

**Meeting Development Objectives with Agricultural Research:  
Priority Setting in Zimbabwe**

by

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**(ABSTRACT)**

In times of tightening national budgets as a result of structural adjustment requirements, the need to make choices in Zimbabwe's publicly funded research is heightened. Adoption of quantitative priority setting methods help improve the objectivity of decision-making while fostering consistency of research priorities with the attainment of research system objectives. This study develops and applies a quantitative methodology for agricultural research priority setting for Zimbabwe's Department of Research and Specialist Services (DR&SS) under multiple objectives. Such a methodology must incorporate the structural characteristics of Zimbabwe's agricultural sector: the existence of different farmer types, five different agro-ecological regions and multiple objectives.

A three part procedure was used in this study to prioritize agricultural research in Zimbabwe. The first part involved identifying the research objectives, defining the list of commodity and non-commodity programs to be prioritized, defining the agro-ecological zones and collecting technology related data and published information. Researchers, extension workers, and farmer representatives were interviewed using a questionnaire to obtain

technology-related data. The second part involved economic analysis to measure the contributions of agricultural research to total economic benefits and their distribution by farmer type and agro-ecological region. Net present values (NPV) of economic surplus gains by research program were used to summarize the total economic efficiency gains projected over fifteen years. Once the benefits have been estimated, the third part of the procedure involved using mathematical programming (MP) to project the optimal allocation of research resources among the various commodities under alternative weights on objectives.

A ranking of the expected NPVs indicated that agricultural research priorities are different between smallholder farmers and large scale commercial farmers, with maize cotton, groundnuts, sunflower, goats, pulses and millets being of high priority for smallholder farmers, while maize, beef, cotton, coffee, wheat, dairy, stonefruit, soybeans and roses were top priority for large scale commercial farmers. Research discipline priorities for smallholder farmers include agronomy, plant breeding and chemistry and soils while for large-scale commercial farmers the priorities are plant breeding, agronomy, and plant protection. Optimal allocation of research resources given two objectives (efficiency and equity) were assessed in a series of runs with the mathematical programming model. The tradeoff costs associated with putting an extra weight of different sizes on the equity objective, given the current total budget constraint were relatively modest implying that DR&SS can allocate resources to research on smallholder farming without great loss in efficiency.

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## List of Abbreviations

ADA	Agricultural Development Authority
AFC	Agricultural Finance Corporation
AGRITEX	Department of Agricultural and Extension Services
AMA	Agricultural Marketing Authority
ARC	Agricultural Research Council
CA	Communal Area
CMB	Cotton Marketing Board
CPI	Consumer Price Index
CSO	Central Statistical Office
DMB	Dairy Marketing Board
DR&SS	Department of Research and Specialist Services
ESAP	Economic Structural Adjustment Program
GDP	Gross Domestic Product
GMB	Grain Marketing Board
LSC	Large Scale Commercial
MOA	Ministry of Agriculture
NPV	Net Present value
RA	Resettlement Areas
SSC	Small Scale Commercial
Z\$	Zimbabwean dollar

## **CHAPTER ONE**

### **INTRODUCTION**

#### **1.1 Introduction**

Zimbabwe's agricultural sector has experienced major adjustments resulting from political and economic changes since it was first colonized by European settlers in 1890. The government, prior to independence in 1980, pursued an agricultural policy that focused exclusively on developing the large-scale commercial farming areas owned by European farmers and companies. As a result, the agricultural sector inherited at independence was dualistic in character with large-scale commercial and smallholder<sup>1</sup> farms co-existing.

The large-scale commercial sector comprised 6,000 farmers owning 42 percent of the land located in the high potential agro-ecological regions, while 1 million smallholder farmers owned about the same amount of land but were located in semi-arid regions. This inequality was further exacerbated by the inequitable distribution of input, marketing, and credit facilities which were wholly biased towards the large-scale commercial sector. The agricultural institutions, research, and extension were established and modeled to support the commercial farming sector while smallholder agriculture was largely neglected.

Agricultural research priorities were based on the need to achieve national self-sufficiency and to promote exports (Shumba, 1990). There was a close linkage between the needs of commercial farmers and the programs of the Department of Research and Specialist

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<sup>1</sup> In this dissertation smallholder is defined to include communal, resettlement, and small scale commercial farmers.

