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THE RATE OF RETURN TO MAIZE RESEARCH IN KENYA: 1955-88

By

DANIEL DAVID KARANJA

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

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1990

ABSTRACT

THE RATE OF RETURN TO MAIZE RESEARCH IN KENYA: 1955-88

By

Daniel David Karanja

Kenya's agricultural sector is facing several contemporary challenges including the need to feed a rapidly growing population. Maize is the staple food for over ninety percent of the population. In 1955, the Kenyan government initiated a hybrid maize research program which resulted in the release of high-yielding maize varieties. The hybrids contributed to a doubling of the national maize yield, near tripling of the area under maize and a fivefold increase in national maize output over the 1955-88 period.

Today, there is a growing interest in the assessment of productivity of agricultural research and development of guidelines on how much national governments and donors should invest in research in Africa. This study pioneers the evaluation of returns to agricultural research in Kenya and uses a production function approach to evaluate the rate of return to investments in maize research from 1955 to 1988. The results indicate that past maize research, extension and seed development programs contributed to increased maize production. The average rate of return to investments in maize research over the 1955-88 period was found to be sixty-eight percent. In policy terms , the results show that one Kenyan pound invested in maize research contributed sixty-eight pounds to the Kenyan society over the 1955-88 period.

To my mother Janet Wanjiru

and my brothers John Kamau and Martin Maina.

Their love and patience gave me strength.

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LIST OF ABBREVIATIONS

CBS = Central Bureau of Statistics

CGIAR = Consultative Group of International Agricultural Research

CIMMYT= International Maize and Wheat Improvement Centre

CPI = Consumer Price Index

FAO = Food and Agriculture Organization of the United Nations

GDP = Gross Domestic Product

IARC = International Agricultural Research Centre

IITA = International Institute of Tropical Agriculture

ISNAR = International Services for National Agricultural Research

KARI = Kenya Agricultural Research Institute

KGGCU = Kenya Green Growers Cooperative Union

KSC = Kenya Seed Company

K£ = Kenyan Pound=Kenyan Shillings 20 = approx. US$ 0.87 (Jun,1990).

MALD = Ministry of Agriculture and Livestock Development

MOA = Ministry of Agriculture

MRST = Ministry of Research, Science and Technology

NARC = National Agricultural Research Centre

NARS = National Agricultural Research System

NCPB = National Cereals and Produce Board

NDFRC = National Dryland Farming Research Centre

NPBRC = National Plant Breeding Research Centre

NSQCS = National Seed Quality Control Station

1. CHAPTER ONE

INTRODUCTION AND BACKGROUND

1.1. Introduction

Kenya's agricultural sector faces the challenge of feeding a rapidly growing population on about 17 percent of the country's total land area. Because almost all the arable land is under cultivation, future increases in food production will have to rely primarily on yield improvement rather than on area expansion. Maize is the staple food for over 90 percent of the population and a cheap source of calories. To meet future food demand, projections indicate that maize supplies will have to double in the next fifteen to twenty years.

The development of maize hybrids since the early 1960s has led to a doubling of maize yields, a near tripling of the area under maize and a fivefold increase in maize production in what can be considered as the Green Revolution success story of Kenyan agricultural research. But the challenge of increasing food production requires continuous investment in the generation, transfer and adoption of productive agricultural technologies. Because such investments are costly and compete for scarce public resources, it is neccessary to ensure that the resources are allocated to priority research programs.

Several techniques have been developed to evaluate agricultural research productivity. Ex-post approaches have been used to evaluate the payoff to past investments in research while ex-ante approaches have been used to estimate future returns to investments in research. The results of such analyses can be used to determine the productivity of alternative research investments and assist in research prioritization and resource allocation. Many such evaluations in Asia, Latin America and in developed countries have revealed a high rate of return (ROR) to investment in agricultural research. But only four of about 170 studies world wide have been published for Africa.

This study evaluates the payoff to investment in improved/hybrid maize research in Kenya from 1955-88. The study is based on data and information collected from a field research conducted in Kenya from October 1989 to March 1990 in order to compile the costs and benefits of maize research from 1955 to 1988. The data and information were assembled by extensive use of archival sources, personal interviews and secondary data sources. The study uses a production function analysis technique to estimate the ROR to maize research over the 1955-88 period.

The outline of the thesis is as follows: Chapter one provides a background to the country and the economy, and highlights the research problem and objectives of the study. Chapter two presents an overview of the maize sub-sector including maize research, production, marketing and consumption. Chapter three reviews the literature on rate of return assessment by highlighting past studies on agricultural research productivity and different assessment techniques. Chapter four presents the results of the rate of return evaluation for investments in maize research in Kenya over the 1955-88 period. Chapter five summarizes the study results and draws implications for research policy in Kenya.

1.2 Location, Climate and Demography

Kenya, located in East Africa astride the Equator, has a total land area of 582,646 square kilometres (km^2). It is bordered to the north by Ethiopia and Sudan, Tanzania to the South, Uganda to the West and the Indian Ocean to the East. The country is divided into seven provinces, excluding the city of Nairobi. These are further divided into 41 districts which are, in turn, subdivided into divisions, locations and sub-locations. Figure 1 shows the administrative boundaries of Kenya.

Largely influenced by its equatorial location, Kenya has a diverse climate that varies greatly with topography. The result is a climate ranging from hot to wet tropical climate on the coastal belt to arid and semi-arid conditions in the north and north-east, and temperate climate in the highlands. Annual rainfall and temperatures follow strong seasonal patterns and vary with altitude. There are two distinct rainfall distribution patterns: a bimodal pattern characteristic of the Rift, Central highlands and the coastal belt and a unimodal pattern characteristic of the regions west of the Rift Valley. The amount and distribution of rainfall combined with soil characteristics are the major factors that determine the agricultural potential of land. Based on these factors, Pratt et al (1966) devised a comprehensive classification of land potential. Six broad Agro-Ecological Zones (AEZ) are distinguished from his work and are presented in Table 1.

Figure 1: Administrative Map of Kenya

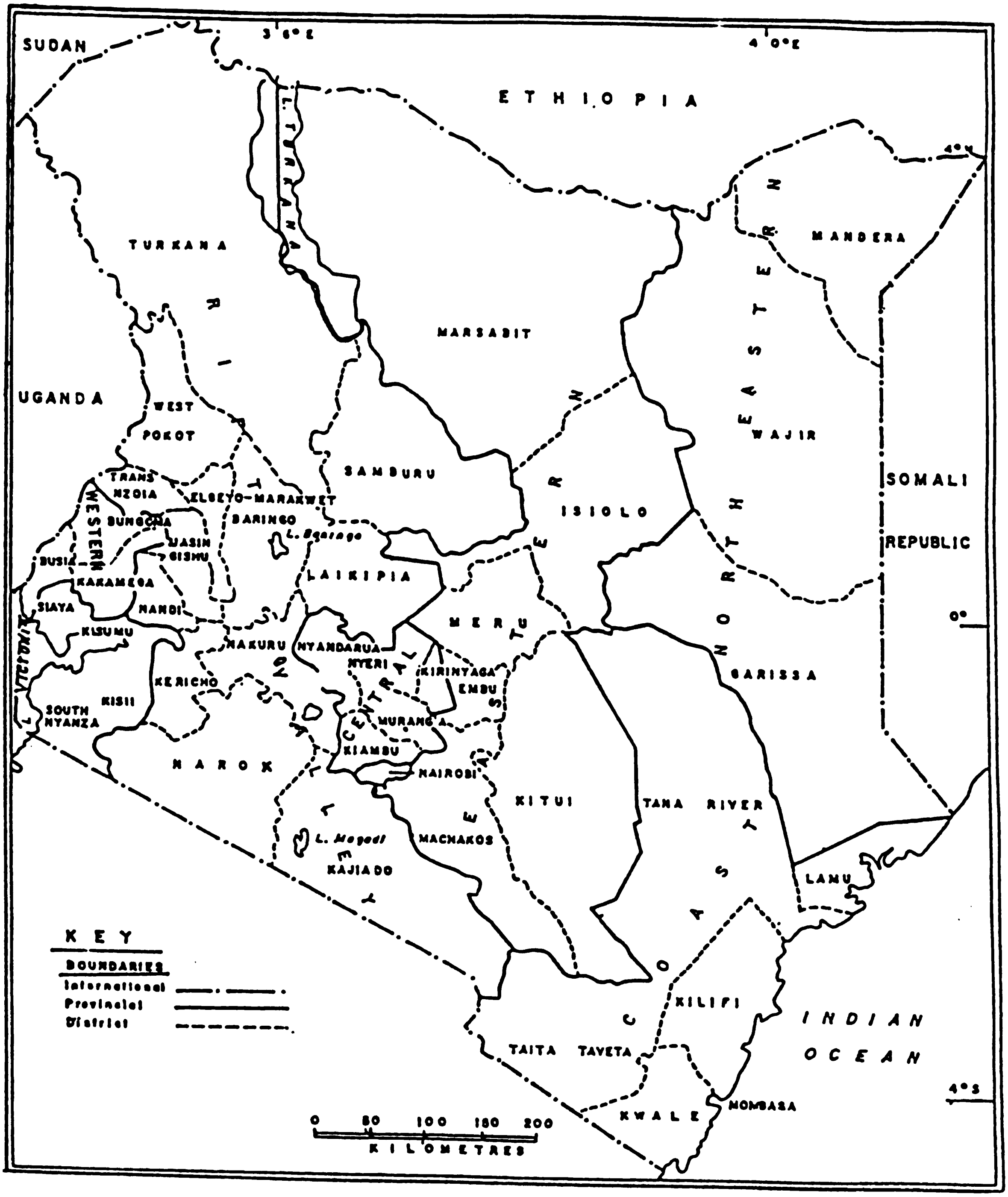


Table 1: Kenya: Agro-Ecological Zones and Land Potential

ZONE AND POTENTIAL	CHARACTERISTICS AND LAND USE	AREA ('000Ha)	% OF TOTAL AREA
I. TROPICAL-ALPINE ZONE (Low Potential)	Above 3000m. Moorland and barren. Land above forest line. Use limited to water catchment and tourism.	60	0.11
II. UPPER HIGHLAND ZONE (High Potential)	Between 2400-3000m. Mostly high rainfall. Suitable for forests, coffee, tea, pyrethrum, intensive livestock. Wheat, barley and maize on lower altitudes.	5,087	8.94
III. LOWER HIGHLAND ZONE (Medium Potential)	Between 1800-2400m. Moderate rainfall. Suitable for mixed farming, maize, wheat, barley, oil crops and livestock. Higher altitudes good for tea, coffee and pyrethrum.	4,670	8.21
IV. UPPER MIDLAND ZONE (Low Potential)	Between 1300-1800m. Semi-arid. Marginal agriculture. Subsistence crop farming. Sunflower, maize, sisal, livestock and wild life.	5,342	9.39
V. LOWER MIDLAND ZONE (Low Potential)	Between 800-1300m. Arid. Sub-marginal agriculture. Sisal, cotton. Moderate rangeland potential. Live-stock and wildlife.	30,192	53.06
VI. LOWLAND ZONE (Low Potential)	Between 0-800m. Very Arid. Mostly rangeland limited to nomadic pastoralism. Higher altitudes may be suitable for sorghum, millet.	11,550	20.29
TOTAL		56,901	100.00

Source: Pratt *et al* (1966).

Table 1 indicates that only about 17 percent of Kenya's total land area is medium and high potential. The rest is a vast arid and semi-arid land (ASAL) characterized by nomadic pastoralism, submarginal agriculture, livestock and wildlife (Kenya, 1983a). With prevailing technology, these dry low-potential lands cannot be used for productive agriculture. But since the early 1980s the government is focusing attention on the development of sustainable technologies for small-scale dryland farming, irrigated agriculture and pastoral subsectors. These ventures require substantial investments in physical and social infrastructures.

Kenya's rapid population growth has put considerable pressure on arable land for food production and settlement. This has also resulted in an out-migration from the high and medium potential land to the ASAL. In the last twenty years arable land per capita has declined by over 50 percent (Henin, 1981). Moreover, the high population growth poses a threat to economic growth and national development. The population has increased from 5.4 million people in 1948 to an estimated 22.7 million in 1988; implying a quadrupling of the population in forty years. Assuming no change in age-specific fertility and the current growth rate, the population is estimated to reach 35 million by year 2000. The combination of a high population growth rate, diminishing per capita arable land and a rising demand for health, education and shelter are exerting severe pressure on the government budget and the need to develop improved and sustainable technologies to increase food production.

1.2 Agriculture in the National Economy

Kenya's economic growth since independence has been very good relative to most countries in Africa. The Gross Domestic Product (GDP) grew at an average 6.5 percent per year between 1964-71, one of the highest growth rates in Africa during the sixties. This growth was fueled by the agricultural sector through a transfer of land from large- to small-farm use, an increase in smallholder cultivation of high-value crops such as tea and coffee, and a modest growth in industrialization based on import-substitution (Kenya, 1983a). Between 1972-81 the growth rate declined to an average 5.2 percent per year; the rate grew at an average 3.8 percent per year between 1982-87.

Agriculture is the largest sector of the Kenya's economy providing nearly all the country's food requirements, 28-38 percent of the GDP, 60-70 percent of total export earnings, 75 percent of total employment and livelihood for about 85 percent of the population (Kenya, 1983a; Ruigu, 1985). The sector remains the main foreign exchange earner with coffee and tea jointly contributing nearly 70 percent of agricultural export earnings and about 45 percent of the total export earnings. Tourism and industrial exports are the other sources of foreign currency.

Kenya's agriculture faces two contemporary problems: a shortage of arable land and the need to provide adequate food for a rapidly growing population. In the 1960s and early 1970s Kenya produced sufficient food but since the mid-1970s, there has been periodic imbalances between food production and demand (Kenya, 1988). The rising population and vagaries of weather have resulted in insufficient domestic food production, thus, undermining national food security. Agriculture also needs to employ a growing potential laborforce and generate foreign exchange and raw materials to support expansion and diversification of the economy.

A drought in 1979 and 1980 resulted in major food shortages and a US$ 265 million food-import bill (Kenya, 1982). Based on this experience, the government re-evaluated its food policies and formulated an agenda to stimulate agricultural production and ensure food security (Kenya, 1981). The severe drought of 1984 again dramatized the precarious food situation in Kenya and the need to accord greater priority to food production. The Sessional Paper No.1 of 1986 on Economic Management for Renewed Growth outlined the challenges facing the economy and the urgent need to stimulate agricultural and economic growth (Kenya, 1986a). Since then the government has adopted policies to revitalize food production through increased public investment in agriculture, particularly subsistence crops, and improvement of the efficiency of production, marketing and distribution of food crops. Agricultural support services have been reorganized to provide a favourable environment for increased and sustained agricultural production. But the options for crop intensification are limited. Because virtually all of the arable land is under cultivation, Kenya has to rely on increasing yields rather than area expansion for increased agricultural production. Over the long run, attempts will have to be made to convert most of the ASAL region, covering 80 percent of the total land area, into agriculturally productive land.

The development and adoption of improved maize varieties, one of the great successes of Kenya's agricultural research, increased national maize output fivefold. The maize yield has more than doubled and the area planted to maize has nearly tripled since 1955. This success is important because maize is the staple food for over 90 percent of Kenya's population and accounts for over 40 percent of the total dietary intake (Blackie, 1989). The average per capita consumption of maize in Kenya is about 113 kilograms per year (kg/Yr) compared to 20 kg/Yr for the whole of the developing world (CIMMYT, 1987; ISNAR, 1985a). In 1981 maize was ranked first in the total area harvested, total production value and total annual employment of all crops in Kenya (Mwangi, 1980).

Increased maize supplies through increased production and/or imports are required to meet future food demand. Projections on population growth and food demand indicate that maize supplies will have to double in the next 15-20 years to meet food demand. The challenge of increasing food production has been met by a government decision to give priority to investment in agricultural research and improve its effectiveness in technology generation and transfer. Yet, in order to achieve this goal, research priorities must be focused on the key staple foods.

Pressure on budgets and growth of public expenditures have increased the demand for economic assessment of research priorities and investments. Schuh and Tollini (1979) highlights three benefits of assessing a research activity: 1) to provide a basis for soliciting and justifying budget support; 2) to provide for an efficient allocation of scarce research resources; and 3) to enable financing of priority research.

Much of Kenya's agricultural success is attributed to agricultural institutions such as the research, extension, credit and input delivery systems, some of which were inherited from the colonial era. Agricultural research in Kenya began with the establishment of a multidisciplinary research centre in Nairobi in 1903. Today, there are 22 agricultural research centres located in different agro-climatic zones and managed by a newly formed Kenya Agricultural Research Institute (KARI), a government parastatal set up to co-ordinate, execute and manage all crop and livestock research activities. Figure 9 in the Appendix presents the organization structure of KARI. The research centres are allocated national and/or regional mandated commodity-research programs (Kenya, 1986b).

The general objective of this study is to estimate the rate of return to maize research in Kenya from 1955-88. The specific objectives are: 1) to describe the evolution of maize and its importance in Kenya; 2) to review the development of maize research and the maize sub-sector; 3) to review studies on the measurement of agricultural research productivity; 4) to generate data and information on the costs and benefits of maize research between 1955-88; and 5) to use a production function approach to evaluate the rate of return to investments in maize research over the 1955-88 period.

2. CHAPTER TWO

OVERVIEW OF THE MAIZE SUBSECTOR

2.1 Origin and Introduction of Maize

Maize was introduced to Kenya following the importation of several types of maize from North and Latin America via South Africa around the turn of this century. By 1903 maize occupied about 20 percent of the total foodcrop area and formed the staple diet of the Kikuyu and Kamba (Meinertzhagen, 1957).[1] By 1960 maize was already established as an important food crop, occupying about 44 percent of the total crop area (Kenya, 1966). The crop spread quickly because it is easy to grow, has few serious pests and diseases, provides a good yield, is easy to store and is more palatable in various forms than traditional cereals such as millet and sorghum (Allan, 1971).

The most popular imported varieties were Hickory King, White Horsetooth, Ladysmith White and Salisbury White. These and other introductions became intercrossed in Kenya to such an extent that their identity was lost, but European settler-farmers established locally adapted strains for different areas mainly by crib selection. In this way, Kenya Flat White emerged as a recognized, variable but reasonably stable, mixed population or complex. From the settler-farms, Kenya Flat White was spread by African labourers to their home areas. During this process, some admixtures with the local Caribbean Flint types must have

[1] These two Kenyan tribes were the first agriculturists to have contact with white settlers.

taken place, accounting for the relatively large proportion of yellow and purple kernels observed in smallholder crops. The Kenya Flat White Complex was adapted locally in Central Province as "Muratha" and in Eastern Province as the "Machakos Local White."

