequently their simultaneous application will result in greater impact.

Limitations and Suggestions for Future Research

Linear programming estimates are limited in that they are generated in the context of assumptions and model specifications underlying the linear model. The closer these assumptions and model specifications approach an accurate reflection of the decision environment for small farmers in the study area, the more valid our results are likely to be. We assumed that each farmer in the study area had as his goal to maximize farm income. To the extent that this assumption fails, farmers' actual decisions may differ significantly from those indicated as optimum by our results.

The lack of risk and uncertainty considerations is another characteristic of the static economic assumptions under which the models were constructed. But the farmer will be faced by uncertainties regarding changing technologies, and economic and institutional elements in the decision-making context. This might lead to different decisions from those charted by our model. The other limitation is the use of yield data from the Ministry of Agriculture/FAO Fertilizer Program. These yields, despite having been obtained from farmers' plots, might differ substantially from those obtained by farmers themselves, thus leading to different results from those obtained in this study.

The computed elasticities were based on the assumption that farmers adjust to price and capital changes instantaneously. Certainly in the short run this is an unrealistic assumption. There is a lag in farmers' adjustments and hence these elasticities might be more applicable in the long run. Given this situation and the normative nature of the results, then their use by policy makers must be tempered by subjective judgment if they are to be used properly.

Further, no valid probability statements or statistical inferences can be made because the data do not meet the assumptions of normality and independence used in regression analysis. This means that the results obtained in the study area cannot be generalized to another area, unless the new area duplicates all physical, economic, and institutional constraints of the study area.

The results obtained in this study are limited to Central Kenya. This means that similar research is needed in other areas of the country if a comprehensive national fertilizer policy is to be formulated.

The zero homogeneity condition, which says that a farmer reacts the same to a 1 percent increase in product price as to a 1 percent fall in fertilizer price, is refuted by the results of this study, but other empirical studies have tended to confirm it. This then calls for more empirical work to resolve this issue which is of importance not only to research workers who often rely on this assumption, but also to policy makers who often have to choose between fertilizer subsidy and product price support.

The government has spent a substantial amount of scarce resources on fertilizer subsidy without adequate knowledge of the payoffs. A study on the impact of past expenditure on agricultural output and income redistribution between the large and small-scale farmers is economically desirable.

Research is further needed to determine the relative cost of alternative policies to increase fertilizer demand, i.e., fertilizer price subsidy policy versus policies aimed at increasing the productivity of fertilizer, such as subsidizing agricultural research, farmer training centers and extension services.

APPENDICES

APPENDIX A

EXPLANATION OF ABBREVIATIONS USED IN THE MATRIX

APPENDIX A

TABLE A.1
EXPLANATION OF ABBREVIATIONS USED IN THE MATRIX

Resources (Rows)		
Row No.	Abbreviation	Complete Heading
1	LAND	Land in hectares
2	$FLCY_2$	Family labor in cycle 2
3	$FLCY_3$	Family labor in cycle 3
4	$FLCY_4$	Family labor in cycle 4
5	$FLCY_5$	Family labor in cycle 5
6	$FLCY_6$	Family labor in cycle 6
7	$FLCY_7$	Family labor in cycle 7
8	$FLCY_8$	Family labor in cycle 8
9	$FLCY_9$	Family labor in cycle 9
10	$FLCY_{10}$	Family labor in cycle 10
11	$FLCY_{11}$	Family labor in cycle 11
12	$FLCY_{12}$	Family labor in cycle 12
13	$FLCY_{13}$	Family labor in cycle 13
14	$FLCY_{14}$	Family labor in cycle 14
15	LMS	Supply local maize
16	HMS	Supply hybrid maize
17	BS	Supply beans
18	EPS	Supply English potatoes
19	PMS	Supply pyrethrum
20	TS	Supply tea
21	SCS	Supply subsistence crop
22	MKS	Supply milk