Services (DR&SS). Priorities were not set formally, but were well articulated through the close interactions between commercial farmers and the research and extension departments.

After independence, the new government set out to redress the marked differences between the two types of farmers created by the colonial regime. This meant the re-direction of resources towards those areas that had been neglected or given low priority including education, health, and civil service employment. For the agricultural sector in particular, a massive expansion of product marketing and credit facilities for rural areas took place, a land resettlement program was initiated, and agricultural research and extension were reorganized to cater to smallholder farmers. Thus agricultural policy objectives were expanded, with emphasis placed on the smallholder sector and environmental sustainability.

However some macroeconomic policies inherited and maintained from the previous regime still discriminated against agriculture. These included producer and consumer price controls, wage controls, huge foreign borrowing, foreign exchange allocation and exchange rate misalignment; instruments typical of an import-substitution development strategy. The increased aggregate demand resulting from increased spending, combined with two exceptionally good years of rain two years after independence resulted in significant economic growth. However in the late 1980s, the country experienced economic difficulties, with the economy characterized by declining investment, low growth rates, weak export performance, and increasing unemployment. The government realized the problems resulting from its macro-economic policies, and in 1990 began to implement a structural adjustment program.

The economic policy reforms, which are aimed at stimulating investment and economic activity, include deregulation of financial and labor markets, reduction of government expenditures, eradication of the budget deficit, and liberalization of trade. For the agricultural sector, the reforms seek to eliminate price and wage controls, and to rationalize research and extension. Thus the DRSS is expected to meet the challenges specified by the broadened research policy agenda with increasingly limited resources exacerbated by the changes in fiscal policies which require reduced government expenditure.

Resources are allocated to research at different levels in the research system. Strategic research priorities are set across commodity and disciplinary programs that affect the locational emphasis of research, the focus on particular factors of production, and the distributional effects of research: for example, effects on different farm types and sizes, on people at different income levels, and on producers versus consumers. Strategic decisions guide a research system over several years. Research priorities are also set across projects and experiments within projects. The purpose of this study is to develop and implement an agricultural research priority setting procedure for Zimbabwe at the strategic level.

## **1.2. The Problem**

Agricultural research is an economic activity that involves the allocation of scarce resources to produce knowledge in order to increase agricultural productivity and to meet other societal goals. Therefore the challenge here is to be able to treat expenditures on agricultural research as an investment which has to improve agricultural productivity and, at the same time, meet other social objectives. Agricultural research must be able to compete with other government projects for the limited funds available. This implies that the Department of Research and Specialist Services must establish priorities and allocate

its limited resources among competing programs to maximize the ability of the Department to attain the nation's economic and social goals.

Agricultural research expenditures in Zimbabwe remained relatively static in real terms in the 1970s, and declined in the 1980s . The DR&SS is expected to fulfill multiple national objectives in the face of a decreasing budget allocation resulting from the changes in fiscal policy. The DR&SS has, since 1980, expanded both its on-station and off-station research efforts to address agricultural production problems in communal areas. "Unfortunately this expansion has not been matched by corresponding increases in financial resources forcing the department to cut out some of its programs." (Shumba, 1991). In order to avoid losing valuable research programs, there is a need to assess research priorities so that DR&SS can allocate available funds in an optimal manner to meet the demands for research services.

The new fiscal policy also calls for a decrease in the number of civil servants, implying that DR&SS faces an additional constraint of restricted manpower. In addition, trained manpower is scarce. There is therefore a need to quantitatively prioritize research to make optimal use of the given manpower.

Another issue facing the administrators of DR&SS and the government as a whole is whether agricultural research is the best instrument for meeting each of the social objectives. Given that there are other policy instruments that can be used to achieve the social objectives it is important to evaluate the relative effectiveness of agricultural research in achieving these objectives.

### **1.3. Justification**

DR&SS does not use formal planning tools in planning research programs and setting departmental policies (Shumba, 1990). Research program planning is the responsibility of individual researchers with the concurrence of the Heads of Institutes or Stations (HI/HS). The current procedures in research allocation require that the HI or HS and the scientists be familiar with the broad government agricultural policy guidelines and take them into account in their planning activities<sup>2</sup>. Generally, researchers are not keenly aware of the broader purpose of their research, nor the stated objectives of the department (Rukuni, 1993). The outcome is that funded research programs, activities, and projects are a collection of individually inspired or individually conceived projects and proposals based on individual interpretations of broad policy and departmental objectives moderated by the head of institute or station and divisional heads. This system may not yield the best results relative to the needs of the research clients. Additional guidance with respect to research priorities might produce research that is more responsive to specific objectives and client needs.