The last distinct type of maize to be introduced to Kenya was a high altitude race, "Cuzco" from Peru (Grobman et al, 1961). It was introduced by missionaries before 1914 and is traditionally known by the Kikuyu as "Githigu." Today, it is the only type found over 2400m ASL in the Central Highlands of Kenya. This variety has shown remarkable resistance to maize streak-virus disease which is common problem in the cool highlands.

2.2 Maize Research

2.2.1 Maize Breeding

The initial hybrid maize breeding effort stemmed from a suggestion in 1909 by an American scientist, G.H. Schull, that sought to exploit the genetic explanation of hybrid vigor (Hallauer and Miranda, 1988). During the period 1910-30 the genetics of hybrid maize breeding were unlocked and a number of synthetic and hybrid varieties developed. By 1950s most of the American Corn Belt was already planted to hybrids (Griliches, 1958).

In Kenya, maize breeding work started at Njoro in 1930, focusing mainly on producing varieties for large-scale settler farmers. The initial effort involved disease screening, inbreeding and hybridization. The program made little progress and was abandoned in 1945. It was resumed in 1948 but the breeding stock and records were destroyed by a fire. However, a more systematic maize improvement program was started at Kitale in 1955 when a full time breeder, Michael Harrison, was appointed to develop late-maturity maize hybrids suitable for the maize-growing regions receiving 750-2000 mm of rainfall annually in 6 to 8 months. From inbred lines of the Kenya Flat White Complex a synthetic variety, Kitale Synthetic II (KS II) was developed and released in 1961. This open pollinated variety gave a seven percent yield advantage over the local maize and was widely adopted by both large- and small-scale farmers. But a narrow genetic base of the Flat White Complex posed a problem to the breeders. To overcome this, accessions from Latin America were imported to provide needed genetic diversity. These introductions formed the foundation of a successful maize improvement program in Kenya. After preliminary screening in a top-crossing block, to KS II as a tester, 124 test crosses were grown in 1961. Most outstanding among them was the cross of KS II and Ecuador 573, an unimproved stock of a high altitude, late-maturing variety fom Ecuador. These two varieties had enough genetic diversity to provide excellent heterosis. The first successful cross, released as Hybrid 611 (H611) in 1964, yielded 40 percent more than KS II (Harrison, 1970). During the same year two other hybrids, H621 and H631, having an average 26 percent yield-advantage over KS II, were released.

Between 1965 and 1989, eleven high-altitude maize hybrids were developed and released to farmers. H625 and H626, released in 1981 and 1989 respectively, were jointly developed by the Kitale program and Kenya Seed Company (KSC). H626 is currently the highest yielding hybrid variety. On average, the late-maturity hybrids out-yielded the local farmers' maize by 30-53 percent (NARC, 1990).

Meanwhile, the Kenya maize improvement program had been expanded to develop varieties suited to different agro-climatic zones, from the semi-arid east and sub-humid coastal belts to the moist highlands and cool, frost-ridden zones above an altitude of 2400 m. Maize research on early-maturity varieties was started at Katumani in 1956 to develop varieties for the semi-arid regions which receive low, erratic rainfall of about 250-400 mm a year falling within 60 days, and barely enough for a successful maize crop. The challenge was to develop drought-resistant/tolerant maize varieties that would withstand long durations of low moisture and still give good yield. The initial breeding effort involved early-maturity "Taboran" from Mexico and Machakos Local White, a derivative of the Kenya Flat White Complex. The results of their crosses led to the development and release of Katumani Composite A (KCA) and Katumani Composite B (KCB) in 1966 and 1968 respectively. These open-pollinated varieties tassled in 55 days and were fairly successful in the semi-arid areas. However, because of their dismal performance in regions where rainfall lasted only two months, a concerted effort was needed to further reduce the flowering and maturity period. The effort paid off in the development of Dryland Composite I (DC I) which was released in 1989. This variety flowers 4 to 7 days earlier and is more reliable in drier conditions than both KCA and KCB. Current programs at Katumani focus on improving existing composites and evaluating new introductions from CIMMYT and IITA. There is, however, great concern on the poor yield performance of the composites, a reason that has made them less attractive to farmers. Part of the reason is that farmers in these regions use little fertilizer or complementary inputs (NDFRC, 1986).

Research on medium-maturity maize was started at the Embu Regional Research Centre in 1965 for regions of the Central Highlands receiving 350-750 mm of rainfall in two distinct seasons and requiring a variety that takes 5 to 6 months to mature. A cross between Kitale late-maturity hybrids and Katumani early-maturity maize led to the release of H511 in 1968, the first medium-maturity hybrid, followed by another medium-maturity variety, H512, in 1970. These varieties had a research yield-advantage of 36 percent over the local maize, "Muratha". H511 and

H512 have been successful in the lower and drier parts of the Central Highlands. In the higher and cooler parts the farmers cultivate local maize types which are more resistant to frost, maize leaf-rust and streak-virus. Current maize programs at Embu focus on improvement of yield and disease-resistance.

Maize improvement for the medium-rainfall, low-altitude tropical region began in 1952 at the Coastal Research Station when short season varieties were screened for resistance against maize leaf-rust (Puccinia Polysora). Ten varieties performed well and were incorporated into a composite, Coast Composite (C.C.), developed from basic material imported from the Latin American lowlands. The C.C. was not widely adopted by farmers because of its low yield and yellow kernels, a characteristic that is not acceptable to the marketing board. Consequently, an ear to row selection program for clearing the yellow-kernel coloring was initiated in 1983. The work was not successful until its sixth cycle in 1987 when the yellow color disappeared. A notable breakthrough by the coastal maize program was the successful development and release of Pwani Hybrid I (PH I), the first hybrid for the Coastal region. PH I, released in 1989, has a 5-15 percent yield advantage over C.C. and matures ten days earlier.

Table 2 presents the remarkable output of the maize improvement program in Kenya since its inception in 1955. Thousands of inbred lines are currently being screened and tested in the maize program; KSC has about 1400 lines on test (Ndegwa, 1990). It is expected that by the year 2000 many more superior varieties will have been released to provide sufficient and suitable choice of maize types to farmers.

Table 2: Kenya: Improved/Hybrid Maize Varieties Developed and Released.

VARIETY	YEAR OF RELEASE	DAYS TO MATURITY	YIELD (t/ha)	GROWING ALTITUDE	DEVELOPED BY
KSII	1961	180-240	3.37	1500-2100	NARC
H611	1964	180-270	4.50	1800-2400	NARC
H621	1964	180-240	4.05	1000-1700	NARC
H631	1964	180-240	4.45	1000-1700	NARC
H622	1965	180-210	5.22	1000-1700	NARC
H632	1965	180-210	4.45	1000-1700	NARC
H612C	1966	180-270	5.88	1200-1800	NARC
H611C	1971	180-240	5.85	1800-2400	NARC
H613C	1972	180-270	5.96	1500-2100	NARC
H614C	1976	180-270	6.30	1500-2100	NARC
H625	1981	180-240	6.75	1500-2100	NARC,KSC
H612D	1986	180-240	6.43	1500-1800	NARC
H613D	1986	180-240	6.03	1500-2100	NARC
H614D	1986	180-240	6.56	1500-2100	NARC
H626	1989	180-240	6.76	1500-2100	NARC,KSC
Kat.SII	1963	90-120	2.00	1000-1700	NDFRC
KCA	1966	90-120	2.25	1000-1700	NDFRC
KCB	1968	90-120	2.80	1000-1700	NDFRC
H511	1968	120-150	3.60	1000-1500	RRC-EMBU
H512	1970	125-155	4.05	1200-1900	RRC-EMBU
DC I	1989	80-110	2.89	1000-1900	NDFRC
CC	1974	120-150	3.30	0-1000	RRC-MTWAPA
PH I	1989	100-130	3.78	0-1300	KSC

Source: Ochieng, (1988); Ndegwa and Ndambuki, 1988.

Key: NDFRC = National Dryland Farming Research Centre, Katumani.
NARC = National Agricultural Research Centre, Kitale.
RRC = Regional Research Centre.
KSC = Kenya Seed Company.

2.2.2 Maize Agronomy

Maize improvement in Kenya is based on plant breeding and complementary research on disease and pest resistance, fertilizer and soil characteristics. An extensive maize agronomy program has been in existence since the breeding program started. Between 1950 and 1960, many uncoordinated trials were carried out and observations made on fertilizers, spacing and other treatments. But this pioneering work came under heavy criticism because most of the limiting factors to yield increases were examined singly or at best in pairs. Also maize varieties with the genetic potential to give full response to improved conditions were not available, planting time of the trials was often late, plant populations were usually low and other cultural conditions were seldomly optimum. Because of these shortcomings, there was confusion over the many factors limiting maize production.

The most notable work on maize agronomy was performed by A.Y. Allan with funds provided by the Rockefeller Foundation and the British Government. Starting in 1963 and working closely with maize breeders at Kitale, Allan developed a systematic agronomy program and evaluated new hybrids from the breeding program over a wide range of agronomic characteristics. He determined six agronomic requirements for the hybrids using 3^3 and 2^6 factorial district maize variety and husbandry trials. His results are shown on Table 3. Each of the six factors considered was included at two levels, a "high" level representing the recommended practice and a "low" level corresponding to the farmer's practice. Time of planting and the genotype were found to be the most

Table 3: Kenya: Effects of Husbandry and Input Use on Maize Yields, 1966-67.

Factor	Treatment	Yields lbs/Acre	Added Return Shillings/Acre[1]	Added Cost Shillings/Acre[2]
Time of planting	Start of rains 4 weeks later	5200 3040	270	Very little
Plants per acre	16,000 8,000	4580 3770	115	8
Type of seed	Hybrid Local	4860 3380	175	12
Amount of weeding	Three times, early Once, late	4640 3600	130	20
Phosphate per acre	50 lb. None	4160 4080	10	32
Nitrogen per acre	70 lb. None	4380 3860	65	72

Source: A. Y. Allan, "District Husbandry Trials in Western Kenya, 1966 and 1967." Quoted in M.N. Harrison, "Maize Improvement in East Africa" in C. L. A. Leakey, Crop Improvement in East Africa, 1970. p. 45.

1 At 1966 price of 25/ -per 200 pound bag.

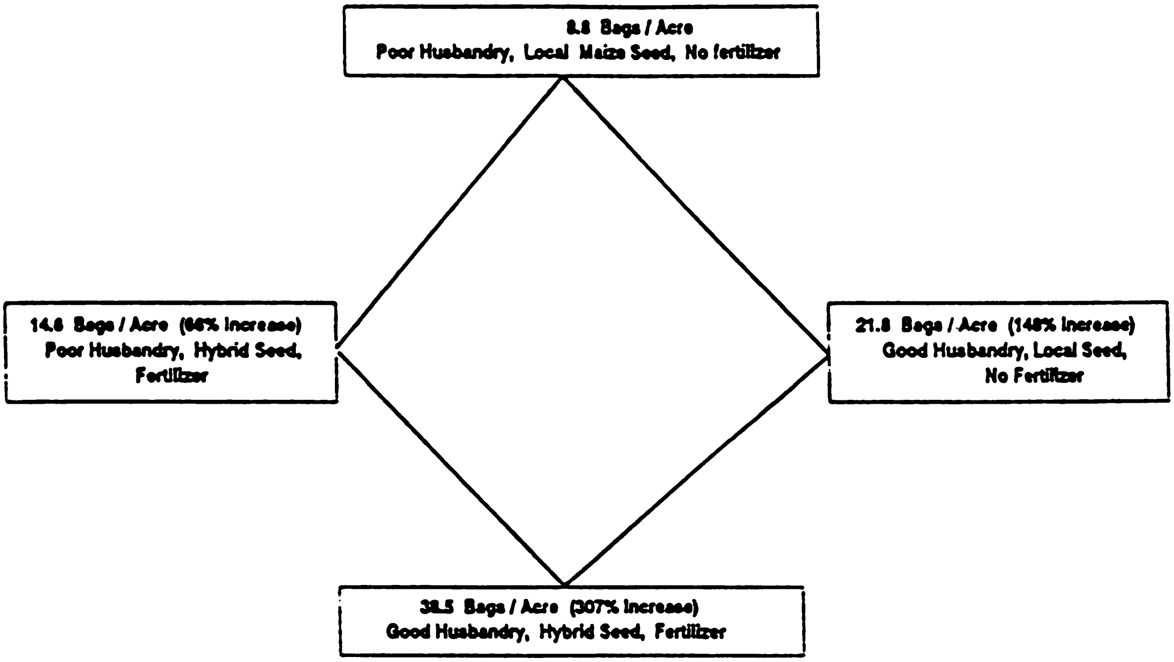
2 Based on costs of inputs required and estimated labor costs.

important factors explaining low farmers' yield, followed by weeding standard and plant population. Fertilizer application was found to be the least important factor influencing yield (Allan, 1971).

Maize researchers at Kitale put the husbandry trials to good use by developing a demonstration "diamond" to serve as a reference for agricultural extension staff. Figure 2 presents the interaction effects of Allan's trials. The interactions between time of planting, plant population and genotype with fertilizer response indicated that apparent uneconomic application of fertilizer is profitable if all the other limiting factors are removed. The lesson of the trials, therefore, was that fertilizer use and hybrid seed are not substitutes for sound farming practices such as timely planting, weeding and appropriate plant population. Thus, it would be unwise to advise farmers, especially poor smallholders, to spend large sums of money on hybrid seed and fertilizer before they can raise their husbandry standards to levels that allow hybrids to express their full yield potential (Harrison, 1970).

Currently, the agronomy program augments breeding research by evaluating the new varieties in different agro-ecological zones, seasons and farmer circumstances. Subsequent agronomic and on-farm research have identified the following factors as influencing maize yields, in order of importance: 1) Land preparation and time of planting; 2) Weed control and plant population; 3) Genotype; 4) Fertilizer; and 5) Pest control and time of harvesting.

Figure 2: Kenya: Maize "Diamond"



Source: Allan (1968)

2.3 Maize Seed Production and Distribution

2.3.1 Seed Development

Today, the production of certified maize seed is accomplished through varietal development, evaluation and release, maintenance multiplication, processing, storage and distribution. The development, evaluation and release of the new seed is the responsibility of the National Maize Programme under KARI. Seed production, processing and distribution is the responsibility of the Kenya Seed Company (KSC) while seed certification and testing are handled by the National Seed Quality Control Services (NSQCS), a designated certifying agency within KARI.

Once a breeder has identified a high performance maize variety in the initial screening trials, it is recommended for inclusion in the National Performance Trials where it is tested for various agronomic characteristics. After three to four seasons in the NPT, the co-ordinator of the trials submits a detailed analysis of the performance data to the National Maize Research Committee which examines the findings and, in turn, submit its recommendations to the National Varietal Release Committee. The latter committee, comprising of participants from KARI, KSC, NSQCS, Universities, extension agents and representative farmers, evaluates the release recommendations and determines whether a variety should be released to farmers.

Usually, a small quantity of breeders' seed is supplied to the KSC from the maize program for multiplication and maintenance. Most certified maize seed is grown through an outgrowers' seed production program by farmers contracted by the KSC. The farmers and farms are selected based on their suitability to basic requirements set by the KSC and NSQCS for seed production. The proximity of the farms to the KSC is important for regular inspection of seed and husbandry practices used by the outgrowers.

2.3.2 Seed Distribution

Prior to 1963, little certified maize seed was available to farmers. Better farmers selected seed from their own crop, processed it on-farm and sold it to other farmers, retaining a portion for the following season. The sale of seed was mainly on a farm-to-farm basis with little or no control by any authority. KSC was formed by large-scale farmers in 1956 in Trans-Nzoia, mainly to multiply improved pasture seed. As a result of a reduction in the demand for pasture seed, KSC almost collapsed in 1961. The National Maize Programme came to its rescue by proposing that it undertake the production of seed for maize varieties released by Kitale. In 1963 KSC entered into an agreement with the Kenyan government to produce and distribute improved maize seed.

Since the KSC was initially geared to serve only large scale farmers in the highlands, its distribution network was limited to terminals at the main centres along the railway line. To respond to the growing demand for improved maize seed, the KSC initiated a seed growing programme and expanded its distribution network by recruiting seed stockists in almost every trading centre. From 104 in 1966, the number of seed stockists increased to 2541 in 1976 and an estimated 6000 by 1980, approximately one for every eighty hectares of improved maize planted. This rapid expansion of coverage followed the existing road network. Although some disparity in the stockists distribution between districts was noted, there was a general improvement in the availability of seed to small-scale farmers (Rundquist, 1989).

Figure 3 shows the rapid increase in hybrid seed sales by the KSC over a period of 26 years. Starting with a mere 4 metric tons (t) in 1962/63, the company's maize seed output increased to 10,600 t in 1975/76 and 21,800 t in 1987/88. This indicates a rapid adoption of the improved seed.[2] Table 4 shows the area planted to improved seed by small- and large-scale farmers.[3] The figures reveal that the greatest increase in area planted to improved and hybrid varieties was due to adoption of hybrid seed by small-scale farmers. Currently, the KSC produces about ten different hybrids and two open-pollinated varieties suitable for four agroclimatic areas of Kenya. In 1984, the company also produced seven new experimental hybrids (Ndegwa et al, 1985). In essence, the KSC and KARI researchers at Kitale, Katumani, Embu and Mtwapa are close partners in the quest for excellence in maize seed production.