TABLE A.1 - CONTINUED
EXPLANATION OF ABBREVIATIONS USED IN THE MATRIX

Resources (Rows)		
Row No.	Abbreviation	Complete Heading
23	CLM	Consume local maize
24	CHM	Consume hybrid maize
25	CB	Consume beans
26	CEP	Consume English potatoes
27	CMK	Consume milk
28	BP_2O_5F	Buy phosphate fertilizer
29	BNPF	Buy Nitrogen and Phosphate fertilizers
30	BNPKF	Buy Nitrogen, Phosphate and Potash Fertilizers
31	OC	Operating capital

Activities (Columns)		
Column No.	Abbreviation	Complete Heading
1	PLM	Produce local maize
2	PHM	Produce hybrid maize without fertilizers
3	PHMPF	Produce hybrid maize with Phosphate fertilizer
4	PHMNPF	Produce hybrid maize with Nitrogen and Phosphate fertilizers
5	PB	Produce beans without fertilizers
6	PBPF	Produce beans with Phosphate fertilizers
7	PBNPF	Produce beans with Nitrogen and Phosphate fertilizers
8	PEP	Produce English potatoes without fertilizers
9	PEPNPF	Produce English potatoes with Nitrogen and Phosphate fertilizers

TABLE A.1 - CONTINUED
EXPLANATION OF ABBREVIATIONS USED IN THE MATRIX

Activities (Columns)		
Column No.	Abbreviation	Complete Heading
10	PEPNPKF	Produce English potatoes with Nitrogen, Phosphate and Potash fertilizers
11	PPM	Produce pyrethrum
12	PT	Produce tea without fertilizers
13	PTNPKF	Produce tea with Nitrogen, Phosphate and Potash fertilizer
14	PTNPKF	Produce tea with Nitrogen, Phosphate and Potash fertilizer
15	PSC	Produce subsistence crop
16	PMK	Produce milk
17	SLM	Sell local maize
18	SHM	Sell hybrid maize
19	SB	Sell beans
20	SEP	Sell English potatoes
21	SPM	Sell pyrethrum
22	ST	Sell tea
23	SMK	Sell milk
24	CLM	Consume local maize
25	CHM	Consume hybrid maize
26	CB	Consume beans
27	CEP	Consume English potatoes
28	CMK	Consume milk
29	BP_2O_5F	Buy Phosphate fertilizer
30	BNPF	Buy Nitrogen and Phosphorus fertilizers
31	BNPKF	Buy Nitrogen, Phosphorus and Potassium fertilizers
32	$HLCY_2$	Hire labor cycle 2
33	$HLCY_3$	Hire labor cycle 3

TABLE A.1 - CONTINUED
EXPLANATION OF ABBREVIATIONS USED IN THE MATRIX

Activities (Columns)		
Column No.	Abbreviation	Complete Heading
34	$HLCY_4$	Hire labor cycle 4
35	$HLCY_5$	Hire labor cycle 5
36	$HLCY_6$	Hire labor cycle 6
37	$HLCY_7$	Hire labor cycle 7
38	$HLCY_8$	Hire labor cycle 8
39	$HLCY_9$	Hire labor cycle 9
40	$HLCY_{10}$	Hire labor cycle 10
41	$HLCY_{11}$	Hire labor cycle 11
42	$HLCY_{12}$	Hire labor cycle 12
43	$HLCY_{13}$	Hire labor cycle 13
44	$HLCY_{14}$	Hire labor cycle 14

APPENDIX B

NOTES ON THE CALCULATION OF PRODUCT PRICE INDEX USED IN THE FERTILIZER DEMAND FUNCTIONS

APPENDIX B

NOTES ON THE CALCULATION OF PRODUCT PRICE INDEX USED IN THE FERTILIZER DEMAND FUNCTIONS

Although the prices of all products in the parametric programming model increase more or less together, a change in the price of maize or coffee may be more important in influencing the demand for fertilizer than a change in the price of beans and hence carry greater weight in the index. Also, the solution quantity of each product did not remain constant over all price changes, presumably due to enterprise substitution.