The previous years' resource allocation seems to be the major basis for the current year's allocation. While the Livestock and Pastures Division is an exception in being able to set divisional priorities, there is no formal mechanism of research allocation to match the identified priorities. This lack of prioritization may reduce the productivity of the research system and hurt its ability to respond to urgent problems of its principal clients, smallholder farmers. Given the country's current economic problems and structural

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<sup>2</sup> Based on discussions with DR&SS management.

adjustment requirements, there is a need for DR&SS to be cost-effective and efficient in its operations. Previous studies by economists have examined changes in agricultural productivity and the benefits of past agricultural research for the commercial sector in Zimbabwe (Thirtle *et. al*, 1993). But few studies have considered research priority setting procedures, especially as related to the communal sector. Also according to Norton, 1991, a common mistake with priority setting studies is to list and rank but not suggest an allocation of resources. This study will provide priority setting information on research benefits by research program that will help decision-makers decide the amount and share of total resources to allocate to various programs. Developing a quantitative approach to priority setting can help foster consistency of research priorities with the attainment of national goals.

#### **1.4. Objectives of the study**

The general objective of this research is to develop a process for agricultural research priority setting in Zimbabwe at the national level. The priority setting analysis will provide information on research benefits by program and on the trade-offs involved in allocating resources to research programs given the country's multiple objectives. The results will be generated with the involvement of research directors, scientists, and industry representatives to facilitate arriving at a consensus on research priorities.

The specific objectives are to: 1) design and apply a method that can be used to assist the government of Zimbabwe in setting agricultural research priorities and making strategic decisions on research resource allocations, and,

2) evaluate opportunity costs associated with using agricultural research to achieve non-efficiency objectives.

### **1.5. Procedures**

A three-part procedure is used in this thesis to prioritize agricultural research in Zimbabwe. The first part involves identifying the research objectives, defining the list of commodity and non-commodity programs to be prioritized and agro-ecological zones, developing a questionnaire and interviewing scientists, national research administrators, research station directors and extension workers in order to obtain technology-related data and collection of published information. Technology-related data include anticipated per unit cost reduction or yield increase, probability of research success, time required to complete the research, extent of adoption, research depreciation and the effect of research on product quality and published data include market-related data and research costs per research program. Once the first round of interviews on technology-related data is completed, the responses to the questions are summarized and presented to program leaders, station directors, and other knowledgeable people who assess and suggest adjustments.

After refining the data, the second part of the procedure involves use of economic surplus analysis to measure the contributions of agricultural research to total economic benefits and their distribution by farmer type and agro-ecological region. A spreadsheet computer program is used to incorporate the market data, technical data, and economic formulas to calculate research benefits under two levels of research resources. Net present values of economic surplus gains by research program are used to summarize the total economic efficiency gains. Benefits and costs are projected over fifteen years, and net present values to research calculated.

Once the benefits have been estimated, the third part of the procedure involves use of mathematical programming (MP) to project the optimal allocation of research resources among the various commodities under different weights on objectives. Application of the MP model involves the maximization of a multiple-goal objective function. The MP model incorporates research response relationships (coming out of the questionnaire and economic surplus models), that relate the marginal benefits of research to different funding levels for the research programs.

This combination method of economic surplus analysis and mathematical programming is used because it allows for the incorporation of multiple objectives for research, the fact that market and policy situations differ across commodities, explicit incorporation of the budget, human resource and other constraints in the research system, and selection of an optimal research portfolio.

## **1.6. Dissertation Outline**

Chapter 2 provides background information on agriculture and agricultural research in Zimbabwe. Chapter 3 presents a review of literature on theory and methods for agricultural research evaluation and priority setting. Chapter 4 gives a detailed description of the empirical application of the research priority setting methodology to Zimbabwe. The discussion includes the details on the procedures used to elicit technology-related data and other secondary data, the estimation of economic benefits, and the mathematical programming model. Chapter 5 presents the results of the priority setting analysis in Zimbabwe and interprets the results. Chapter 6 presents conclusions, policy implications and areas for future research.