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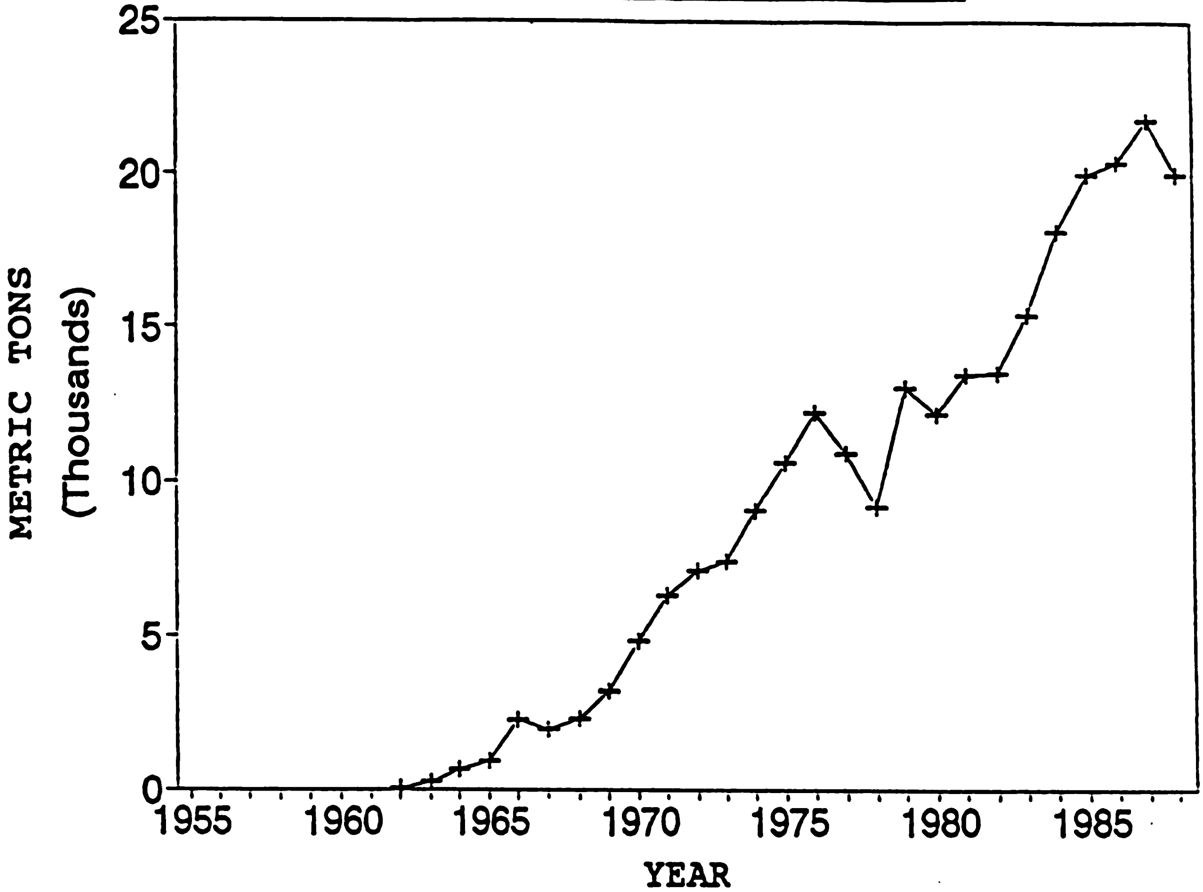
[2]See Figure 5 in the Appendix A.

[3] The area is estimated from a recommended seed rate of 22.45Kg/Ha and assuming no loss of seed at planting.

Figure 3: Kenya: Hybrid Seed Sales



Source: KSC. Unpublished data.

Table 4: Kenya: Area Under Improved Maize Seed, 1967-75.

Year	Small-scale Farms	Large-scale Farms	Total Area
	(Area in Hectares)		
1967/68	51320	36516	87836
1968/69	64333	39516	103849
1969/70	96971	45915	142886
1970/71	149971	63811	213782
1971/72	206947	73975	280922
1972/73	264871	53392	318263
1973/74	292501	39232	331733
1974/75	352276	50717	402993
1975/76	421553	50607	472160

Source: KSC. Unpublished data.

2.4 Maize Production and Consumption

Maize is considered the national food staple because it accounts for over 50 percent of both calories and protein intake and is a major source of fats (ISNAR, 1985b). In Kenya maize can be consumed as: (1) roasted or boiled grain on cob, a favorite snack; (2) whole grain meal, boiled in mixture with beans or peas to make a popular meal called "Githeri"; (3) ground maize flour which is boiled in water to make another popular meal called "Ugali", a thick semi-solid mass, or a thin porridge, "Uji"; and (5) an alcoholic drink brewed from a fermented mixture of maize and sorghum or millet in water. A survey of 349 families in Nairobi in 1958 revealed that maize accounted for 80 percent of starchy-staple calories while data from a 1969-70 Nairobi Urban Survey indicated maize as the cheapest source of calories and was second only to cowpeas as a source of inexpensive protein (Miracle, 1966; Gerhart, 1975).

About 90 percent of smallholders account for 80 percent of the total maize area and produce between 70 and 90 percent of the total annual maize production (Ruigu, 1985; Ackello-Ogutu and Odhiambo, 1986; Odhiambo, 1988). These smallholders consume most of their maize on the farm, selling only 22 percent to the market compared to their large-scale counterparts who market 75 percent (Paliwal et al, 1984). Table 5 presents a summary of estimates of maize output, area and yield in Kenya for the period 1955-88. Figures 4(a), 4(b) and 4(c) in Appendix A show the trends of maize area, yield and production, respectively.

Table 5: Kenya: National Maize Production, Yield and Area, 1955-88.

YEAR	OUTPUT (t)	YIELD (t/ha)	AREA (ha)	IMPROVED/HYBRID MAIZE AREA(ha)[a]	% OF TOTAL
1955-59	542224	0.868	625240	-	-
1960-64	805650	1.058	760900	13623	1.79
1965-69	1089678	1.292	843195	95487	11.32
1970-74	1344400	1.510	891078	309378	34.72
1975-79	1772000	1.562	1143817	498989	43.62
1980-84	1936880	1.622	1204823	648855	53.85
1985-88	2670400	1.845	1445085	917576	63.50

SOURCE: Kenya colony, Crop Production Review. Various issues.
Kenya, MOA/DPD. Various Reports.
FAO Production Yearbook, various issues.
[a] Estimated from the recommended seed rate of 22.45kg/ha.

During the decade from 1955-1964 maize production and area increased steadily while average national maize yield remained relatively constant. The total maize area averaged 684,000 ha, increasing from about 509,000 ha in 1955 to 830,000 ha in 1964, the time of the first hybrid release. This increase in area was largely attributed to increased accessibility of agricultural land to the local people and greater incentives to farmers following the initiation of the Swynnerton Plan in the mid-1950s (Ruthenberg, 1969).

From 1965-1974 seven hybrids and three composite varieties were released from the maize program. The average yield increased from 0.937 t/ha in 1955-64 to 1.401 t/ha in 1965-74, an increase of about 49 percent. In the same period, maize area increased by 27 percent. These area and yield effects led to an 83 percent increase in total maize output. Between 1975 and 1989, seven more hybrids and one composite were made available to farmers; the average yield improved by about 19 percent during this period accompanied by an area and output increase of 44 and 72 percent respectively. The area planted to improved maize seed increased from an average 1.8 percent in 1962-64 to an average 63.5 percent in 1985-88. This compares to an increase in hybrid maize coverage in the US Corn Belt from 0.2 to 90 percent in about the same number of years, from 1933-58 (Jugenheimer, 1958). In summary, the national average maize yield increased from 0.87 t/ha in 1955-59 to 1.85 t/ha in 1985-88; the area more than doubled, from 625,000 ha to 144,500 ha; and output increased fivefold, from 540,000 t to 2,670,000 t during the same period.

Disaggregation of maize yield, area and output by high- and marginal-potential regions revealed that between 1955-88: 1) a larger proportion of maize area was in the marginal-potential (M-P) maize-growing region; 2) farmers in the M-P region achieved lower maize yield than those in the high-potential (H-P) maize region; and 3) the rate of growth of maize yield in the M-P region was slower than that in the H-P region.[4] Four reasons account for these trends. First, maize varieties for the H-P areas are higher-yielding than those available for the M-P areas. Second, the climate of the H-P region is more favorable for maize

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[4] High-Potential regions represent maize-growing in the highlands traditionally occupied by settler farmers. Marginal-Potential regions refer to maize-growing area in the medium- and low-potential zones which are largely occupied by smallholders.

production, allowing greater exploitation of the genotype, than that of the M-P region. Third, farmers in the H-P region adopted maize technologies relatively faster than the farmers in the M-P region (Ongaro, 1988). Finally, a greater proportion of agricultural land is in the M-P regions. The trend indicates that maize area, yield and output increased in both the H-P and M-P regions between 1955-88. Area increases in the H-P region are attributed to a shift from pasture to maize cultivation by large-scale farmers and the sub-division of formerly large wheat farms into smallholder farms where mixed-farming is pursued. In essence, large wheat farms have been transformed into maize farms (NPBS, 1987). On the other hand, the increase in area in the M-P regions was largely due to an increase in cultivated land.

But the percentage changes in maize area, yield and output reveal a slowing of maize production increases. Yield increased by about 49 percent between 1955-59 and 1965-69, but only by 18 percent between 1975-79 and 1985-88; area increases slowed from 35 to 26 percent for the same periods. Efforts are required to increase maize production and sustain the increases in the wake of rising food demand in Kenya. Various medium term options have been suggested, such as increased adoption of existing maize technologies, and appropriate pricing, marketing and credit incentives. In the long term, improved technologies to enhance land and labour productivity in maize production, especially among the smallholders, are required.

Previous research identified the time of planting followed by genotype as the most important factors affecting maize yield (Allan, 1969,1980; Ngugi, 1982). Based on Allan's work at Kitale, the KSC estimated, as a rule of thumb, that there is a loss of 90 kg/ha per day for maize planted late, so that with approximately one million hectares of maize planted 10 days late on average, the loss from planting is approximately 900,000 t of maize per year (Schluter, 1984), about 30 percent of the average national maize output. Late planting is often caused by delays in payments to farmers for the previous year's crop delivery to the NCPB, credit disbursement and input delivery. In many countries it has been shown that maize output can be increased through the adoption of hybrid seed and complementary inputs such as fertilizer. But on-farm research in Kenya reveals low input-use on maize among smallholders, especially in marginal areas (NPBRC, 1987). Ackello-Ogutu and Odhiambo (1986) reported that between 1969-85, phosphorus and nitrogen application on maize in Kenya increased by one and four percent per year respectively, and that an increase in fertilizer expenditure by 10 percent led to a 15 percent increase in maize output between 1976-1978.

Gerhart noted that despite the fact that "both large- and small-scale farmers in the high rainfall portions of western Kenya adopted hybrid maize at a rate faster than American farmers in Iowa in the 1920s and 1930s" (1975, p.26), there were differences in adoption rates between small- and large-scale farmers, and between agro-ecological zones. Table 6 shows the adoption of hybrid maize technology in western Kenya by farm size and agro-ecological zones. The results indicate that large farms consistently led small farms in adopting maize technologies except insecticides in zone 3. Bridging the gap in maize technology adoption between the two farm categories and between different agro-climatic zones will increase maize production. The World Bank (1984) contends that maize production in Kenya could increase by up to 70 percent if the current maize technology is improved and that, in many cases, smallholder yield could be doubled through the expanded use of improved inputs and husbandry. But intensification of maize production will require a concerted effort of agricultural support services, particularlly extension and credit, and improvement of policies to stimulate production. Table 7 shows the response of some farmers in western Kenya who had not planted hybrid seed in 1973. All the farmers interviewed in Zones 1 and 2 gave "cost" as the only reason for non-adoption while in Zone 3 identified "cost" as the major constraint. Even today, the cost of hybrid seed and fertilizer make up a large share of a smallholder's farm-inputs budget and constantly feature as a constraint to adoption of improved maize technology.

Table 6: Western Kenya: Percentage Adoption of Hybrid Maize Technology By Farm Size, 1973.

	Zone 1	Zone 2	Zone 3
1. HYBRID MAIZE:			
Small	95.7	83.7	14.9
Large	95.8	95.1	17.4
2. FERTILIZER:			
Small	47.8	71.4	2.1
Large	75.0	92.5	6.4
3. INSECTICIDES:			
Small	2.2	21.3	7.1
Large	10.6	43.9	2.2

Source: Gerhart, 1975, p. 24.

Table 7: Western Kenya: Responses of Non-Hybrid Adopters, 1973.

	(Percentage)		
	Zone 1	Zone 2	Zone 3
No. of responses	9	14	102
1. Cost: Too expensive/No money.	100	100	52
2. Not available/Distance to stocklist/ Must buy every year.	0	0	6
3. Never heard of it/ Does not know how to use it/No experience with it.	0	0	14
4. Performance: Yields less/Less Certain/ Does not do well.	0	0	20
5. Congruence: Too much work/Planted late/Misc.	0	0	7

Source: Gerhart, 1975, p. 23.
Note: Total responses exceed the number of non-adopters since some farmers gave more than one answer.

2.5 Maize Marketing

Maize marketing is controlled by the Government through the operation of a parastatal marketing board, the National Cereals and Produce Board (NCPB), established in July 1979 as a result of a merger of the former Maize and Produce Board and the Wheat Board of Kenya. NCPB handles the purchase, storage and distribution of all major food grains throughout the country. Maize is its most important commodity.

A dual marketing structure was developed for maize as a result of pre-independence policy and practice. Under colonial rule, African producers had no access to a marketing board, thus, forcing them to create a parallel or informal market. Most smallholders sell their maize in the parallel market. Because of the small size and dispersion of such maize sales, small traders tend to be more efficient and cost effective in handling smallholder sales than NCPB, whose activities are largely concentrated in maize-surplus, large farm areas (World Bank, 1986). The NCPB controls the official marketing channel.

For most of the period after independence, the grain marketing board has had instructions to purchase all the marketed maize that is not sold directly from a producer to a consumer at a controlled price, and to sell the maize at a higher, also controlled, price. The official producer price is announced each year before planting and is not expected, by law, to fluctuate through the year. But, in reality, both producers and consumers have faced large price fluctuations because of an increasing dependency of both groups on the parallel market, especially when surpluses have exceeded NCPB's storage capacity

(Pinckney, 1988). This often results in maize flooding the parallel market and depressing prices.

The Sixth National Development Plan outlines the intentions of the government to reduce the mandate of the NCPB to a custodian of a proposed national strategic food reserve and a buyer of the last resort. Under this plan, NCPB would leave up to 75 percent of maize marketing to private traders, millers and farmer co-operative societies. This reform will be accompanied by the removal of the inter-district maize movement restriction imposed to reduce consumer price parity between maize-surplus and maize-deficient regions (Kenya, 1988). These changes are expected to take place during the current five-year development period. Meanwhile, the government is taking steps to reorganise and prepare NCPB for its new role and to improve the existing market infrastructure. Already, studies have been undertaken to work out a reform program for NCPB in the field of general management, rationalizing of buying centres, financial restructuring and monitoring of market conditions (Odhiambo and Wilcock, 1989). This restructuring will, however, require substantial financial costs because the NCPB has incurred huge financial losses in the past.

Kenya urgently requires more grain storage capacity. The current NCPB's storage capacity is 896,000 tons. This is supplemented by a 886,000-ton capacity provided by the private sector. Maize occupies 84 percent of the total storage capacity. However, it is estimated that a capacity of 1,346,000 tons is needed for maize. Because of poor on-farm storage conditions and inadequate NCPB storage capacity, a considerable amount of grain is lost. Most NCPB's buying centres have no storage facilities. During peak buying periods, bags of grain from farmers are piled up or stacked on the yards of buying centres until trucks are available to transport them to depots. If transport is delayed and rainfall comes, the grain losses are considerable. The construction of additional storage facilities is underway. And when it is completed, the storage capacity is envisaged to increase from 40 to 70 percent of the total marketable maize production (Kenya, 1984).

Table 9 in Appendix A presents the amount of maize purchased by NCPB by province from 1966/67 to 1988/89. The data show an increasing trend in maize purchases from about 225,000 t in 1966/67 to about 570,000 t in 1976/77 and 833,700 t in 1985/86. Large fluctuations in the amount of purchased maize exist by province and year. These fluctuations are attributed to fluctuations in maize production and NCPB's purchasing ability. Rift Valley and Western Provinces combined account for about 70 percent of the total maize sales to NCPB. Future projections indicate increases in marketable maize production and hence the need for storage expansion.

2.6 Financing Maize Research

The 4th National Development Plan (1979-83) identified the need for a substantial increase in resources to agricultural research to overcome technological constraints on agricultural production (Kenya, 1979). A target level of two percent of Kenya's agricultural GDP has been suggested as an appropriate level of funding for research (ISNAR, 1985a). Funding for agricultural research in Kenya is provided almost entirely by the public sector through the Ministry of Research, Science and Technology (MRST). Until 1987/88, funds were channelled through the Ministry of Agricultural and Livestock Development (MALD), except in 1982/83 when MRST provided the appropriation for KARI. Kenya's research also benefits from donations by external governments and agencies. Besides KARI and independent institutions such as the Coffee Research Foundation, Tea Research Foundation and the National Irrigation Board, agricultural research is carried out by universities (Nairobi, Moi and Egerton) and several international research centres and regional programs based in Kenya. Private sector involvement in agricultural research has been minimal, mainly adaptive in nature and the results are seldomly made public.[5]

In a survey carried out in 1985/86 on private sector research and resource allocation, it was found that 69 out of 364 responding firms were undertaking some research and development (R & D) work

[5] Examples of private firms engaged in agricultural research include East African Industries (Oilcrops), Kenya Breweries Ltd. (Barley), British Tobacco Company (Tobacco), Kenya Canners Ltd. (Pineapples), East African Tanning Company (Wattle) and Wellcome Kenya Ltd. (Livestock Drugs). Several of these work very closely with the public research network.

(Makau, 1988). These firms spent a total of Kenyan pounds (K £) 2.38 million on R & D in 1985/86, averaging about K £ 34,500 per firm. By comparison, the public sector spent K £ 25.06 million on R & D at an average of K £ 1.14 million per institution.[6] Therefore, the country spent nearly K £ 27.5 million on R & D in 1985-86, of which only 8.7 percent came from the private sector. The total national expenditure on R & D was only 0.51 percent of the national GDP. Table 8 shows the distribution of research expenditure by the private sector.

Table 8: Kenya: Distribution of Research Expenditure by the Private Sector, 1985-86.

Science Group	Number of Establishments	Total Expenditure (K £)	Average Expenditure (K £)
Agricultural	17	1,000,000	58,824
Medical	4	802,250	20,063
Industrial	44	1,273,750	28,950
Natural & Physical	2	18,750	9,375
Social	2	5,250	2,625

Source: Makau, B.F. (1988). p.7.