Thus, in order to give individual products weights that are commensurate with their importance, their prices were weighted by the quantities of individual products generated by the optimum solution using Fisher's "Ideal" formula:

$$P = \left(\frac{\Sigma P_1 q_0}{\Sigma P_0 q_0} \times \frac{\Sigma P_1 q_1}{\Sigma P_0 q_1} \right)^{1/2}$$

where P = price index

P_0 = base price of the product

P_1 = price of the product increased by a certain proportion

q_0 = base quantity of the product derived from the first linear programming solution

q_1 = quantity of product when its price is increased by a certain proportion.

APPENDIX C

OBSERVATION INPUTS FOR FERTILIZER AND DEMAND FUNCTION FOR THE TEA ZONE, THE COFFEE ZONE, AND THE HIGH ALTITUDE GRASS (HAG) ZONE

APPENDIX C

TABLE C.1
OBSERVATION INPUTS FOR FERTILIZER AND DEMAND FUNCTION
FOR THE TEA ZONE

D_F (Kgs)	P_F (Shs)	P_I	K (Shs)
203.10	1.43	1.09	1,266
397.83	1.43	1.45	1,266
357.47	1.43	1.82	1,266
343.69	1.43	1.84	1,266
309.20	1.43	3.22	1,266
309.20	1.43	4.14	1,266
309.20	1.43	5.33	1,266
183.48	1.79	1.10	1,266
180.76	1.79	1.33	1,266
260.50	1.79	1.83	1,266
225.90	1.79	1.85	1,266
203.80	1.79	3.21	1,266
203.80	1.79	4.12	1,266
203.80	1.79	5.30	1,266
264.98	1.43	1.16	1,520
556.89	1.43	1.50	1,520
535.09	1.43	1.88	1,520
521.31	1.43	2.52	1,520
486.82	1.43	3.36	1,520
486.82	1.43	4.34	1,520
486.82	1.43	5.62	1,520
240.76	1.79	1.10	1,520
320.52	1.79	1.40	1,520
402.40	1.79	1.82	1,520
367.80	1.79	2.51	1,520
345.70	1.79	3.34	1,520
345.70	1.79	4.31	1,520
345.70	1.79	5.58	1,520

TABLE C.2
OBSERVATION INPUTS FOR FERTILIZER AND DEMAND FUNCTION
FOR THE COFFEE ZONE

D_F (Kgs)	P_F (Shs)	P_I	K (Shs)
59.30	1.43	1.12	832
84.92	1.43	1.39	832
78.27	1.43	1.66	832
77.39	1.43	1.99	832
116.47	1.43	2.59	832
116.47	1.43	3.66	832
117.96	1.43	4.06	832
64.62	1.79	1.13	832
64.62	1.79	1.30	832
68.91	1.79	1.65	832
68.91	1.79	1.94	832
97.25	1.79	2.52	832
97.25	1.79	3.54	832
98.96	1.79	3.91	832
119.89	1.43	1.08	998
177.92	1.43	1.36	998
172.32	1.43	1.88	998
170.39	1.43	2.01	998
205.01	1.43	2.60	998
205.01	1.43	2.85	998
206.50	1.43	4.14	998
133.30	1.79	1.08	998
133.30	1.79	1.20	998
133.30	1.79	1.84	998
133.30	1.79	2.05	998
171.53	1.79	2.24	998
171.53	1.79	2.80	998
173.23	1.79	4.23	998

TABLE C.3
OBSERVATION INPUTS FOR FERTILIZER AND DEMAND FUNCTION
FOR THE HIGH ALTITUDE GRASS (HAG) ZONE

D_F (Kgs)	P_F (Shs)	P_I	K (Shs)
159.03	1.15	1.19	1,056
159.03	1.15	1.42	1,056
163.69	1.15	1.71	1,056
163.69	1.15	2.04	1,056
163.69	1.15	2.44	1,056
163.69	1.15	2.92	1,056
163.69	1.15	3.49	1,056
151.58	1.44	1.19	1,056
151.58	1.44	1.42	1,056
156.96	1.44	1.71	1,056
156.96	1.44	2.04	1,056
156.96	1.44	2.44	1,056
156.96	1.44	2.92	1,056
156.96	1.44	3.49	1,056
191.98	1.15	1.20	1,267
188.15	1.15	1.43	1,267
188.15	1.15	1.71	1,267
188.15	1.15	2.04	1,267
188.63	1.15	2.44	1,267
188.63	1.15	2.93	1,267
188.63	1.15	3.51	1.267
181.37	1.44	1.19	1,267
181.37	1.44	1.43	1,267
181.37	1.44	1.71	1,267
181.37	1.44	2.04	1,267
182.04	1.44	2.44	1,267
182.04	1.44	2.92	1,267
182.04	1.44	3.50	1,267