## CHAPTER 2

### BACKGROUND ON THE AGRICULTURAL SECTOR AND AGRICULTURAL RESEARCH IN ZIMBABWE

#### 2.1. Introduction

Assessing agricultural research priorities in Zimbabwe requires an understanding of the structure of the agricultural sector and its past performance. Agriculture has undergone much adjustment over the past 30 years due first to the increased self-reliance forced on the economy during the UDI<sup>3</sup> period, and then to the changed economic and political priorities of the independent government<sup>4</sup>.

Agriculture plays a strategic role in the economy in terms of providing food, foreign exchange, employment and raw materials for industry, despite the fact that its contribution to Gross Domestic Product (GDP) in most years is less than 20 percent (see table 2.1). The agricultural sector of Zimbabwe is by far the largest source of employment, accounting for approximately 70% of informal employment in the rural sector and 26% of formal employment (World Bank,

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<sup>3</sup>UDI refers to Unilateral Declaration of Independence by the Smith government in 1965 from Britain. Through the British insistence, the world responded to UDI by imposing international trade and economic sanctions on Rhodesia until independence in 1980.

<sup>4</sup>Zimbabwe became independent in 1980 and changed its name from Rhodesia.

1990). Fifty percent of the manufactured output is dependent on agriculture for raw materials. The Zimbabwean economy is highly dependent on the agricultural sector for its foreign exchange earnings. Farm products account for about 40 percent of total exports (value terms).

Prior to 1980, agricultural growth was negative because of the war and the overall economic growth rate was also low (see in table 2.1). Between 1980 and 1990, agriculture grew by 2.4 percent, while the overall economy grew by 3.2 percent, a growth rate barely above the population growth rate of 2.9 percent. The importance of agriculture to overall economic growth is further indicated by the fact that the economic cycles experienced by the nation's economy are highly correlated with rainfall. A poor agricultural season has historically been associated with a poor economic performance in terms of national growth rates and private consumption,<sup>5</sup> and *vice versa* because of the strong interdependence between agriculture and the manufacturing sector. "Consequently, agricultural research in providing the new technologies for agriculture will be a primary engine of growth on which all national development efforts will ultimately hinge." (ISNAR, 1988). This chapter provides an overview of the country's agricultural sector and agricultural research. It describes Zimbabwe's physical resource base, land tenure and distribution, farming systems, agricultural production patterns, trends in input usage, and investment in and institutions affecting agriculture including government credit policy, irrigation, extension, research, product pricing and marketing, and trade and exchange rate policies.

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<sup>5</sup> CSO, 1989, p 100.

Table 2.1. Zimbabwe Key Macro-economic Indicators

	1970-1980	1981-1990	1991-1993
GDP Z\$ million (1980base)	2724.7	3780.4	4453.4
Agriculture Percent of Total GDP	17.0	14.6	12.2
Total Exports Z\$ million (1980base) <sup>1</sup>	787.5	826.5	1119.9
Real Agric. exports as % of Total Exports <sup>1</sup>	35.3	47.7	38.9
Exchange rate (Nominal, Z\$/ US\$) <sup>2</sup>	0.6	2.6	6.9
GDP growth <sup>3</sup>	0.6	3.2	4.3
Agriculture annual growth <sup>3</sup>	-0.6	2.4	3.1
Population (million) <sup>2</sup>	7.1	9.3	10.4
GDP / Capita (Z\$) <sup>4</sup>	383.8	403.5	428.2
Fiscal Deficit Z\$ million (1980base) <sup>2</sup>	375.0	347.0	302.0
Fiscal Deficit as percentage of GDP <sup>2</sup>	14.0	10.0	7.0
Average annual change in CPI (%)	8.0	14.0	43.0

<sup>1</sup> First and last column figures refer to 1980 and 1991 figures only, they are not averages. 1980base means that 1980 was used as the base year in deflating the figures.

<sup>2</sup> Figures refer to 1980, 1990, and 1993 for columns 1, 2, and 3 respectively.