The level of gross recurrent and development budget funding to the Ministry of Agriculture (MOA) increased considerably between 1955 and 1988. In real terms, the recurrent expenditure increased from an average of K£ 4.066 million per year in 1955-59 to K£ 12.242 million per year between 1985-88 while the development expenditure rose from K£

[6]Excludes salaries of teaching staff at the national universities.

5.018 million to K£ 16.279 million over the same periods. Thus, the total agriculture expenditure increased from an average K£ 9.8 million per year for the period 1955-59 to about K£ 28.5 million per year in 1985-88 in real terms. This represents a threefold increase in real terms; in nominal terms, the total agricultural expenditure was increased by over twenty times between 1955 and 1988. Figure 6 in Appendix A shows the trend of the MOA expenditure in nominal and real terms.

The government's expenditure on crop improvement averaged 43 percent of the total agriculture budget between 1955 and 1988. Whereas the crop development expenditure rose, in real terms, from K£ 4.29 million per year between 1955-59 to nearly K£ 12 million per year in 1985-88, the crop research allocation increased only from K£ 1.03 million to about K£ 1.2 million annually in the same periods. Estimated maize research expenditures increased in real terms by about 182 percent between 1955-59 and 1974-79, and then declined by 55 percent between 1974-79 and 1985-88.[7] The decline in budget-funding in real terms constrained the maize research program from the late 1970s until 1987-88 fiscal year when KARI received aid from several donors.

Meanwhile, there has been a continuous build up of resources, facilities and manpower in Kenya's agricultural research system, making it one of the largest research establishment in Africa. Kenya is second to Nigeria in per capita research expenditure. The number of Kenyan agricultural researchers increased from 18 in 1963 to 566 in 1982.

[7]Figure 7 in Appendix A compares the estimated maize research and extension expenditures in real terms.

During the period, the proportion of expatriates in the research institution dropped from 86.9 percent to 11.3 percent (Jamieson, 1981; ISNAR, 1981,1985a). A review of Kenya's agricultural research system indicates that there were 504 Kenyan agricultural researchers (275 Bsc., 212 Msc., and 17 Phd.) in 1986 (ISNAR, 1990). In 1980, Kenya had a larger number of agricultural research scientists per million people (24.3) than Sub-Saharan Africa (15.1), Asia (15.2) and Latin America (22.7) (Oram and Bindlish, 1981).

Agricultural research receives 70 percent of Kenya's national government budget for research, reflecting the importance and dominant role of agriculture in the economy (Ruigu, 1985). Research on the traditional export crops, coffee and tea, receives about 32 percent of the total agricultural research funding as compared to 25 and 23 percent for food crops and livestock research respectively. In 1979/80, tea and coffee received nearly one-third of the allocation while livestock research got about one-fifth (ISNAR, 1985b).

The allocation of research funds varies by region. In 1983/84, more than 90 percent of funds and scientific manpower were concentrated on high- and medium-potential areas. But in recent years there has been greater effort by the government to shift resources to medium-potential regions as they become increasingly important sources of agricultural growth following rapid population growth and migration. Jamieson(1981) studied resource allocation in agricultural research during the first fifteen years of independence and found that: (1) the government played an important and direct role in agricultural research through the former Scientific Research Division (SRD); (2) research was predominantly applied in nature; (3) a greater amount of research effort was spent on biological and chemical research rather than mechanical, other applied or basic research; (4) nearly all the research was directed at the needs and problems of large-scale, high-income farmers but it was mostly scale-neutral; (5) the largest proportion of the resources was allocated to livestock followed by cash-crops, food-crops, pasture and fodder crops; (6) coffee, maize, wheat and tea received the largest allocation of crop research in that order; (7) relatively more research was done on medium-potential than high- or low-potential areas, with low-potential zones receiving the least attention; and (8) most research focussed on increasing the yield level rather than increasing the reliability of yield or improvement of crop storage. The study also found that the resource allocation process was influenced by the availability of farm inputs whereas changes in the relative product prices or levels of output seemed to have little impact. Lastly, the allocation process was found to be only slightly responsive to economic, social and political inducements for change, and the political and institutional factors retarded changes in the orientation of research policy.

Several studies have identified the following constraints to Kenya's agricultural research: 1) a persistently high turnover of trained and experienced scientists; 2) lack of adequate manpower and/or research-oriented training; 3) inadequate and erratic budget funding for research; and 4) a growing deterioration of research infrastructure. Unless these problems are offset, they could seriously reduce the capacity of KARI to generate agricultural technologies needed for agricultural and economic growth (ISNAR, 1981, 1990).

3. CHAPTER THREE

RATE OF RETURN: LITERATURE REVIEW

3.1 Technical Innovation and Resource Productivity

"The capacity to develop and to manage technology in a manner consistent with a nation's physical and cultural endowments is the single most important variable accounting for differences in agricultural productivity among nations" (Ruttan, 1982, p.17). Exploitating such capacity generates appropriate technologies which facilitate the substitution of inexpensive, abundant resources for scarce and expensive resources, thus releasing constraints to agricultural growth imposed by inelastic supply of resources. The resulting benefits accrue to consumers from increases in productivity and supplies of agricultural goods at relatively lower prices while producers experience lower production costs as efficiency is enhanced by the new technologies. For these reasons, it has become widely accepted that agricultural research is an important means of raising agricultural productivity.

Investments in research are usually costly and in most cases the results are not immediate. This raises the issue of how scarce research resources should be allocated among alternative uses. Rationally, such resources should be allocated to those investments that ensure a high rate of return. Moreover, pressure on public and private investments in agricultural research has heightened the need to justify such investments vis a vis alternative public investments such as extension, irrigation and non-agricultural investments. Tighter research budgets make it important for national agricultural research systems (NARS) to improve their priority-setting and resource allocation among competing research programs.

Most NARS managers make allocative decisions based on their past experience, an understanding of research goals and objectives, research problems and a sense of what is achievable through research. Then allocative decisions are made on priority commodity research programs, regions, factors of production, long-term versus short-term, basic versus applied research, and the distributional effects of research (Norton and Pardey, 1987). In Kenya, resource allocation decisions are heavily influenced by the previous year's budget. Changes in research programs and budgets often results from requests by scientists, which are evaluated relatively informally and aggregated into an overall plan, and from the introduction of donor-assisted research projects.

Resource allocation decisions based on past experience are important. In addition, increased use of analytical techniques may be neccessary to improve priority-setting procedure for NARS decision-makers and aid funding decisions. Such techniques can minimize large and costly changes in research priorities, especially in systems characterized by rapid turnover of research administrators (Schuh and Tollini, 1979). There is a great need to improve the relevance and productivity of agricultural research by focusing on priority research and adopting appropriate funding decisions.

3.2 Measurement of Research Productivity

Numerous studies have been carried out to assess the impact of research on agricultural productivity growth, particularly in the US, Asia and Latin America. Table 10 in Appendix B presents a summary of the results of these studies. Almost all of the studies indicated a high rate of return to investment in agricultural research. Empirical studies of social profitability in national agricultural research, particularly in developing countries, have also shown consistently significant productivity growth as a result of these kinds of investments (Ruttan, 1982).

There are several methodologies for assessment of the contributions of research to agricultural growth. They can be grouped into two major categories: ex post and ex ante approaches. The ex post approach has been used to determine the past impact of investments in research while the ex ante approach has been a useful guide to future allocation of research resources in order to maximize their social return. These methods help to evaluate research proposals and programs with respect to their funding requirements in order to establish priorities and justify budget requests.

The procedures used to make ex post evaluations can be grouped into five different approaches: 1) the inputs-saved approach; 2) the impact on national economy; 3) the production function approach; 4) the economic surplus approach; and 5) the nutritional impact approach (Schuh and Tollini, 1979). The inputs-saved approach attempts to estimate the resources saved by the adoption of a new technology. The benefits of research are estimated as the resources saved when a new technology is used to produce an output compared to a base period production technology. The costs are computed from publicly- and privately-financed research and extension expenditures. A benefit-cost ratio or rate of return can then be computed from the data. Schultz (1953) used this method in what is believed to be the first attempt to quantify the returns to investment in U.S. agriculture. He approximated social benefits by comparing the costs of producing 1950 outputs using 1910 technologies with the actual cost of producing the 1950 outputs. He was interested in the whole sector and, thus, he made no attempt to consider individual research programs or particular innovations. This approach could be extended to individual research programs or to narrowly defined technological innovations, especially those that are more resource-saving than output-increasing. The procedure requires only modest data but provides a crude estimation of the social benefits.

The impact-on-national-income approach is almost similar to (1) and it provides a crude estimation of agricultural productivity by considering the benefits of a new innovation as the resources it releases to the non-farm sector. Tweeten and Hines (1965) calculated how much lower the national income would have been if the farm population never changed and the additional farmers had the income of today's farmers rather than today's non-farmers. This provided a crude measure of benefits from technical change as a results of farmers adopting new production technologies. The costs of public and private research, education and federal support programs were estimated and used to compute a benefit/cost ratio.

The production function methodology involves the estimation of input-output relationships for a commodity or sector. Griliches (1958), Peterson (1967) and Evenson (1967) used this approach in the analysis of hybrid corn, poultry and U.S. agricultural research productivity respectively. Evenson (1967) estimated the rate of return (ROR) to research from 1949-59 to be 47 percent. Griliches (1964) had estimated 35-40 percent ROR to aggregate U.S. agricutural research for the same time period; education of the farm labour force was also found to be a significant variable in explaining increased agricultural productivity.

The production function approach involves aggregating various outputs from the same commodity, using e.g. price weights, and inputs (such as agricultural research, extension, etc.), and estimating the contribution of each input to changes in output. One advantage of this method is that marginal productivity of an input can be calculated. Regression analysis is used to aportion the increase in productivity to the various farm and non-farm inputs, and to test statistically the impacts. Thus, the benefits of research can be imputed to particular research programs, forming a basis for resource allocation. Brendahl and Peterson (1976) estimated the marginal rate of return to investments in research on cash grains, poultry, dairy and livestock by state for the U.S., thereby providing a guide to allocation of research resources among the commodities and geographic areas. Evenson and Kislev (1975) separated research into indigenous research and research done in other countries. Using cross-country data on maize and wheat, they determined the contribution of each type of research to improvements in yields. Evenson and Binswanger (1979) used publications as a proxy of research output and, after separating research into scientific and applied research, they calculated the impact of research on cereal grain production across countries in nine major geoclimatic zones and forty five regions in the world. Their results reported a strong complementarity between the two types of research. The study determined the contribution of regional and zonal research to country production. Later, Evenson, Flores and Hayami (1976) also used a basic production function approach to assess the difference in technology transfer between an international and a national research program on rice.

The third method of estimating research productivity is the economic surplus approach. This method measures the benefits and losses from the adoption of a new technology by assessing its impact on producers and consumers. The new technology is assumed to shift the supply curve to the right and create benefits to consumers through an increased supply of product at reduced prices; producers benefit from reduced unit production costs. This method is flexible and can be modified to assess the distributional impact of price and trade policies of different structure of the economy (open or closed), among other things. Akino and Hayami (1975) used this approach to estimate the distribution of returns to investment in Japan's rice breeding program among producers and consumers in different economic scenerios. Evenson et al (1976) evaluated the distribution of benefits from rice research in Phillipines, while Echeverria (1990) studied the benefits of generation and transfer of technology for rice in Uruguay. Griliches (1958) study of the benefits of hybrid corn in the U.S. and the range of examples cited here indicate the potential of using the economic surplus model in different problem settings.

Although the economic surplus approach does identify the contribution of research to an overall increase in productivity, the specification of an appropriate supply curve and supply-curve shift are crucial to the results. Misspecification of the supply shift can lead to inaccurate quantification of research benefits and their distribution to producers and consumers (Daniels et al, 1990). Several studies have focused on the effects of inappropriate supply function formulation. Lindner and Jarrett (1978) used an alternative formula for measuring social surplus in corn production and found that Griliches (1958) had overestimated the ROR to hybrid corn research by at least 50 to 100 percent. Similar comparisons with Petersons'(1967) study revealed that he had overestimated social surplus by more than 150 percent.

Some studies have evaluated the effects of policy interventions on research productivity measurement. Oehmke (1988) found a divergence of up to 100 percent in the rate of return (ROR) by comparing benefits without intervention with benefits which account for market and government budget effects. Alston et al (1988) examined the effects of production quotas, subsidies and target prices on the benefits from research to producers, consumers and the government. They concluded that government intervention modified the pattern of distribution of benefits from research relative to free-trade and, therefore, proposed that such interventions should be accounted for in ROR measurements.

The nutritional impact approach does not in itself provide a rate of return estimate but instead provides valuable information in establishing research priority when improved nutrition is the research goal. Pinstrup-Andersen, Londono and Hoover (1976) developed a such a procedure to estimate the distribution of supply increases among consumer groups, the related adjustment in total food consumption and implications of these to calorific and protein nutrition. This procedure derived the impact of increases in agricultural output on nutrition, by income groups, and equity.

In addition to these five ex post evaluation procedures, there are several ex ante procedures that are used to improve the decision-making process in research resource allocation. The models range from approaches which provide a systematic means of utilizing informed judgement to approaches which attempt to provide empirical knowledge on the consequences of alternative causes of action. These models can be classified on the basis of time-frame (i.e. static or dynamic), degree of uncertainty (i.e. deterministic or probabilistic) and by the "environment" of the decision-maker (one-, two- or n-decision-makers). In turn, the degree of complexity of the models will depend on 1) the scope of the agenda; 2) the set of control variables; and 3) the degree of programming required.

The degree of methodological sophistication of ex ante models ranges from the simpler scoring models to more complex mathematical programming and simulation models. Scoring models utilize weighted multiple criteria for ranking priorities. A panel of specialists evaluate and rank various research programs using a predetermined set of criteria. The programs are then funded according to their ranks until the budget is exhausted. This procedure is commonly used to allocate limited research funds to research projects in the order of their priorities. Other _ex ante_ models that have been used in priority-setting include: Minnesota Model, Pinstrup-Andersen and Franklin Model, Cartwright Model, Castro and Schuh Model, Easter and Norton Model and Atkinson-Bobis Model.[8] In addition, benefit-cost analysis has been used in various forms to select research priorities; Araji _et al_ (1978), Fishel (1971), Davis _et al_ (1986) and Norton _et al_ (1987) present examples. Most _ex ante_ analyses employ the economic-surplus concept and incorporate expert opinion to determine projected research impacts, adoption rates and probabilities of success and provide estimates of the economic efficiency and distributional implications of agricultural research resource allocation.

Mathematical programming models rely on mathematical optimization to choose a research portfolio through maximizing a multiple-goal objective function, given the research resource constraints. This procedure may require more detailed information than the weighted-criteria method, and usually selects an "optimal" research option rather than simply ranking them. Russell (1969) used this method to maximize the contributions of a research program in the United Kingdom to several goals, given budget and human resource constraints, and different policy scenerios. Simulation models vary in their construction and require extensive amounts of data and estimation of mathematical relationships. Pinstrup-Andersen and Franklin (1977) provides an example of the use of a simulation model as an appoach to agricultural research resource allocation in developing countries.

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[8] See Schuh and Tollini (1979) for a discussion of these models.

The advantage of <u>ex ante</u> models compared to <u>ex post</u> is that they provide a basis for decision-making with a focus on the future rather than in the past. Hence, they provide a means of relating research efforts explicitly to a set of goals. The disadvantage is that they are based more on predictions about the future, can be both time-consuming and costly, and rely on subjective judgement.

3.3 Rate of Return Studies in Africa

Various studies in developed countries, Latin America and Asia have indicated high rate of return to investment in agricultural research. Many feasibility teams have drawn on these studies to justify projects for donor assistance to NARS in Africa. But there is a need for caution in interpreting these studies because most agricultural institutions, including NARS, in Africa are at a relatively early stage of institutional development (Eicher, 1990). There is now growing evidence that a combination of misplaced and inappropriate projects, weak management and financial accountability, and shifts of the research agenda have resulted in a poor performance by the African NARS.

Surprisingly, only four published studies on the payoff to investments in agriculture have been documented for Africa: Norgaard (1988), Abidogun (1982), Evenson (1987) and Schwartz et al (1989). By contrast there are at least 25 for Asia and 60 for Latin America. Schwartz et al (1989) estimated an average ROR of 60-80 percent to the combined research and promotion programs for cowpea in Senegal. Noorgard (1988) estimated the benefits and costs of research on biological control of cassava mealybug in Ghana, deriving a benefit-cost ratio of 149:1 for the program. The average rate of return to four cotton development projects in Burkina Faso, Cote d'Ivoire and Togo were estimated at were 31, 37, 11 and 41 percent (Daniels et al, 1990).

Evenson (1987) used data from 24 countries in Africa, Asia and Latin America to estimate the ROR to national research investments by region and commodity groups. The ROR ranged from 30-40 percent for maize and staple crops in Africa and maize in Latin America, to 60-70 percent for maize and cereals in Latin America, cereals in Asia and staple crops in Asia. He also studied the effects of research and extension investments on productivity of various commodities in West and East/Southern Africa. He found that national research investments had significant production impacts on wheat, rice, cotton, sugar, cassava, irish and sweet potatoes; East/Southern Africa showed larger wheat, maize and groundnuts impacts than West Africa, but lower impacts for potatoes, cotton, sugar, cassava, soybeans, beans and rice; the International Agricultural Research Centre's (IARC) investments had an impact on wheat, irish and sweet potatoes production in West and East/Southern Africa, beans in East/Southern Africa and rice in West Africa; and impacts of national research and, to a lesser extent, IARC research on productivity are lower in West Africa than in other developing countries, suggesting that many of the smaller NARS such as those found in West Africa have little or no impact on productivity.

Studies using a descriptive non-ROR approach to assess the impact of agricultural research include an evaluation of the impact of the thirteen Consultative Group of International Agricultural Research (CGIAR) centres on world agriculture (Anderson, Herdt and Scobie, 1988). The authors found that the CG-centres have had a large impact on NARS through wheat and rice research but less impact in maize research. An evaluation of USAID involvement in Kenyan maize research (Johnson et al, 1979) indicated that great success is possible when public and private sectors cooperate in technology development and diffusion. Research funded by the government of Kenya, USAID and other donors led to the development of a high-yielding hybrid maize -H611- in 1964 which had a yield advantage of 40 percent over the local synthetic. Subsequent breeding generated sixteen hybrids and three composites for almost all maize-growing regions of Kenya. Hybrid maize research in Zimbabwe began in 1932 and took seventeen years to release its first hybrid, SR-1. But the major breakthrough came eleven years later in 1960 when SR-52, a high yielding long-season variety, was released. Smallholder area under hybrids increased from 30 percent in 1979 to nearly 80 percent in 1986 (Rohrbach, 1988).