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Anderson, J.C. and Heady, E.O. "Normative Supply Functions and Optimum Farm Plans for Northeastern Iowa," Iowa Agriculture and Home Economics Experiment Station Research Bulletin 537, 1965.

2. Ayub, M.A. "An Econometric Study of the Demand for Fertilizer in Pakistan," Pakistan Development Review. 14, 1 (Spring 1975).

3. Barker, R. and Stantan, R. "Estimation and Aggregation of Farm Supply Functions," Journal of Farm Economics. 47 (1965).

4. Burt, O.R. "Curve Fitting to Step Functions," Journal of Farm Economics. 46, 3 (August 1964).

5. Clayton, E.S. "Economic and Technical Optima in Peasant Agriculture," Journal of Agricultural Economics. 14, 3 (1961).

6. Dalrymple, D.G. "Evaluating Fertilizer Subsidies in Developing Countries," Agency for International Development Discussion Paper No. 30, 1975.

7. Day, R.H. "On Aggregating Linear Programming Models of Production," Journal of Farm Economics. 45 (1963).

8. Donaldson, G.F. and Von Pischke, J.O. Small Farmer Credit in Kenya. Washington, D.C.: Agency for International Development, 1973.

9. Food and Agriculture Organization. Annual Fertilizer Review (Rome). 1975.

10. Goldsworthy, P.R. "Response of Cereals to Fertilizer in Nigeria II," Maize Samaru Research Bulletin 85. Institute for Agricultural Research, Ahmadu Bello University, Samaru, Nigeria, 1968.

11. Griliches, Z. "The Demand for Fertilizer: An Economic Interpretation of a Technical Change," Journal of Farm Economics. 40 (August 1958).

12. Heady, E.O. and Candler, W. Linear Programming Methods. Ames, Iowa: Iowa State University Press, 1958.

13. Heady, E.O. and Dillon, J.H. Agricultural Production Functions. Ames, Iowa: Iowa State University Press, 1961.

14. Heady, E.O. and Tweeten, L.G. Resource Demand and Structure of Agricultural Industry. Ames, Iowa: Iowa State University Press, 1963.

15. Heady, E.O.; Haroldsen, E.O.; Mayer, L.V. and Tweeten, L.G. Roots of the Farm Problem. Ames, Iowa: Iowa State University Press, 1965.

16. Heyer, J. "A Linear Programming Analysis of Constraints on Peasant Farms in Kenya," Food Research Institute Studies in Agricultural Economics, Trade and Development. 10, 1 (1971).

17. Heyer, J. "An Analysis of Peasant Farm Production Under Conditions of Uncertainty," Journal of Agricultural Economics. 23 (1972).

18. Heyer, J. "The Marketing System," Agricultural Development in Kenya. Nairobi: Oxford University Press, 1976.

19. Hsu, R.C. "The Demand for Fertilizer in a Developing Country: The Case of Taiwan, 1950-66," Economic Development and Cultural Change. 20, 2 (January 1972).

20. Ibach, D.B. "Fertilizer Use in the United States," Economic Research Service, Agricultural Economic Report No. 92. United States Department of Agriculture, Washington, D.C., 1966.

21. International Labor Organization. Employment, Income and Equality: A Strategy for Increasing Productive Employment in Kenya. Geneva: International Labor Office, 1972.