<sup>3</sup> First column figures refer to 1979-80 average, and last column refers to 1991 only, in 1992 GDP growth was -6.2 an agricultural growth was -24.4 because of the drought.

<sup>4</sup> Calculated from dividing GDP by total population.

Source: Central Statistical Office, 1995, World Bank, 1995, and personal calculation.

It traces out elements in the agricultural sector that can help in determining agricultural research priorities. Differences in agro-ecology, land tenure and distribution, and farming systems have important bearing on how the results of agricultural research are adopted and hence on research priorities. Conditions and policies within particular product markets that distort agricultural research benefits are also discussed.

## **2.2. Zimbabwe's Natural Resource Base**

Zimbabwe is a landlocked tropical country situated in southern Africa. It is located between 15° and 22° south latitude and between 24° and 33° east longitude. The country has a total surface area of 390, 759 square kilometers and a population of 10.4 million (1992 census). The country is bordered by Zambia to the north, South Africa to the south, Mozambique to the east, and Botswana to the west. (see appendix 1).

The main topographical feature is the high plateau, the high veld, which runs from southwest to northeast across the country. The country's topography and the fact that it is landlocked give rise to a very diverse climatic structure. The high altitude areas generally receive higher rainfall and have lower temperatures compared to low altitude areas. Zimbabwe has three seasons: (i) a dry winter, covering the months from April to August, with cool temperatures especially at night when frost is sometimes experienced, (ii) a hot season with temperatures building up to a maximum in October and (iii) a wet summer season in which the main rains are received from November to March. Most of Zimbabwe's rainfall is received during the five summer months. A significant feature of the rainfall is its unreliability both in terms of amount and duration. The

onset of the rains, critical for planting, is rather unpredictable. The areas of lowest rainfall are also the areas of least rainfall reliability.

Zimbabwe's soils are derived predominantly from granite and are often sandy, light textured, and of only fair agricultural potential (Nyamapfene, 1992). In all regions, however there are some soils with heavier content having excellent cropping potential if irrigated. On the basis of the climatic pattern, altitude, and soil type, Vincent and Thomas classified the country into five agro-ecological regions with agricultural potential declining from Region I to Region V as shown in table 2.2 and appendix 1.0.

## **2.3 Farming Systems of Zimbabwe**

### **2.3.1. Farm Structure and Land distribution**

Zimbabwe has a number of distinct farming systems which reflect historical allocation and tenure as well as natural resources and available technologies: large-scale commercial, small-scale commercial, resettlement, and communal farming systems.

The large-scale commercial farm areas were the former European farming areas during the colonial period. They occupy 40% of the total area of Zimbabwe and are concentrated in the high potential areas: natural region I, II and III (See table 2.3). Commercial farming is well organized and financed and produces most of the marketed surplus. There are approximately 4,500 large-scale farms ranging in size from 200 to 2,200 hectares mostly owned by owner-operators, operating on an individual freehold tenure basis.

Small-scale commercial farm areas, the former African purchase lands, occupy 4% of all land. More than 70% of this land is located within Natural Regions III and IV where conditions for production are inferior to those in the large-scale commercial farm areas. There are approximately 8,600 small-scale farms with an average farm size of 124 hectares. As in the large-scale sector, small-scale commercial farm land is individually owned and titles may be registered.

Communal land areas (CA), the former tribal trust lands, occupy 42% of national land. This area was originally set aside for rural families by the colonial authorities and was largely neglected in the pre-independence period. Almost 75% of the communal lands are located in the low potential Natural regions IV and V (see table 2.3). Most communal area residents were displaced from other lands acquired by settlers, and almost always they were forced onto the most remote and dry lands with the shallowest soils. More than 50% of the total population lives in communal areas. Land tenure rules allow unrestricted access to grazing areas and individual rights to plots for houses, gardens and fields. "All CA land is nominally owned by the state and cannot be formally bought, sold, or rented." (Masters, 1991).