Despite Kenya's widely acclaimed success in agriculture since independence, no rate of return study has been documented for agricultural research in Kenya. Many evaluations of agricultural projects have relied upon quantitative and qualitative indicators such as rates of adoption of particular technologies, the extent of farmer participation in a project, nutrition improvement, potential income generation, etc. Indicator matrix-type of analysis (MSI, 1990) and simple benefit-cost analysis have been commonly used by donor analysts. In the Kenyan NARS, most researchers use indicators such as technology diffusion rates, crop area and yield increases as measures of research success.

4. CHAPTER FOUR

RATE OF RETURN: MAIZE IN KENYA

This study represents the first assessment of the impact of agricultural research within KARI. Whereas the study aimed at estimating the payoff to past investment in maize research, its broader objective is to lay the groundwork for systematic evaluation of agricultural research by Kenyan scientists. Agricultural institutions need to develop the capacity to internalize such evaluations and to generate information on the payoff to research to justify budget support to policy makers. The overall aim is to develop a set of tools that can be used to aid decision-making on resource allocation and research priorities.

The maize program in Kenya has been considered successful by many agriculturalists. But no one has ever attempted to quantify, economically, this success. To date, the following indicators have been used to measure the success: rate of adoption of improved maize technology, area under hybrid seed, increase in maize output over the years, and improved nutrition and cash-flow for the rural poor.

This study uses a production function approach to isolate the impact of breeding and agronomic research on maize production from the effects of maize extension and seed development, and to identify the relationship between the production and expenditure variables.[9] The study focuses on the research component.

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[9]The success of maize in Kenya is attributed to the maize breeding and agronomic research, extension and seed development programs.

4.1 The Sample

The data and information for this study were collected from secondary sources in Kenya between October 1989 and March 1990. The sources included the Ministry of Agriculture, Ministry of Research, Science and Technology, Ministry of Planning and National Development, Kenya Agricultural Research Institute, Kenya Seed Company, Kenya Green Growers Cooperative Union, University of Nairobi, Egerton University, Kenya National Farmers Union, Central Bank of Kenya and Central Bureau of Statistics. International data sources included: the Food and Agriculture Organization of the United Nations (FAO), the International Maize and Wheat Improvement Centre (CIMMYT) and the International Services for National Agricultural Research (ISNAR).

Digging up a reliable time-series data set is probably the hardest task of carrying out research in many developing countries. Collecting data for this study was not an exception. A lot of time was spent extracting data from the archives and from loose, dusty files.

This study covered the 1955-88 period, which coincides with the inception of a maize improvement program in Kenya in 1955. Data were collected on maize production and research and development (R & D) expenditure, as well as other micro- and macro-economic variables that explain observed changes in production and consumption of maize over time. Most of the data were aggregate because of unavailable or inadequate micro-level data.

Maize area, yield and output data were collected from the Ministry of Agriculture (MOA) and KARI, and supplemented with FAO estimates. Both recurrent and development estimates of expenditure on agriculture were obtained from the MOA and the Treasury Department. Using a time-series ratio of the number of maize breeders and agronomists (with at least one university degree) to that of the total crop researchers in the Kenyan research organization, an estimate of Maize Research Expenditure (MRE) was derived from the crop research expenditure.[10] Maize Extension Expenditure (MEE) data was obtained from gross non-research crop development expenditure using the same ratio of maize researchers to the total crop researchers, assuming that allocation of resources to maize extension activities follow the same pattern as research resource allocation.

The value of maize production was computed from the total national output of maize and the official domestic producer-price for maize. This price is announced by the government at the beginning of each crop season.[11] Kenya is normally self-sufficient in maize in good-weather years. During extensive drought-years like 1984, large ammounts of basic food commodities, including maize, are imported. Because such incidences are infrequent and Kenya's participation in the world maize-grain market is minimal, the domestic producer price was used for this study.

Data on several other variables related to maize production were collected. The amount of annual sales of improved and hybrid seed were obtained from the KSC office at Kitale. The price of seed was obtained

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[10] Some studies use number of publications or proportion of crop area as a proxy of the proportion of resources allocated.

[11] Although a parallel market exists, prices vary greatly with location and time, making it difficult to measure and to obtain them for this study.

from seed stockists and the Kenya Green Growers Co-operative Union (KGGCU), the largest wholesaler of maize seed. The volume of fertilizer imported was extracted from trade reports of the Central Bureau of Statistics (CBS). Prices of fertilizers were obtained from the FAO production statistics. The CBS was also a valuable source of information on the economy such as on demography, food supply and demand, agricultural and economic growth, etc., extracted from various government publications and reports.

The MRE included both the recurrent and development expenditures on breeding and agronomic activities.[12] The MEE estimated the recurrent and development expenditure on extension activities, including soil conservation and farm management, on maize crop. The cost of the multiplication, maintenance research and distribution of improved/hybrid seed by the KSC was estimated by using the market price of seed. This assumed that the KSC, in which the government has the controlling shares, does not extract abnormal or economic profits from farmers.[13] Additional private funding for maize R & D was also included.[14] All expenditure and price variables were deflated by the Consumer Price Index (CPI, 1971=100).

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[12] This does not include personal emoluments and development expenditures on the work done by Dr. Harrison and Dr. Allan in the 1950s and 1960s.

[13]Griliches (1958) used a similar proxy to estimate the expenditure on maize seed production in the United States.

[14]Most funding from donor sources are channelled through the Department of Treasury in the Ministry of Finance and included in the annual appropriations.

4.2 Results and Discussion

Before calculating a rate of return (ROR), regression analyses were carried out to derive the relationship between the production and expenditure variables. Instead of regressing on output, logarithmic regressions on area and yield were done to gain greater insight into the specific effects of explanatory variables on maize yield and area, and thus on output:

$$OUTPUT = YIELD * AREA$$

$$Ln(OUTPUT) = Ln(YIELD) + Ln(AREA)$$

Where: OUTPUT=Maize output in tons;
YIELD=Average national maize yield in kg/ha;
AREA=Area under maize in Hectares; and
Ln=Natural logarithm.

The endogenous variables were area and yield while the instrumental variables included research and extension expenditure variables, seed development variable, producer price for maize, an estimate of the quantitity of fertilizer used on maize, and area and yield. The inclusion of area and yield on the right-hand side of the equations enabled determination of the secondary effects of area on yield. A seed development variable, the volume of hybrid seed sales by the KSC, was included to isolate the effect of seed development on maize production.

A two-stage least square (2SLS) regression technique was used because of a high likelihood that there was lack of statistical independence between the random variables representing the equations' errors and the explanatory variables. This is due to the interdependent nature of the data-generation procedure. A residual plot of the regression results indicated that some residuals were scattered. These residuals were identified to correspond to unusual climatic and economic seasons. Thus, a dummy variable (D) was introduced to capture the exceptional agro-climatic and economic effects on maize production.

Actual data on fertilizer use on maize were not available. Therefore, an estimate of fertilizer use was derived by assuming that farmers were 1) using fertilizer only on hybrids; 2) using the blanket recommendation rate of 123.5 kg/ha; and 3) applying only phosphatic fertilizer to maize. The world price (c.i.f. Mombasa) of Di-Ammonium Phosphate (DAP) fertilizer was used to estimate fertilizer cost to farmers in this study.[15] Since Kenya imports almost all of its manufactured fertilizer requirements, it was more appropriate to use the world rather than the local fertilizer prices which are mostly subsidized.

Research usually has a long gestation period. It took a decade (1955 to 1964) to develop and release the first maize hybrid in Kenya. Subsequent releases took approximately eight years.[16] Most of the maize varieties released afterwards came from similar or close parentage of the initial inbreds. It takes the Kenya Seed Company two to three years after the release of a variety to make it available to farmers in sufficient quantities. Therefore, a lag of ten years between the cost and benefits of maize research was used in the study.

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[15]Various on-farm investigations have identified that DAP is the most common fertilizer used on hybrid maize.

[16] More time is required when the source of germplasm is a new introduction.

The maize extension variable was unlagged because it was assumed that extension messages delivered by extension agents to farmers is usually most valuable in the current crop season. It was also assumed that the farmers get the extension messages prior to cultivation so that they can benefit from it during the same season. In later years, the impact would include both extension information and the farmers' experience.

The cost of seed to the society is computed as the volume of improved/hybrid seed sales by KSC multiplied by the market price of seed (based on assumptions discussed earlier in this chapter). The cost of fertilizer is obtained by multiplying the volume of fertilizer used on maize by the world market price of fertilizer. Both seed and fertilizer are the common and major cost inputs in maize cultivation.

Ideally, the cost to a farmer of using improved/hybrid maize should include the cost of seed, fertilizer, herbicide (if applied), incremental labour cost, other capital costs such as credit and all extra costs that are incurred as a result of using the new maize technology. But since data on some of these inputs were lacking, it was assumed that seed and fertilizer are the only extra costs of using the improved maize technology. This is a reasonable assumption, especially for small-scale farmers who usually adopt only these two inputs.

The calculation of ROR involved an assessment of the benefits and the costs of breeding and agronomic research from 1955 to 1988. The results of the regressions were used to identify the impact of the research on maize production. A marginal rate of return was derived in the following way:

Suppose V = Value of Maize Output; A = Maize Area; Y = Maize Yield; R = Research Expenditure; P = Maize Price; and Q = Quantity of Maize output, where $V = Q * P$.

Then, $\text{Ln } V = P (\text{Ln } A + \text{Ln } Y)$, assuming P is constant. (i)

By differentiation,

$$d(LnV)/d(LnR) = P \{(d(LnA)/d(LnR)) + (d(LnY)/d(LnR)\}, \quad \text{(ii)}$$

assuming that maize research does not affect the maize price. This would be the case for research in a tradable commodity by a country that is too "small" to affect the world market price of that commodity or a country where there is strict government price control. Also, the same case would apply to a scenerio where maize forms a small proportion of the overall food demand by the people and/or substitutes are available. Kenya fits into the price-control scenerio since maize prices are controlled by the government.

Let $LnV = V^*$; $LnA = A^*$; $LnY = Y^*$; and $LnR=R^*$.

Thus, $dV^*/dR^* = P \{(dA^*/dR^*) + (dY^*/dR^*)\}$ (iii)

But $dY^*/dR^* = (dY/Y)/(dR/R) = (R/Y)*(dY/dR)$ (iv)

and $dA^*/dR^* = (dA/A)/(dR/R) = (R/A)*(dA/dR)$ (v)

It follows that:

$$dY/dR = ((Y/R)*(dY^*/dR^*))$$

and

$$dA/dR = ((A/R)*(dA^*/dR^*))$$

But, dY^*/dR^* is given by coefficient of research in the yield regression equation (0.2529), and dA^*/dR^* by the coefficient of research in the area regression equation (0.4922).

The change in maize output due to research, given by the sum of dA^*/dR^* and dY^*/dR^*, is adjusted by the secondary effects of yield and area, dY^*/dA^* and dA^*/dR^* respectively. These secondary negative effects of yield and area were obtained from the coefficients of the regression results. The resulting overall equation measures the change in the value of maize production due to research. In order to get the marginal ROR, benefits were lagged ten years and the following formula used:

$$MRE\ (1+r)^{10} = B \qquad \text{(vi)}$$

where MRE = Deflated maize research expenditure; B = Benefits due to research; and r = marginal ROR.

In essence, the marginal ROR gives an estimate of how much benefits are obtained by the society when research expenditures are increased by one Kenyan Pound (K£).

The study also computed an average ROR which measures the average benefits that accrue to all previous expenditure on maize research. Because of the nature of the data and the fact that estimation of an ROR is more accurate around the means of the variables, this study used the mean values of research (R_m), area (A_m) and yield (Y_m) to derive an average ROR. From the regression equations and using sample means of all the explanatory variables, before (1955-64) and after (1965-88) research impact on maize production, the changes in maize area and maize yield attributed to research were computed. The benefits due to research were estimated as the difference between the value of maize before the research impact and the value after research impact. Equation (vi) is then applied on the average research expenditure and the benefits from research to obtain the average rate of return. The average ROR is a measure of the average benefit to the society achieved by investing all the previous streams of research expenditure. The calculations of the marginal ROR and average ROR are presented in Table 11(a) and 11(b) in Appendix B.

The regression analysis results of the logarithmic functions of yield and area are presented below:

1) $$YIELD = \underset{(2.545)}{9.0478} - \underset{(0.293)}{0.5705}AREA + \underset{(0.187)}{0.2529}MRE10 + \underset{(0.068)}{0.0732}MEE + \underset{(0.071)}{0.0763}FERT + \underset{(0.058)}{0.1216}HYBSALE + \underset{(0.055)}{0.2406}DUM$$

(F VALUE=7.455; PROB>F=0.0006; DF=22; ADJ R-SQ=0.6377)

2) $$AREA = \underset{(1.467)}{8.4670} - \underset{(0.175)}{0.2623}YIELD + \underset{(0.084)}{0.4922}MRE10 + \underset{(0.049)}{0.0673}MEE + \underset{(0.110)}{0.1013}MPP + \underset{(0.053)}{0.0177}HYBSALE + \underset{(0.057)}{0.1262}DUM$$

(F VALUE=23.468; PROB>F=0.0001; DF=22; ADJ R-SQ=0.8597)

where: AREA = Maize area in ha;
YIELD = Average national maize yield in kg/ha;
MEE = Deflated Maize Extension Expenditure in K£ ;
MRE10 = Deflated Maize Research Expenditure in K£, lagged ten years;
FERT = Fertilizer Imports in t;
MPP = Deflated annual Official Maize Producer Price in K£ per t;
HYBSALE = Annual Maize Seed Sales by KSC in t; and
DUM = Dummy variable.

The results indicate that expenditures on maize research, extension and seed development increased maize yield, area and production. From the coefficients of the regression equations, the impact of research on both maize area and yield, and consequently on maize production, was greater than that of extension and seed development. The impact of extension on maize area was greater than that of seed development but the converse was true for maize yield.

The use of improved/hybrid maize varieties and fertilizer has contributed to an improvement in maize yield throughout the country. The results of this study show that the availability of hybrid seed and fertilizer led to increases in the maize yield, with the former having a larger impact on yield. The producer price of maize also induced a maize area expansion.

The effects of weather and the economy on maize production were crudely captured by the dummy variable. The results indicate a large and positive effect of favourable weather and economic conditions on both area and yield, and hence on maize production. This suggests that during adverse weather or economic problems, maize production falls whereas maize production increases in periods of good weather and economic prosperity. Looking at the maize production data over the past three decades, it is clear that good maize harvests coincide with good-weather years and/or periods when the economy is performing well.

The regression analysis also indicated that an increase in maize research expenditure (MRE) by one percent lead to an increase in yield by 0.2529 percent and an area increase of 0.4922 percent after a decade. But the change in area by 0.4922 percent resulted in a change in yield by -0.2808 percent (i.e., 0.4922 * -0.5705); and the yield change by 0.2529 percent underestimates the area by 0.0663 percent (i.e., 0.2529 * -0.2623). Thus, the secondary effect of area on yield was -0.2808 and yield on area was -0.0663. Therefore, when adjusted, an increase in research expenditure by one percent raised maize output by 0.3988 percent ten years later.

The marginal rate of return (ROR) on investment in maize research from 1955 to 1988 was found to be 33 to 47 percent. This is a high rate of return and in policy terms it means that an increase in research expenditure by one Kenyan pound increased benefits to the Kenyan society by between thirty-three and forty-seven Kenyan pounds. The mean marginal rate of return was found to be 41 percent.

The average rate of return was estimated to be 68 percent, i.e., overall, each Kenyan pound invested in maize research between 1955 and 1988 yielded sixty-eight Kenyan pounds.

5. CHAPTER FIVE

SUMMARY

Today, the agricultural sector provides nearly all of Kenya's food requirements, more than a quarter of the GDP, over three-fifths of the export earnings, and three-quarters of total employment. But the agricultural sector is facing several contemporary challenges such as feeding a rapidly growing population on less than twenty percent of the country's land area. Whereas the country produced sufficient food staples in the sixties and early seventies, there have been marked imbalances between food production and demand since the mid-seventies. These imbalances are basically caused by rapid population growth, the growing demand for food and the vagaries of weather. Because of limited supplies of arable land, Kenya has to rely primarily on yield increases rather than area expansion for increased maize production in the years ahead.

The development and adoption of improved maize varieties, one of the great successes of Kenya's agricultural research and extension program, led to a fivefold increase in maize output, doubling of yield and near tripling of area in three decades since the inception of a maize improvement program in 1955. This success is of strategic importance to food policy because maize is the staple food for over 90 percent of the population and it accounts for over 40 percent of the total dietary intake. But projections indicate that maize supplies from domestic production and/or imports will have to double in the next 15-20 years to meet future food demand.

The government of Kenya introduced a systematic maize breeding program in 1955 and it took ten years to produce the first Kenyan hybrid, H611, which had a 40 percent yield advantage over the best local variety, KS II. The success of H611 hybrid maize was based on excellent cooperation between maize breeders and agronomists, an agressive seed development program and an extensive promotion campaign by the extension services. To date, the maize research program has released seventeen hybrids, four composites and two synthetic maize varieties. These varieties have a 30-55 percent on-station yield-advantage over the traditional varieties and they are suited to a wide range of agro-climatic conditions. More than half of these are still being supplied by the Kenya Seed Company (KSC).

The KSC played a crucial role in the diffusion of maize hybrids. Responding to a government request to undertake the production and distribution of hybrid maize seed, the KSC expanded its service to both the large- and small-scale farmers through an extensive seed development and distribution network. This network improved smallholders' access to seed and as a result, the KSC seed sales increased from a mere 4 tons in 1962/63 to 10,600 tons in 1975/76 and 21,800 tons in 1987/88, indicating a rapid adoption of the hybrids. Data indicate that the greatest increase in the area planted to hybrid seed was due to smallholder adoption of seed.

Despite the availability of the new seed and complementary inputs, the average maize yield is low compared to the potential. In 1981, the average national yield was 25-50 percent of the on-station yield. This is attributed to low adoption of the new maize technology, particularly among smallholders. In many countries, maize output has been increased through improved adoption of hybrid seed and complementary inputs such as fertilizer and insecticides. The World Bank (1984) contends that maize production could be increased in Kenya by 70-100 percent through the expanded use of improved inputs and husbandry. But intensification of maize production, especially among smallholders, will require a concerted effort from the various agricultural support services.