22. Johnson, R.W.M. "The African Village Economy: An Analytical Model," The Farm Economist. 11 (1969).

23. Kenya Farmer. Nairobi: Agricultural Society of Kenya, January 1977.

24. Kottke, M. "The Anatomy of Step Supply Functions," Journal of Farm Economics. 42, 1 (February 1967).

25. Krenz, R.D.; Baumann, R.V. and Heady, E.O. "Normative Supply Functions by Linear Programming Procedure," Agricultural Economics Research. 14, 1 (1962).

26. Krishna, R. "Agricultural Price Policy and Economic Development," Agricultural Development and Economic Growth, edited by H.M. Southworth and B.F. Johnston. Ithaca, New York: Cornell University, 1967.

27. Lard, C.F. "Profitable Organizations of Representative Farms in Lower Michigan and Northeastern Indiana with Special Emphasis on Feed Grains and Livestock" Unpublished Ph.D. Dissertation. Michigan State University. 1963.

28. McFarquhar, A.M.M. and Evans, A. "Linear Programming and the Combination of Enterprises in Tropical Agriculture," Journal of Agricultural Economics. 12, 4 (1957).

29. Moore, C.V. and Trimble, R.H. "A Method for Estimating the Demand for Irrigation Water," Agricultural Economics Research. 15, 4 (1963).

30. Muthee, A.M. "Distribution of Non-farm Inputs in Kenya, with Special Emphasis on the Role of Agricultural Cooperatives," Unpublished Ph.D. Dissertation. University of Nairobi, Kenya. 1975.

31. Norman, D.W. "Economic Analysis of Agricultural Production and Labor Utilization Among Hausa in the North of Nigeria," African Rural Economy Paper No. 4, Department of Agricultural Economics, Michigan State University, East Lansing, Michigan, 1973.

32. Ogwel, L.O. and Clayton, E. A Regional Programming Approach to Agricultural Sector Analysis. Ashford, Kent: Wye College, 1972.

33. Ogunfowora, A. "A Linear Programming Analysis of Income Opportunities and Optimal Farm Plans in Peasant Farming," Bulletin of Rural Economics and Sociology. 5, 2 (1970).

34. Ogunfowora, O. "Derived Resource Demand, Product Supply and Farm Policy in the North Central State of Nigeria." Unpublished Ph.D. Dissertation. Iowa State University. 1972.

35. Ogunfowora, O. and Norman, D.W. "Farm-Firm Normative Fertilizer Demand Response in the North Central State of Nigeria," Journal of Agricultural Economics. 24 (1973).

36. Republic of Kenya. Report of the Working Party on Agricultural Inputs. Nairobi: Government Printer, 1971.

37. Republic of Kenya. Development Plan, 1974-78. Nairobi: Government Printer, 1974.

38. Republic of Kenya. Integrated Rural Survey 1974-75, Basic Report. Nairobi: Central Bureau of Statistics, Ministry of Finance and Planning, March 1977.

39. Sheehy, S.J. and McAlexander, R.H. "Selection of Representative Benchmark Farms for Supply Estimation." Journal of Farm Economics. 47 (May 1965).

40. Stanley, S.J. and Carter, H.O. "Supply Functions for Cotton in Imperial Valley California," Agricultural Economics Research. 15, 1 (1963).

41. Timmer, C.P. "The Demand for Fertilizer in Developing Countries," Food Research Institute Studies in Agricultural Economics, Trade and Development. 13, 3 (1974).

42. Timmer, C.P. "Fertilizer and Food Policy in LDCs." Economics Planning of Food and Agriculture. 1, 2 (1976).

43. United States Department of Agriculture. "Agricultural Development in Kenya Since 1967," Foreign Agricultural Economics Report No. 123, July 1976.

44. United States Department of Agriculture. "Kenya: Annual Agricultural Situation Report," Foreign Agricultural Economics Report No. 125, August 1976.

45. Watson, K.A. "Fertilizer in Northern Nigeria: Current Utilization and Recommendations for Their Use," Samaru Research Bulletin 38, Samaru Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria, 1964.

46. Zschernitz, K. "Marketing of Fertilizer Through Local Stockists in Kenya," a paper presented at FAO/NANIDA Seminar, Nairobi, Kenya, December 1972.