Table 2.2 The Natural Regions of Zimbabwe

Natural Region	Average Annual Rainfall (mm/ yr)	Area km <sup>2</sup>	% of Total National Area	Recommended Farming
I	> 1,000	7,050	1.8	Specialized commercial farming: forestry, fruit, tea, coffee, macadamia nuts and intensive animal husbandry
II	750 - 1,000	58,750	15.0	Intensive Farming: flue-cured tobacco, cotton, soybeans, coffee, groundnuts, horticultural crops, winter wheat, beef, dairy, poultry, pigs, and ostrich.
III	650 - 800	72,900	18.6	Semi-intensive farming: Livestock breeding, and marginal production of maize, tobacco and cotton
IV	450 - 650	147,700	37.8	Semi-extensive farming: Livestock breeding and production of drought resistant crops (e.g. millets)
V	< 450	104,500	26.7	Extensive farming: Extensive cattle farming or game ranching.
Total	650	390,900	100	

Source: Central Statistics Office, Statistical Yearbook (1989).

The majority of communal farmers are engaged in subsistence farming. In the better agricultural areas, they are becoming increasingly commercialized. Communal land tenure arrangements have been criticized for creating disincentives for investment and development and for having detrimental effects on the environment. The communal lands have very high population densities of about 25 people per km<sup>2</sup>, while the commercial farms have a density of about 9 and urban areas of 870 (Zimbabwe Government, 1992). Over the years, rapid population growth and the limited land resources have resulted in overpopulation and deterioration of the land resources.

Resettlement areas are a product of the post-independence government land-redistribution efforts. Communal families are resettled on underutilized land bought from the large-scale commercial sector. The tenure system is based on permits which authorize settlers to reside, cultivate, and graze livestock on the land (Rukuni *et. al.*, 1995). The permit requires that the farm be used productively or the farmer loses access to land, and the system appears less secure than the one for communal areas.<sup>6</sup> Land allocations are made administratively at standard rates of five arable hectares per household and communal grazing for animals. This size is substantially larger than average farm sizes in the communal areas. By 1994, 57,000 families had been resettled on almost 3.3 million hectares, of which 2.7 million hectares were purchased from large-scale commercial farmers (Ministry of Agriculture, 1996).

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<sup>6</sup> Following recommendations by the land tenure commission, a new Land Act is to be introduced which will allow resettled families to get long leases with options to purchase.

Table 2.3. Zimbabwe Land Distribution by Farm Sector and Natural region (% of total), 1988.

Natural Region	Area 000 ha	Large-scale Commercial %	Small-scale Commercial %	Communal Areas %	Resettlement areas %	State Farms %	Parks & Wildlife %
I	700	1.8	0.6	0.8	0.9	2.0	1.0
II	5 860	32.8	17.9	7.8	17.9	2.0	0.5
III	7 290	21.5	35.4	17.2	37.8	32.0	11.0
IV	14 780	21.7	38.2	44.9	24.6	12.0	50.3.0
V	10 440	22.2	7.9	29.3	18.8	52.0	37.2
Total area (000 ha)	39 070	11 213.0	1 239.0	16 365.0	3 290.0	500.0	4 978.0

Source: Rukuni *et. al.* (1995, p. 417)

The actual pace of land purchase and resettlement is determined by financial availability as prescribed by fiscal targets. Most of the land acquired for resettlement is of poor quality due to the fact that land was sold on a willing buyer and willing seller basis. Although the program has brought more land under production, production levels realized so far do not seem to justify the investment. Shortage of funds, droughts, and poor management skills have been cited as the reasons for the program's failure (Rukuni *et. al.*, 1995). The resettlement program now places heavy emphasis on proper farmer selection. Masters (1994) argues that higher productivity from the resettlement program can be achieved through a market-based system where land allocations can be more closely tailored to local conditions and each family's resources and skills.

The existence of different farm groups and agro-ecological regions means that research benefits may not be equally distributed among farmers. Producers at different income levels, with different farm sizes, in different locations, and with diverse land tenure situations can gain or lose depending on the suitability of the new technology to their particular situations (Alston *et. al.*, 1995). Therefore in undertaking agricultural research priority setting, the distribution of benefits needs to be taken into account.