The government is deeply committed to invest in agricultural research in order to overcome technological constraints on agricultural production. Currently, agricultural research receives the largest share of the total national budget for research. The budget on crop research and development (R & D) accounted for an average of 43 percent of the total agriculture expenditure during 1955-88. In real terms, the government's crop R & D expenditure rose from an average of K£ 4.29 million in 1955-59 to about K£ 12 million in 1985-88. During the same period, maize research expenditures increased about threefold in real terms and nearly tenfold in nominal terms. Over the past 30 years, government investment and foreign assistance to agricultural research have made KARI one of the largest research establishments in Africa.

Agricultural research is an important means of raising agricultural productivity. But this requires costly investments with long gestation periods. The growing pressure on scarce public resources has heightened the need to justify such investments vis a vis alternative public investments such as agricultural extension and irrigation as well as non-agricultural investments. Tight research budgets require NARS managers to improve their research priority-setting and resource-allocation procedures.

Many NARS managers make their research-priority decisions on the basis of past experience and intimate knowledge of national research policies and goals. These sources are important but the identification of the payoff to past research can provide supplementary information to guide future research funding decisions. Several analytical techniques are now available for the NARS managers to analyze the costs and returns to various research programs and generate information which can be used for priority-setting.

Numerous studies have documented a high rate of return to investments in agricultural research throughout the world. Several methods are available for assessing the payoff to research. They are grouped into two major categories: ex post and ex ante approaches. The ex post approach is used to determine the impact of past investments in research while the ex ante approach estimates the impact of future funding. The results of these studies have been used by the managers of NARS to justify the need for continued political support for agricultural research and improve the decision-making process with respect to research resource allocation.

This study evaluated the payoff to investment in maize research over the period 1955-88. The data and information used in the study were collected from archival sources, personal interviews and secondary sources in Kenya between October 1989 and March 1990. The study found that the maize research program, in conjuction with an active agricultural extension program and a seed delivery system contributed to a doubling of the national maize yield, near tripling of the area under maize and a fivefold increase in maize production over the 1955-88 period.

The results from regression analyses show that an increase in Kenya's maize research expenditure by one percent increased maize production by 0.40 percent a decade later. This may seem like a small effect but considering the size of national maize output of over 2 million tons, then 0.40 percent is a substantial increase in production attributed to research. The marginal rate of return (ROR) on investment in maize research from 1955 to 1988 was found to be 33 to 47 percent. This is a high rate of return and in policy terms it means that an increase in research expenditure by one Kenyan pound increased benefits to the Kenyan society by thirty-three to forty-seven Kenyan pounds. The average rate of return was found to be sixty-eight percent; this means that one Kenyan pound invested in maize research yielded sixty-eight Kenyan pounds over the 1955-88 period. Whereas this study cannot determine the appropriate level of future funding for maize research, the high ROR suggests that Kenya's maize research program had been underfunded in the past.

This study points up the crucial complementary role of the seed industry, extension service and complementary government policies in increasing maize production and contributing to the overall success of the maize research program. Because of these institutional linkages, further research should be carried out to identify the contribution of the seed program, extension and government policy to maize production. The focus of rate of return studies should move from this ex-post study to an ex-ante study to evaluate the potential future benefits of maize research in Kenya.

Further studies of factors influencing research productivity could provide information on the constraints on improving the productivity of KARI. Several constraints require further research: lack of adequate budget support for KARI, high personnel turnover, inadequate and/or inadequately-trained manpower and the optimal size of scientists and support staff. It is important that the managers of KARI and government policy makers realize the need to train and maintain an experienced cadre of scientists and provide them with working incentives, competitive remunerations and the means to carry out their research programs efficiently. The re-organization of KARI is expected to help overcome some of these problems.

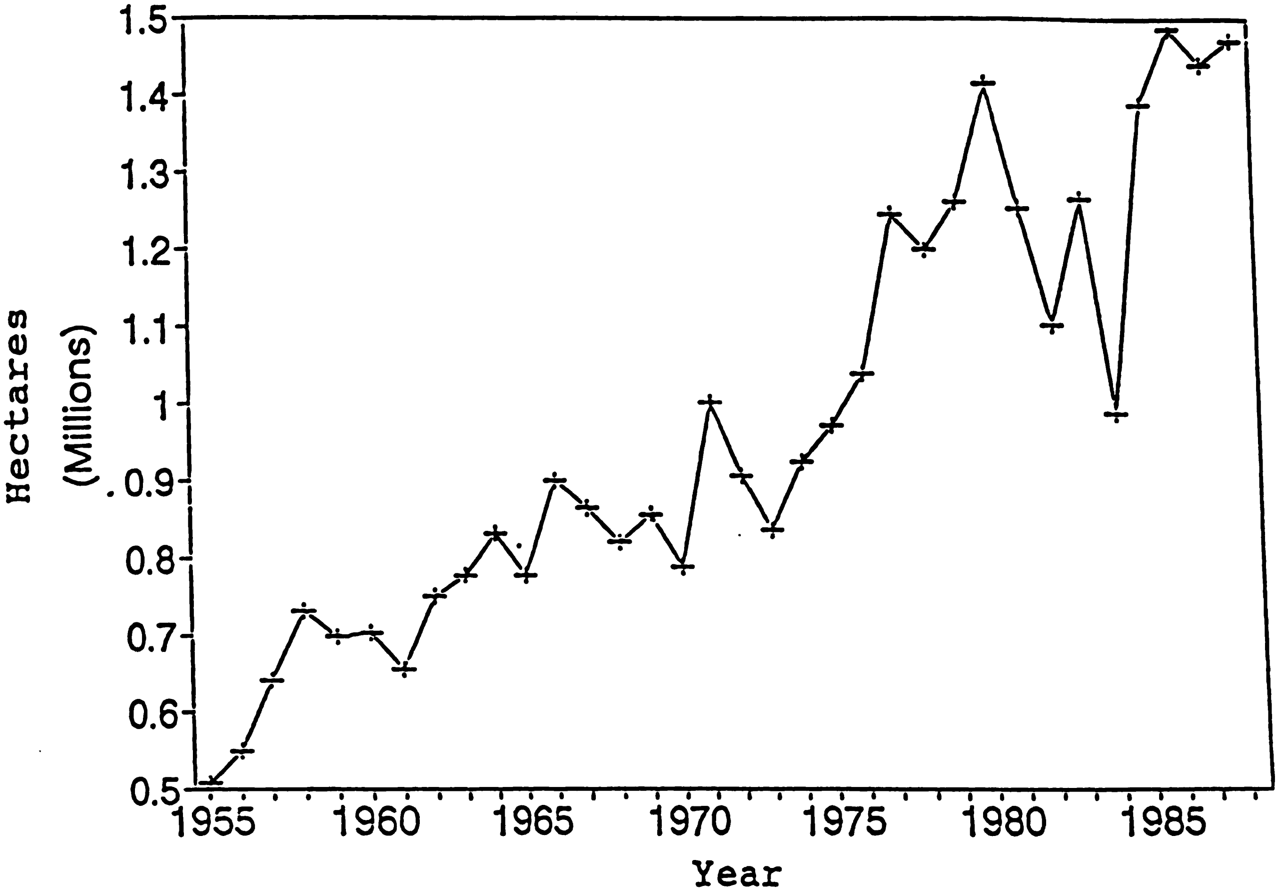
The urgency of increasing maize production in the wake of a rising food demand compels KARI researchers to search for germplasm throughout the world. After all, the initial success of the maize hybrids in the mid-sixties started with the importation of maize seed (Ec 573) from Ecuador. Therefore, KARI should develop and hone the capacity to generate improved maize varieties through conventional breeding, "intelligent" borrowing of germplasm from other countries, and biotechnology. But it takes vision, continuity of research staff and stability of domestic financial support to develop an efficient capacity to borrow, screen and adapt technology to micro-environments.

APPENDICES

APPENDIX A

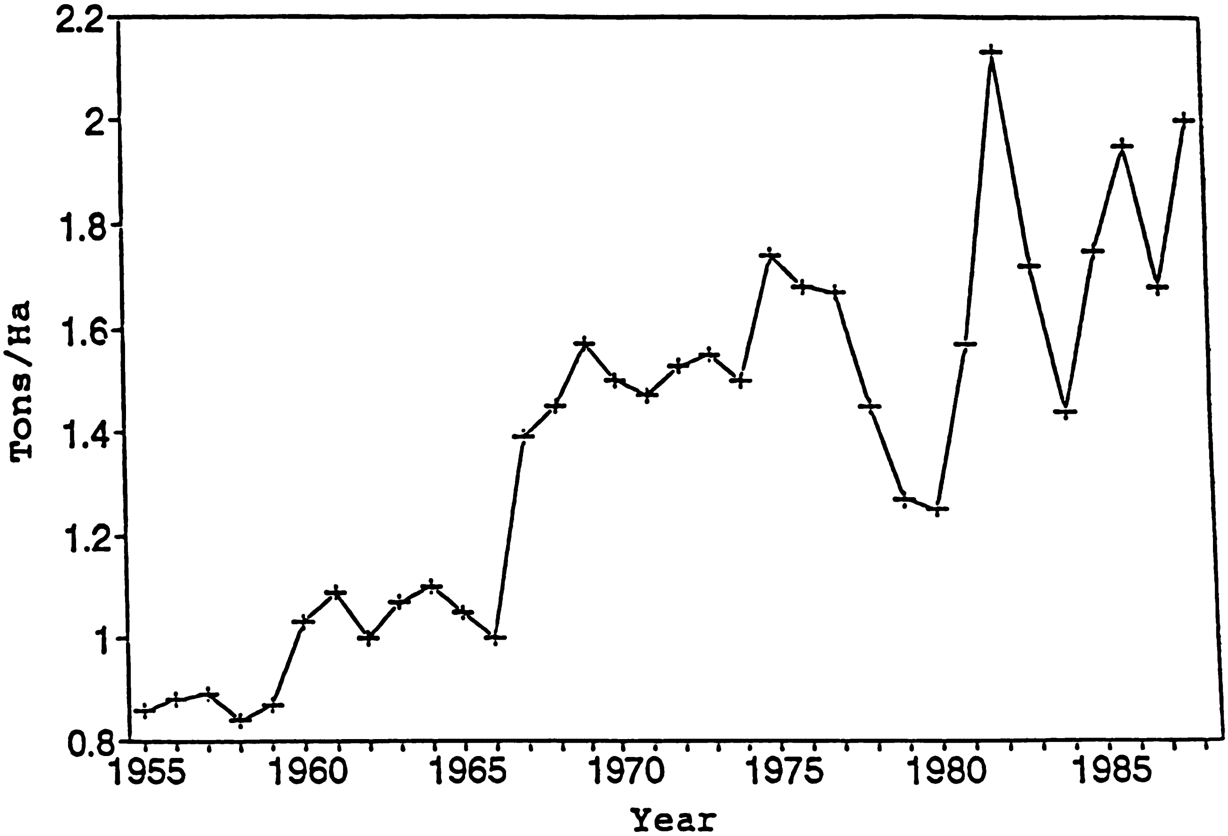
Appendix A

Figure 4(a): Kenya: Maize Area



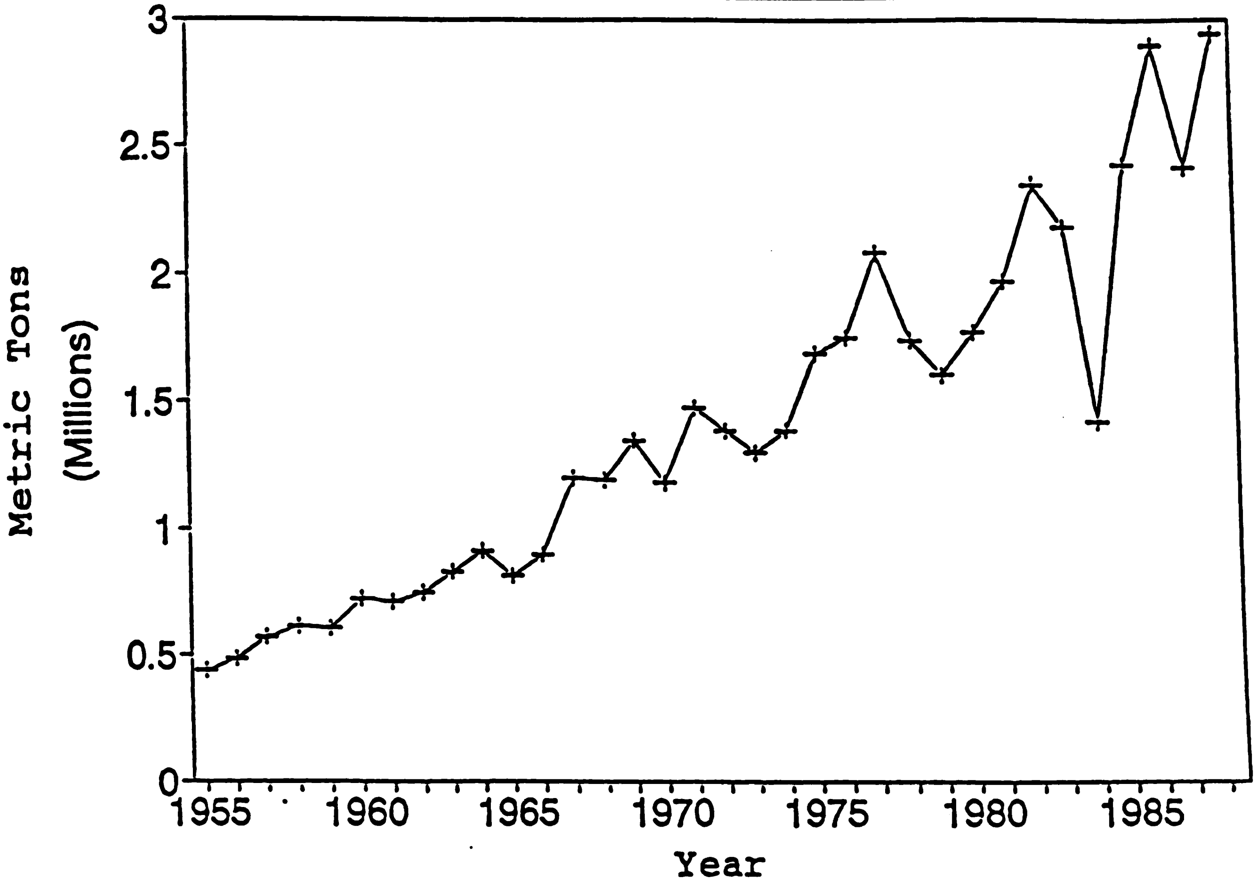
Appendix A [Continued]

Figure 4(b): Kenya: Maize Yield



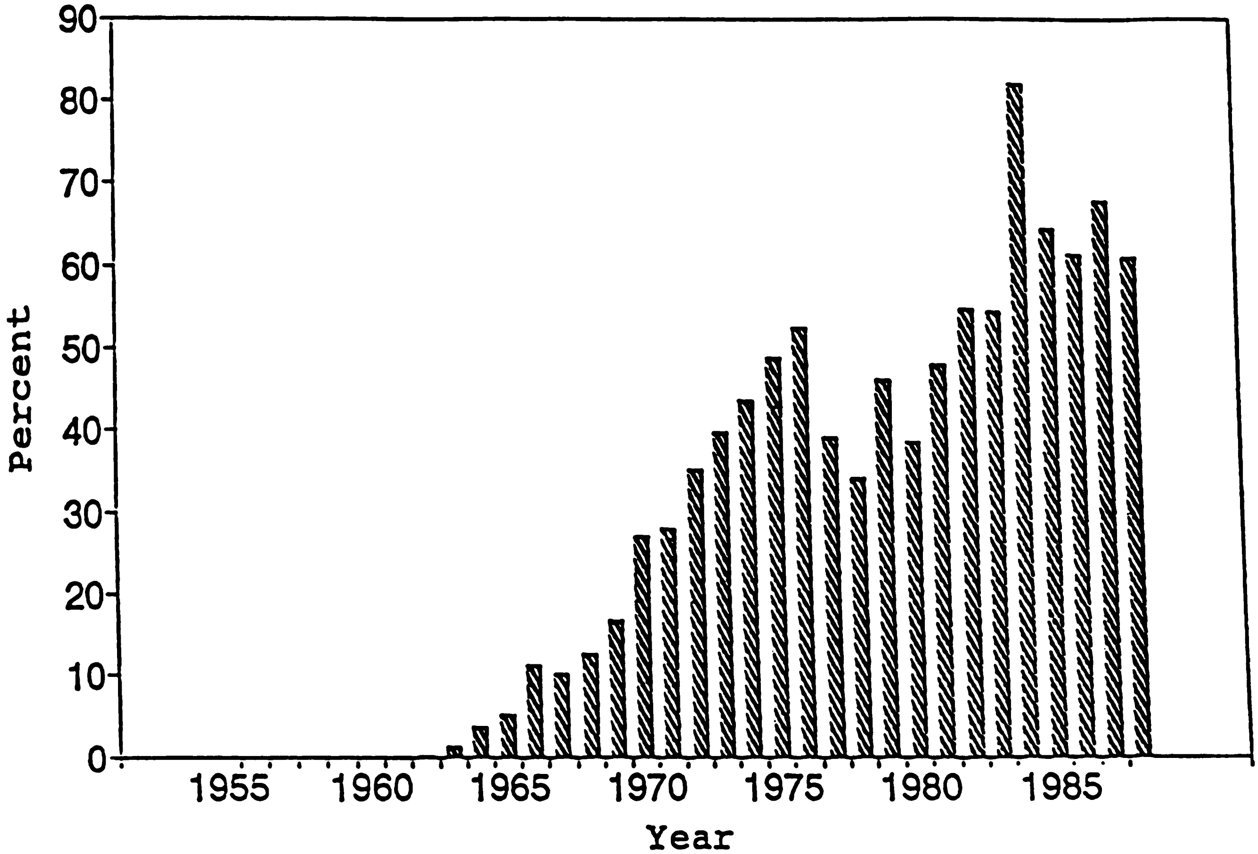
Appendix A [Continued]

Figure 4(c): Kenya: Maize Production



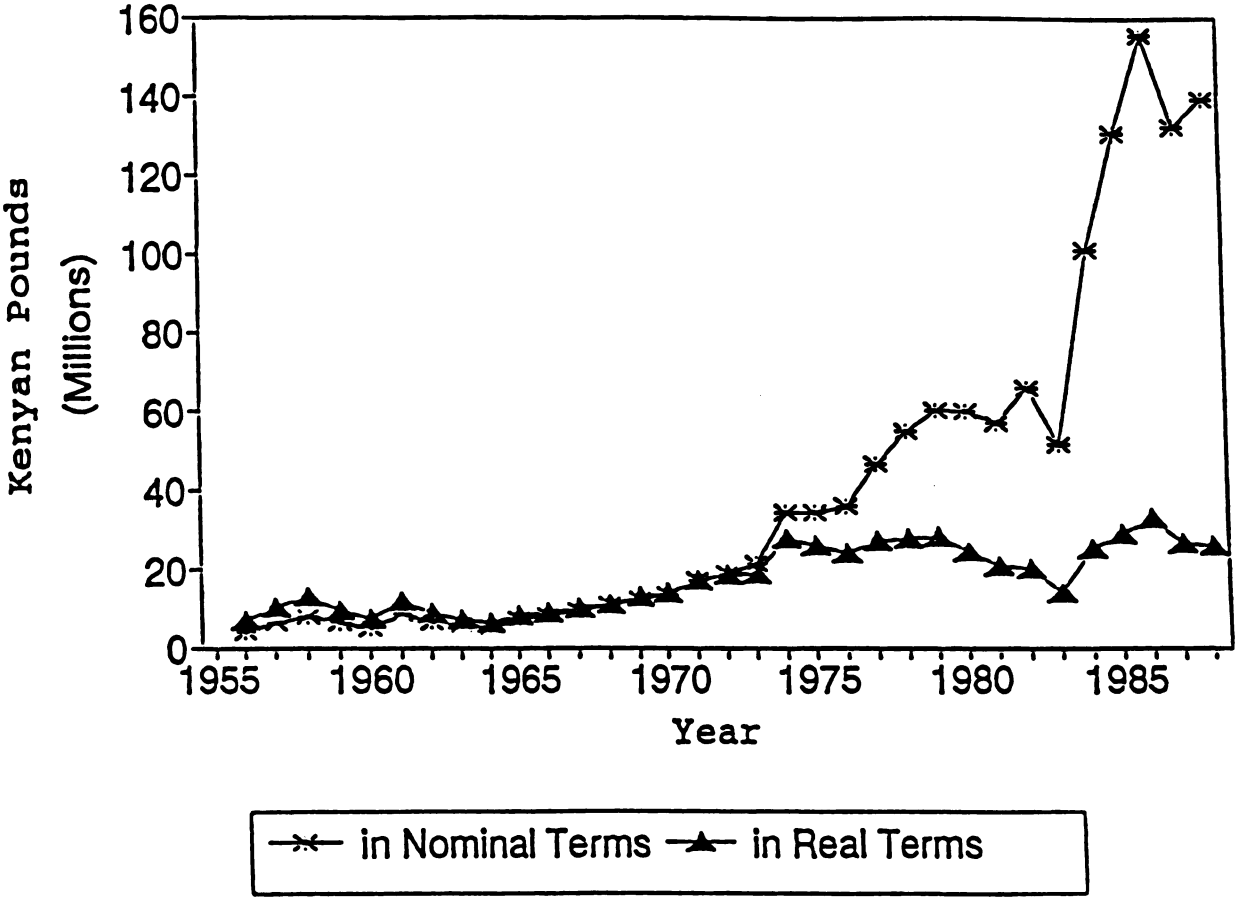
Appendix A [Continued]

Figure 5: Kenya: Hybrid Maize Adoption



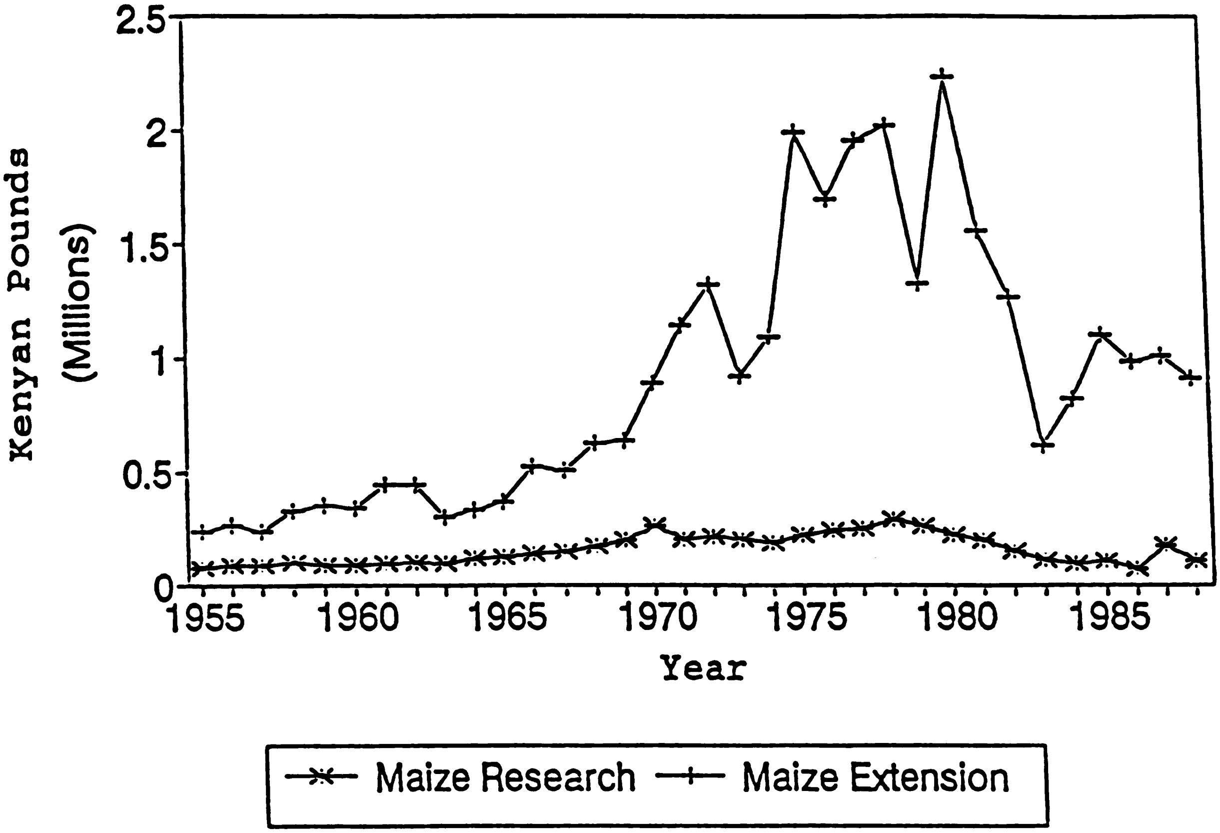
Appendix A [Continued]

Figure 6: Kenya: MoA Expenditure



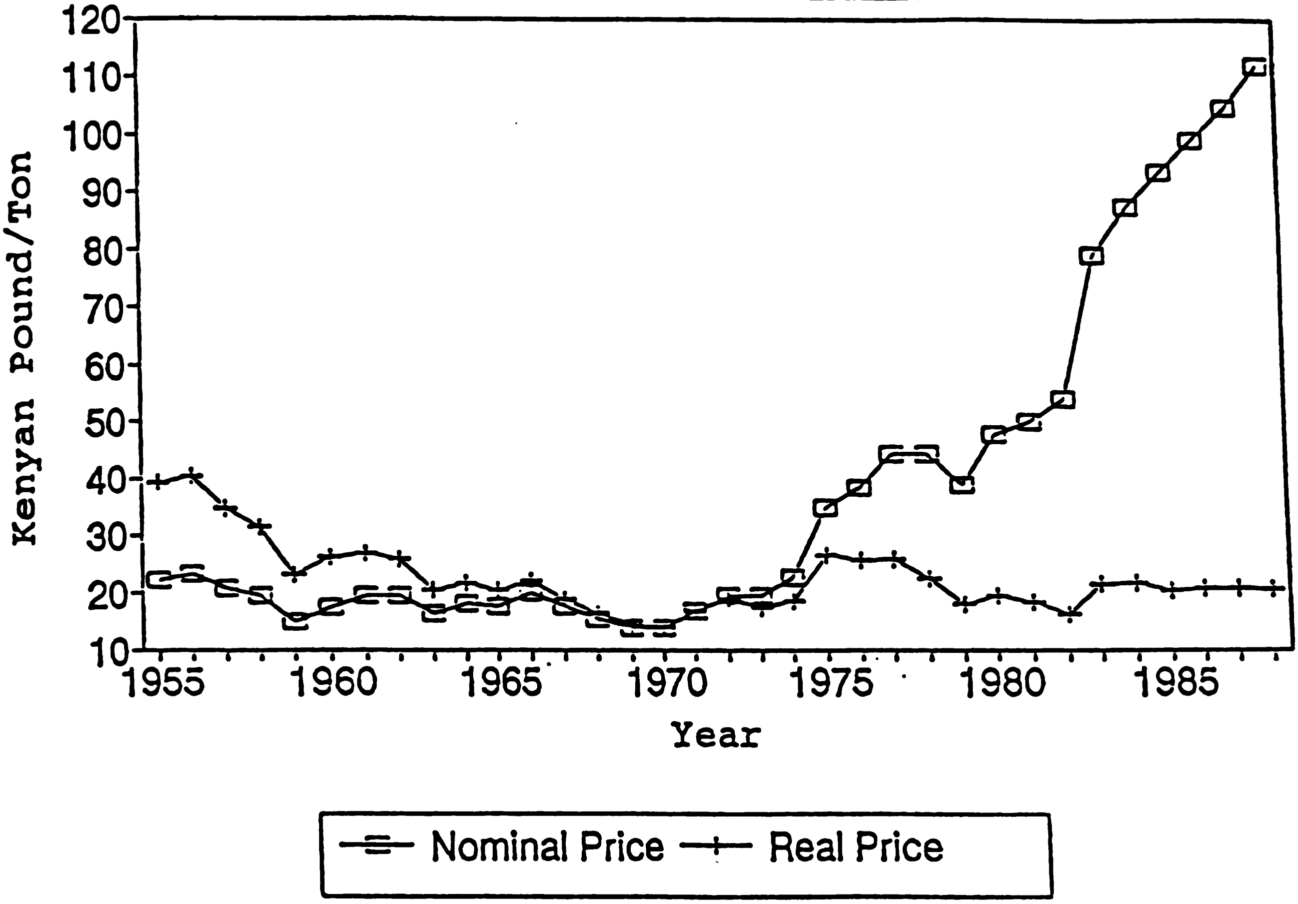
Appendix A [Continued]

Figure 7: Kenya: Maize Expenditure
(Estimated in Real Terms)



Appendix A [Continued]

Figure 8: Kenya: Maize Price



Appendix A [Continued]

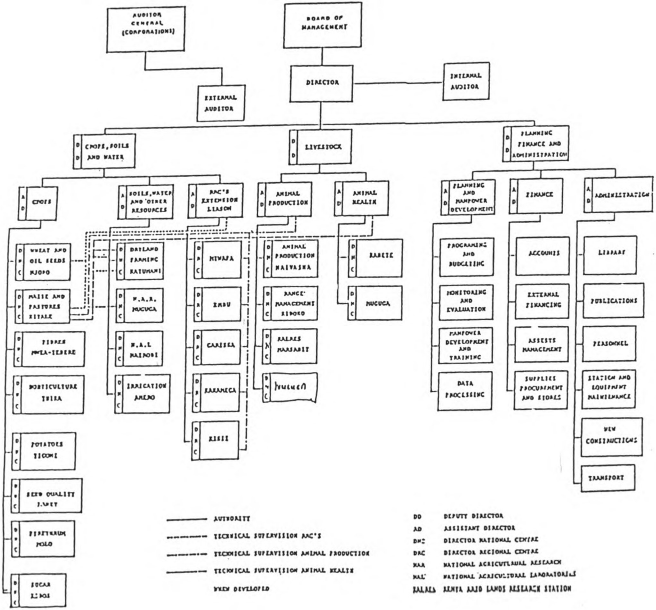
Table 9: Kenya: NCPB Maize Purchase (in '000 Tons) by Province, 1966-88.

	PROVINCE						
YEAR	R/Valley	Western	Nyanza	Eastern	Central	Coast	TOTAL
1966/67	143.5	58.1	9.44	4.87	9.2	0.5	225.6
1967/68	106.7	92.2	13.98	5.51	9.7	0.1	228.2
1968/69	167.3	72.7	24.04	22.70	5.2	0.01	292.0
1969/70	173.3	75.2	15.51	7.63	3.5	-	275.1
1970/71	173.3	75.2	1.78	1.20	0.5	-	252.0
1971/72	217.1	57.8	15.50	15.95	11.9	-	318.3
1972/73	290.3	100.2	36.07	35.14	19.3	-	481.0
1973/74	214.8	126.1	12.58	2.05	12.8	-	368.3
1974/75	234.8	150.6	21.09	8.39	34.0	-	448.9
1975/76	333.3	173.1	35.51	0.64	12.9	0.01	555.5
1976/77	270.0	171.8	60.58	43.82	21.6	2.4	570.2
1977/78	140.6	82.6	14.96	3.14	2.8	0.1	244.2
1978/79	154.3	51.3	4.21	8.39	8.5	-	226.7
1979/80	95.7	28.2	3.24	4.91	0.1	-	132.2
1980/81	269.7	80.8	31.40	0.34	0.4	-	382.6
1981/82	469.3	123.2	54.47	41.84	7.6	0.03	696.4
1982/83	437.6	96.0	50.95	33.29	9.3	-	627.1
1983/84	374.8	74.9	45.85	0.04	1.9	-	497.5
1984/85	238.3	115.8	14.71	10.03	0.9	0.05	379.8
1985/86	580.7	175.7	51.00	16.19	10.1	0.04	833.7
1986/87	544.9	118.1	48.06	1.93	5.8	0.03	718.8
1987/88	339.6	81.6	55.41	0.66	0.2	0.02	477.5
1988/89	467.8	69.1	22.28	35.55	28.8	0.5	624.0

Source: NCPB. Unpublished data.
Note: "-" means '<u>negligible</u>'.

Appendix A [Continued]

Figure 9: KENYA AGRICULTURAL RESEARCH INSTITUTE ORGANIZATIONAL STRUCTURE



APPENDIX B

Appendix B

Table 10: A Summary of Returns to Agricultural Research and Extension, 1958 to 1990.

Study[a] Author(s)	Year	Country (Region or Institute)	Commodity	Period of Analysis	Type of Study[b]	Results[c] (rate of return) — comments
Bare and Loveless	1985	USA	Forestry (Timber)		ES	9%-12%
Bengston	1985	USA	Forestry (Aggregate lumber & wood)		ES	34%-40%
Brinkman and Prentice	1985	Canada (Ontario)	Aggregate	1950-72	ES	66% — includes private R&D and education.
Doyle and Ridout	1985	UK	Aggregate	1966-80	EC	10%-30% — lower estimate for 1978-80, higher for 1966-70.
Farrell and Funk	1985	Canada	Plant Biotechnology			15%-40% — ex ante estimation of a social internal rate of return using a Delphi forecasting approach
Furtan and Ulrich	1985	Canada	Wheat Rapeseed Barley Alfalfa	1950-83	ES	29% 51% 22% 14%
Herruzo	1985	Spain	Rice	1941-80	ES	16%-18%
Muchnik	1985	Latin America	Rice	1968-90		17%-44%
Nagy	1985	Pakistan	Aggregate	1959-79	EC	64% — includes extension
Ulrich et al.	1985	Canada	Malting barley		ES EC	51% — social internal rate of return and 35%-private internal rate of return 13:1 — social marginal rate of return
Boyle	1986	Eire	Aggregate	1963-83	EC	26%
Braha and Tweeten	1986	USA	Aggregate	1959-82	EC	47%
Brunner and Strauss	1986	USA	Forestry (Preserved wood)		ES	73%
Chang	1986	USA	Forestry (Loblolly pine)		ES	a benefit-cost ratio of 16 : 1.
Fox	1986	USA	Livestock	1944-83	EC	150% — commodity specific research and 116% for disciplinary biological research.
			Crops			180% — commodity specific research and 180% for disciplinary biological research.

Source: Echeverria (1990).

Appendix B (Continued)

Table 10 (Continued)

Study[a] Author(s)	Year	Country (Region or Institute)	Commodity	Period of Analysis	Type of Study[b]	Results[c] (rate of return) — comments
Haygreen et al.	1986	USA	Forestry (Lumber, plywood pulp, and paper)	1972-81	ES	14%-36% —depending on the technology group and type of costs considered. includes private R&D
Khan and Akbari	1986	Pakistan	Aggregate	1955-81	EC	36% — includes extension
Newman	1986	USA	Forestry (Southern softwood stumpage)		ES	0%-7% — includes private R&D
Unnovehr	1986	S.E. Asia	Rice quality	1983 84	ES	61%
Westgate	1986	USA	Forestry (Timber, containerized seedlings)	1969-2000	ES	37%-111% — includes private R&D
Wise	1986	UK	Aggregate	(Present)	EC	8%-15%
Evenson	1987	India	Aggregate	1959-75	EC	100%
Haque et al.	1987	Canada	Eggs	1968-84	ES	106%-123% — accounts for distortions in product market and the marginal excess burden of taxes on the magnitude and on the distribution of net benefits of public research.
Libroro and Perez	1987	Philippines	Maize	1956-83	EC	27%-48% and 27%-43% including extension
Libroro et al.	1987	Philippines	Sugarcane	1956-83	EC	51%-71%
Norton et al.	1987	Peru (INIPA)	Aggregate	1981-2000	ES	17%-38% includes extension. Includes an ex post evaluation 1981-1987 and an ex ante evaluation 1987-2000
			Rice			17%-44%
			Maize			10%-31%
			Wheat			18%-36%
			Potatoes			22%-42%
			Beans			14%-24%
Scobie and Eveleens	1987	New Zealand	Aggregate	1926-84	EC	30% — for a 23 year period over which research benefits accrue, varies from 15% to 66% for lags of 29 to 8 years. Includes extension.
Seldon	1987	USA	Forestry (Softwood plywood)	1950 80	EC	163%-707% — depending on regression assumptions and if results include consumer surplus only or consumer and producer surplus. Utilizes a non residual surplus function approach as an extension of the production function (econometric) approach.