### **2.3.2. Agricultural Production Patterns**

Agricultural production patterns in Zimbabwe are strongly determined by the agro-ecological zones, and in large-scale commercial areas, production closely follows the production systems indicated by the natural regions indicated in table 2.2. The average cropping patterns of the smallholder sector and the large-scale commercial sector for selected crops are shown in table

2.4. As indicated in the table, communal farmers are actively involved in the production of maize, cotton, sunflower, and the traditional crops. What is not indicated in this table is the fact that maize is the dominant crop grown by smallholder farmers in both the low and high potential areas.<sup>7</sup> According to the Ministry of Agriculture Farm Management survey, in the high potential areas, maize is the main source of income, whereas in the low potential areas beside maize, the millets which are drought resistant and groundnuts are also major sources of income. Large-scale commercial farms produce on a commercial basis maize, soybeans, cotton, groundnuts, barley, wheat, tobacco, coffee, tea, sugar-cane, dairy, beef, pigs, and poultry. In recent years, commercial farmers have diversified into horticultural production in particular flowers and wildlife farming, such as, ostrich, and crocodiles. The large-scale commercial farmers are substantially more capital intensive and technologically advanced than the majority of farms in other subsectors.

Compared to smallholder farmers, production in the large-scale commercial sector is more diversified in the aggregate, although individual farms may be more specialized. Many of the large-scale commercial farms (32.8 percent) are located in natural region II. There is widespread use of irrigation, chemicals, tractors, and combine harvesters. "Yields are typically among the highest in the world, with high levels of input use" (Masters, 1994) (see table 2.5).

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<sup>7</sup> Natural regions IV and V are too dry for successful crop production without irrigation, but communal farmers grow maize in these areas despite the low rainfall. Maize yields are very low and there is very high risk of crop failure. Survey evidence presented by Jayne, 1994 indicates that smallholder farmers in low potential areas have higher propensity to plant maize rather than cash crops such as oilseeds.

Table 2.4. Cropping Patterns By Farming Sector (in % of Cropped Land Under Indicated Crops)

Commodity	Communal Areas (1987-89)	Resettlement areas (1991)	Large Scale Commercial (1993)	Small Scale Commercial (1991)	Zimbabwe Total <sup>1</sup>
Maize	51	54	39	55	49
Millet	15	6	*	4	12
Cotton	8	11	7	11	8
Groundnuts	9	11	*	12	8
Sorghum	8	3	2	1	7
Sunflower	5	10	1	9	5
Tobacco	*	1	18	*	3
Wheat	*	*	9	*	2
Soybeans	*	*	8	*	1
Others	4	5	14	8	6
Total	100	100	100	100	100

<sup>1</sup> Weighted average of the sub-sector figures.

\* Less than 1% when rounded.

Source: Ministry of Agriculture, 1996.

Table 2.5. Comparative Yields for Major Crops ( 1989-91 average: tons/ha)

Commodity	Large Scale Commercial	Communal Areas	Resettlement areas	Small Scale Commercial	Zimbabwe Average	Africa Average
Maize	4.73	1.28	1.33	1.77	1.60	1.65
Sorghum	3.01	0.55	0.51	0.54	0.59	0.78
Pearl Millet	--	0.60	0.58	0.45	0.51	0.71
Finger Millet	--	0.54	0.62	0.57	0.51	0.71
Wheat	5.51	--	3.49	--	5.66	1.64
Cotton	2.00	0.82	0.99	0.70	1.34	1.01
Soybean	2.14	0.85	0.69	0.68	2.16	1.07
Groundnuts	3.07	0.50	0.52	0.56	0.58	0.82
Sunflower	0.72	0.52	0.65	0.51	0.77	0.91

Source: Ministry of Agriculture, 1996.

Many smallholder producers depend on livestock (cattle or donkeys) to provide tillage with an ox-plough or transport with ox-cart. All other operations such as weeding, manuring, harvesting and threshing are done by hand. Small-scale commercial farmers and communal farmers own or hire tractors and other mechanical equipment. Several donor-funded tractor-hire schemes are in operation, but they require large subsidies because long distances between fields, small field sizes, high capital and maintenance costs typically make tractor plowing more intensive than ox-drawn ploughing (Masters 1994). Most of the communal farmers typically operate on a subsistence basis, so that in a typical year about half of the smallholder production is devoted to home consumption. As a result the large-scale commercial sector dominates most formal marketing of the listed crops. Yields on smallholder farms are generally much lower than on the commercial farms. As shown in table 2.5, yields in the large-scale commercial are about two to three times higher than in the three smallholder subsectors.

Clearly there are major differences in production patterns between large-scale commercial farms and communal farms. An agricultural research priority setting procedure must be able to capture these differences, justifying the need to set priorities by farmer types and agro-ecological zones.