Appendix B (Continued)

Table 10 (Continued)

Study[a] Author(s)	Year	Country (Region or Institute)	Commodity	Period of Analysis	Type of Study[b]	Results[c] (rate of return) — comments
Seldon and Newman	1987	USA	Forestry (Softwood plywood)		EC	236%-430% — marginal rate of return
Sumelius	1987	Finland	Aggregate	1950-84	EC	25%-76% — marginal rate for public research only and 26%-77% including private R&D. Both include university education.
Tung and Strain	1987	Canada	Aggregate	1961-80	EC	High
Beck	1988	UK	Horticultural crop protection	1979-2001	ES	50%
			Hybrid sprouts	1979-2000		22%
Echeverria et al.	1988	Uruguay	Rice	1965-85	ES	52% — includes extension and private R&D
Evenson	1988	Paraguay	Crops	1988	EC	75%-90% — Marginal rate of returns to investment in extension
Harvey	1988	UK	Aggregate	Present)	ES	-38% to +4% — includes extension.
Huot et al.	1988	Canada	Swine	1968-84	ES	45%
Librero et al.	1988	Philippines	Mango	1956-83	EC	85%-107%
Luz Barbosa	1988	Brazil (EMBRAPA)	Aggregate	1974-97	ES	40%
Norgaard	1988	Africa	Cassava Biological control	1977-2003	ES	A benefit-cost ratio of 149 : 1
Power and Russell	1988	UK	Poultry feeding	Present	ES	A benefit-cost ratio of 78 : 1
Russell and Thirtle	1988	UK	Rape seed	1976-85	EC	A benefit-cost ratio of 327 : 1.
Thirtle and Bottomley	1988	UK	Aggregate	1950-81	EC	70%
Widmer et al.	1988	Canada	Beef	1968-84	ES	63%
World Bank	1988	Burkina Faso Cote d'Ivoire and Togo	Cotton			11%-41% — measures returns to cotton development programs including technological development, input supply networks, and other variables
Zachariah et al.	1988	Canada	Broilers	1968-84	ES	48%

Appendix B (Continued)

Table 10 (Continued)

Study[a] Author(s)	Year	Country (Region or Institute)	Commodity	Period of Analysis	Type of Study[b]	Results[c] (rate of return) — comments
Ernstberger	1989	Brazil	Rice		ES	78% - and 66% when extension is included
Evenson and da Cruz	1989	South America (PROCISUR)	Wheat Soybeans Maize	1979-88	ES	110% Measures the impact of a research network among the following 179% countries: Argentina, Bolivia, Brazil, Chile, Paraguay, and Uruguay 191%
Fox et al.	1989	Canada	Dairy	1968-84	ES	97%
Huffman and Evenson	1989	USA	Aggregate Crops Livestock	1950-82		43%-public sector applied research 67%-public sector pre-tech science 45%-public sector applied research 57%-public sector pre-tech science 11%-public sector applied research 83%-public sector applied research
Schwartz et al.	1989	Senegal (CRSP)	Cowpeas	1981-87	ES	60%-80%
Bojanic and Echeverria	1990	Bolivia (CIAT-Santa Cruz)	Soybeans	1974-89	ES	63%-80%
do Frahan	1990	Mali	Aggregate	1990-2010	ES	1%-25% — internal rates of return, an ex ante evaluation of combinations of on-station and farming systems research, extension and credit institutions, marketing system improvements, and fiscal policy reforms
Evenson and McKinsey	1990	India	Rice	1954-84	EC	65% — public research
Horton et al.	1990	Tunisia	Seed Potato	1976-85	ES	81%
Librero and Emlano	1990	Philippines	Poultry	1962-87	EC	154%-358%
Pray and Ahmed	1990	Bangladesh	Aggregate	1948-81	EC	100%
Seré and Jarvis	1990	Latin America	Pastures	1987-2037	ES	Ex ante study assuming a closed economy; 15%-20% return assuming an 11-year lag on benefits, lower estimate with poultry substitution, higher estimate without. Rates of return above 100% when benefits start in year 1 (without lag).

Appendix B (Continued)

Table 10 (Continued)

Study[a] Author(s)	Year	Country (Region or Institute)	Commodity	Period of Analysis	Type of Study[b]	Results[c] (rate of return) —comments
Griliches	1958	USA	Hybrid corn Hybrid sorghum	1940-55 1940-57	ES	35%-40% 20%
Tang	1963	Japan	Aggregate	1880-1938	EC	35%
Griliches	1964	USA	Aggregate	1949-59	EC	35%-40%
Latimer	1964	USA	Aggregate	1949-59	EC	not significant
Grossfield and Heath	1966	UK (NRDC)	Mechanical potato harvester	1950-67	ES	net contribution using simple cost-benefit analysis is UK £271,000
Peterson	1967	USA	Poultry	1915-60	EC	21%-25%
Evenson	1968	USA	Aggregate	1949-59	EC	47%
Evenson	1969	S. Africa	Sugarcane	1945-62	ES	40% — Same result using a production function for the period 1945-58.
Ayer	1970	Brazil (Sao Paulo)	Cotton	1924-67	ES	77%-110%
Barletta	1970	Mexico	Crops Wheat	1943-63	EC ES	45%-93% 90%

Appendix B (Continued)

Table 10 (Continued)

Study[a] Author(s)	Year	Country (Region or Institute)	Commodity	Period of Analysis	Type of Study[b]	Results[c] (rate of return) —comments
Schmitz and Seckler	1970	USA	Tomato harvester	1958-69	ES	37%-46%
Elias (*revised by Cordomí*	1971 1989)	Argentina (EEAT-Tucumán)	Sugarcane	1943-63	EC	33%-49% — includes extension.
Duncan	1972	Australia	Pasture improvement	1948-69	EC	58%-68%
Hines	1972	Peru	Maize	1954-67	ES	35%-40% and 50%-55% including cultivation.
Evenson and Jha	1973	India	Aggregate	1953-71	EC	40% — includes extension and the interaction between research and extension.
Patrick and Kehrberg	1973	Brazil (Eastern)	Aggregate	1968	EC	Not significant estimate of returns to extension (number of contacts between farmers and extension agents).
Huffman	1974	USA (Corn belt)	Maize	1959-64	EC	Estimate of returns to extension yield a social return above 16%.
Cline	1975	USA	Aggregate	1939-48	EC	41%-50% — lower estimate for 13-year time lag and higher for 16-year lag between beginning and end of output impact.
del Rey (*revised by Cordomí*	1975 1989)	Argentina (EEAT-Tucumán)	Sugarcane	1943-64	EC	35%-41% — includes extension.
Mohan and Evenson	1975	India	Aggregate	1959-71	EC	Estimate of a social rate of return to extension is 15%-20%.
Monteiro	1975	Brazil	Cocoa	1923-85	ES	19%-20%
Peterson and Bredahl	1975	USA	Aggregate	1937-42 1947-57 1957-62 196[illegible]-72	EC	50% 51% 49% 34%

Appendix B (Continued)

Table 10 (Continued)

Study[a] Author(s)	Year	Country (Region or Institute)	Commodity	Period of Analysis	Type of Study[b]	Results[c] (rate of return) — comments
Bredahl and Peterson	1976	USA	Cash grains	1969	EC	36% Lagged marginal product of 1969 research on output discounted
			Poultry			37% estimated mean lag of 5 years for cash grains
			Dairy			43%
			Livestock			47%
Huffman	1976	USA (Iowa, N. Carolina, Oklahoma)	Crops and livestock	1964	EC	Estimate of returns to extension; marginal product of extension is $1,000 to $3,000 per day.
Fonseca	1976	Brazil	Coffee	1953-95	ES	23%-27% and 17%-22% when including extension.
Easter and Norton	1977	USA	Maize		ES	An ex ante study of the land grant university research and extension system
			Crop protection	1982-2000		Benefit-cost ratio of 137 : 1
			Production efficiency	1985-2000		Benefit-cost ratio of 118 : 1
			Soybeans		ES	an ex ante study of the land-grant university research and extension system
			Crop protection	1982-2000		benefit-cost ratio of 45 : 1
			Production efficiency	1985-2000		Benefit-cost ratio of 40 : 1
Eddleman	1977	USA	Aggregate	1978-85	ES	28 % An ex ante study to estimate expected economic benefits from federal
			Maize			32% funding for production-oriented research by state experiment stations
			Soybeans			31%
			Wheat			46%
			Beef cattle & forage			16%
			Swine			52%
			Dairy			38%
Halim	1977	Philippines (Laguna Province)	Aggregate	1963-68-73	EC	Estimate of returns to extension, positive and significant result.
Hayami and Akino	1977	Japan	Rice breeding	1915-53	ES	25%-27% — research programs before Assigned Exp. System
				1932-61		73%-75% — research programs under Assigned Exp. System. Both analyses consider autarky and open-economy cases.
Hertford et al.	1977	Colombia	Rice	1957-80	ES	60%-82%
			Soybeans	1960-80		79%-96%
			Wheat	1927-76		11%-12%
			Cotton	1953-72		0%
Huffman	1977	USA (Corn Belt)	Crops	1959-64	EC	Estimate of returns to extension yield a social rate of return of 110%.
Kahlon et al.	1977	India (Four states)	Aggregate	1960-73	EC	63%
				1956-73		14%-64% — States are A. Pradesh, Bihar, Maharastra, and Punjab.

Appendix B (Continued)

Table 10 (Continued)

Study[a] Author(s)	Year	Country (Region or Institute)	Commodity	Period of Analysis	Type of Study[b]	Results[c] (rate of return) — comments
Lu and Cline	1977	USA	Aggregate	1938-72	EC	24%-31%
Pee	1977	Malaysia	Rubber	1932-73	ES	24%
Peterson and Fitzharris	1977	USA	Aggregate	1937-72	ES	34%-51% — considers four 6-year periods: 1937-42, 50%; 1947-52, 51%; 1957-62, 49%; and 1957-72, 34%. Includes extension and private R&D.
Wennergren and Whittaker	1977	Bolivia	Sheep Wheat	1966-75	ES	44% - 48%
Evenson	1978	USA	Aggregate	1948-71	EC	110% — estimate of returns to extension.
Evenson and Flores	1978	Asia (national) (intern'al)	Rice	1950-65 1966-75	EC	32%-39% 73%-78% 74%-102%
Flores et al.	1978	Philippines	Rice	1966-75	EC	75% and 46%-71% for the tropics.
Kislev and Hoffman	1978	Israel	Wheat Dry farming Field crops	1954-73	ES	125%-150% 94%-113% 13%-16%
Lu, Quance, and Liu	1978	USA	Aggregate	1939-72	EC	25% — includes extension
Mooch	1978	Kenya (Vihiga)	Maize	1971	EC	Estimate of returns to extension, significant impact on yields.
Nagy and Furtan	1978	Canada	Rapeseed	1960-75	ES	95%-110%
Pray	1978	Punjab (British India) (Pakistan)	Aggregate	 1906-56 1948-63	ES	 34%-44% — includes extension 23%-37% — includes extension
Scobie and Posada	1978	Colombia	Rice	1957-64	ES	79%-96%
Davis	1979	USA	Aggregate	1949-59	EC	66%-100% and 37% for the period 1864-1974.

Appendix B (Continued)

Table 10 (Continued)

Study[a] Author(s)	Year	Country (Region or Institute)	Commodity	Period of Analysis	Type of Study[b]	Results[c] (rate of return) — comments
Evenson et al.	1979	USA	Aggregate	1868-1926	EC	65% — all agricultural research
				1927-50		95%-110% — lower estimate for technology-oriented research and higher for science-oriented research.
				1948-71		45% — science-oriented research and 110% for farm management research and agricultural extension
		(Southern)				130% — technology-oriented research
		(Northern)				93% — technology-oriented research
		(Western)				95% — technology-oriented research
Knutson and Tweeten	1979	USA	Aggregate	1949-72	EC	28%-47%, depending on the period analyzed, lower estimate for 13 year time lag between the beginning and end of output impact; higher estimate for 16-year lag.
Lu, Cline, and Quance	1979	USA	Aggregate	1939-72	EC	23.5%-30.5% — includes extension
White et al.	1979	USA	Aggregate	1929-77	EC	28%-37%
Moricochi	1980	Brazil (Sao Paulo)	Citrus	1933-85	ES	18%-28%
Pray	1980	Bangladesh	Wheat and Rice	1961-77	ES	30%-35%
Araji	1981	USA	Integrated pest management	1978-2000	ES	An ex ante study in 20 selected commodities, includes extension, rates of return ranging from 191% for soft red winter wheat to a negative return for sweet corn.
Avila	1981	Brazil (R.G. Sul)	Irrigated rice	1959-78	ES	Includes extension 83%-119%
		(Central)				83%-87%
		(N. Coast)				92%-107%
		(S. Coast)				111%-115%
		(Frontier)				114%-119%
Davis and Peterson	1981	USA	Aggregate	1949-74	EC	37%-100% — assumes a 14-year research lag period, analyses the decline in rates of return over the 25 year period: 100% in 1949, 79% in 1954, 66% 1959, and 37% for 1964, 1969, and 1974.
Hastings	1981	Australia	Aggregate	1926-68	EC	Increasing returns for increases in research activities.

Appendix B (Continued)

Table 10 (Continued)

Study[a] Author(s)	Year	Country (Region or Institute)	Commodity	Period of Analysis	Type of Study[b]	Results[c] (rate of return) — comments
Norton	1981	USA	Cash Grains Poultry Dairy Livestock	1969	EC	31%-57% and 44%-85% for 1974. (Lower estimates for 9-year research 30%-56% time lag and higher for 5-year lag.) 27%-50% and 33%-62% for 1974 56%-111% and 66%-132% for 1974
Otto and Havlicek	1981	USA	Corn Wheat Soybeans	1967-79	EC	152%-210% 79%-148% 188%
Sundquist et al.	1981	USA	Maize Wheat Soybean	1977	EC	115% assumes a research lag of 6 years for the three crops and includes a 97% research spillover variable to account for the effects of research 118% across state boundaries.
da Cruz et al.	1982	Brazil	Physical capital Total investment	1974-81 1974-92	ES	53% 22%-43%
Evenson	1982	Brazil	Aggregate	1966-74	EC	69%
Ribeiro	1982	Brazil (M. Gerais)	Aggregate Cotton Soybeans	1974-94	ES	69% 48% 36%
White and Havlicek	1982	USA	Aggregate	1943-77	EC	7%-36% — includes extension
Yrarrazaval et al.	1982	Chile	Wheat Maize	1949-77 1940-77	ES	21%-28% 32%-34%
Zentner	1982	Canada	Wheat	1946-79	ES	30%-39% — includes extension
Avila et al.	1983	Brazil (EMBRAPA)	Human capital	1974-96	ES	22%-30%
da Cruz and Avila	1983	Brazil (EMBRAPA)	Aggregate	1977-91	ES	38% (20% for an EMBRAPA-IDRC project in 1977-82)
Martinez and Sain	1983	Panama (IDIAP-Caisan)	Maize (on-farm research)	1979 82	ES	188%-332%
Nagy	1983	Pakistan	Maize Wheat	1967-81	ES	19% — includes extension 58%

Appendix B (Continued)

Table 10 References;

ᵃ Studies are listed in chronological and alphabetical order respectively. Total number of studies listed in table is 136 with the following regional distribution: Sub-Saharan Africa - 6; Asia - 23; Latin America and Caribbean - 35; total less-developed countries - 65; more-developed countries (U.S.A., Canada, Australia, New Zealand, Japan, Israel and Western Europe) - 71.

ᵇ Methodology used: *ES* = Economic surplus *EC* = Econometric.

ᶜ Depending on the methodology utilized in the study, these are average rates of return (economic surplus methods) or marginal rates of return (econometric methods). The occurrence of more than one value is the result of different assumptions, periods of analysis and model specification. Results are rounded. Results of conducting sensibility tests on various parameters of the models are not presented in this table.

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Table 11: Kenya: Calculation of Rate of Return to Maize Research, 1955-88.

(a) Marginal Rate of Return (MRR)

YEAR	MRE (K£)	BENEFITS (K£)	MRR(%)
1955	79560		
1956	86301		
1957	88832		
1958	99100		
1959	89402		
1960	91067		
1961	95050		
1962	98605		
1963	94105		
1964	119316		
1965	123739	3359445	45.54
1966	136834	4205820	47.48
1967	143253	3452924	44.20
1968	168446	2824647	39.79
1969	194579	2597562	40.06
1970	260816	2354378	38.44
1971	203815	3534710	43.56
1972	213886	3628495	43.41
1973	204195	3080544	41.74
1974	185368	3639347	40.74
1975	216464	5463819	46.05
1976	234524	5673138	45.13
1977	239197	6849479	47.22
1978	298090	5721437	42.27
1979	256437	4826376	37.86
1980	216448	5861908	36.51
1981	186670	4868457	37.35
1982	143067	3824449	33.43
1983	106660	5784639	39.71
1984	92293	4542570	37.70
1985	108772	6035377	39.49
1986	74087	6366767	39.11
1987	172045	6169541	38.40
1988	105614	6687926	36.49

$$MRR(\%) = [1-(B/MRE)^{1/10})]*100$$

where B = Benefits; MRE = maize research expenditure

The mean (average) Marginal Rate of Return = 40.90

Table 11 (Continued)

(b) Average Rate of Return

Using the regression equations on maize yield and area, and mean values of the explanatory variables, the following values are obtained:

Y_0 = 737.90 kg/ha; Y_R = 1385.78 kg/ha; A_0 = 679752.34 ha;

A_R = 1066280.10 ha;

$V_0 = P*(A_0 * Y_0)$ and $V_R = P*(A_R * Y_R)$; Benefit $(B) = (V_R - V_0)$;

where P = 29.022 K£ per ton.

$$\text{Average ROR} = [\ 1-\{(B/MRE)^{1/10}\}]*100$$
$$= [\ 1-\{(28326644/157094.54)^{1/10}\}]*100$$
$$= 68.11\%$$

where Y_0=Average Maize yield before research impact; Y_R=Average Maize yield after research impact; A_0=Average area under maize before research impact; A_R=Average area under maize after research impact; V^0=Average value of maize before research impact; V_R=Average value of maize after research impact; B=benefits of research or increase in the value of maize production due to research; ROR=rate of return; MRE=Average maize research expenditure; and P is average official producer price for maize.

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