#### **2.4. Changes in input usage**

This section describes changes in input usage. The aim is to identify government policies that could alter the relative prices of inputs and influence the direction of agricultural research.

### **2.4.1. Land**

Since independence there have not been major changes on land use besides the creation of the resettlement areas discussed above. The government is still developing a land reform program that could lead to the increase in average land holdings for smallholder farmers.

### **2.4.2. Labor**

The agricultural sector is by far the largest source of employment for the country. Employment and wage trends since 1954 are presented in table 2.6. The share of total formal employment in Zimbabwe's agricultural sector fell from 40 percent in 1964 to about 24 percent in 1992. "The pre-independence governments pursued low wage rate policies in order to provide a pool of cheap labor for commercial agriculture, mines and manufacturing sectors." (Zvinavashe, 1990). At independence, in 1980, in order to gain popular support and raise the wages of the poorly paid, the government instituted minimum wage legislation. The minimum wage policy, however, led to labor retrenchment and dampened new employment opportunities in the 1980s. "Employers substituted labor with machinery not because machines were substantially cheaper than labor, but to minimize government interference in their operations." (Zvinavashe, 1990). As a result several researchers questioned the viability and usefulness of this policy for its cost was clear, increased unemployment. (Ngobese, 1987). While commercial farms rely almost entirely on hired labor, smallholder farmers predominantly use family labor with less hired labor.

Table 2.6. Zimbabwe Employment and Wage Trends (1980base)

Year	EMPLOYMENT (000)			AVERAGE MONTHLY REAL WAGES (Z\$ 000)		
	AGRIC	NON-AGRIC	TOTAL	AGRIC	NON-AGRIC	TOTAL
1954	221	396	617	0.37	1.24	0.93
1955	228	415	643	0.38	1.31	0.98
1956	231	444	675	0.39	1.33	1.01
1957	230	470	700	0.39	1.43	1.09
1958	234	480	714	0.39	1.50	1.14
1959	235	481	716	0.41	1.50	1.14
1960	244	485	729	0.41	1.52	1.15
1961	245	472	717	0.40	1.57	1.17
1962	248	457	705	0.40	1.65	1.21
1963	262	434	696	0.43	1.75	1.25
1964	300	436	736	0.41	1.73	1.19
1965	295	453	748	0.40	1.75	1.22
1966	278	457	735	0.39	1.75	1.24
1967	278	473	751	0.38	1.76	1.25
1968	288	502	790	0.37	1.78	1.27
1969	308	527	835	0.36	1.85	1.30
1970	298	556	854	0.37	1.89	1.36
1971	311	581	892	0.36	1.97	1.41
1972	342	611	953	0.36	2.04	1.44
1973	357	641	998	0.38	2.11	1.49
1974	366	675	1041	0.39	2.18	1.55
1975	364	691	1055	0.42	2.24	1.61
1976	356	683	1039	0.35	2.24	1.33
1977	348	670	1018	0.36	2.20	1.37
1978	341	645	986	0.36	2.22	1.37
1979	335	650	985	0.37	2.19	1.36
1980	327	683	1010	0.38	2.53	1.55
1981	294	743	1037	0.56	2.47	1.65
1982	274	772	1046	0.62	2.76	1.89
1983	264	770	1034	0.59	2.44	1.71
1984	271	765	1036	0.54	2.56	1.55
1985	275	787	1062	0.53	2.69	1.61
1986	275	806	1081	0.51	2.57	1.54
1987	263	820	1083	0.48	2.56	1.52
1988	277	854	1131	0.51	2.67	1.59
1989	285	881	1166	0.49	2.65	1.57
1990	290	877	1167	0.67	3.59	2.13
1991	304	929	1233	0.57	2.97	1.77
1992	300	936	1236	0.32	2.54	1.43
1993	324	916	1240			

Source: Up to 1990, Masters, 1994, from 1991 onwards personal calculations

The minimum wage and employment legislation caused inflation and increased costs of production making agricultural products less competitive on world markets. The ultimate aim of the economic reform program (ESAP) is to relax or remove all the regulations governing the labor market. With the commencement of ESAP, direct intervention in wage setting has already been replaced by collective bargaining. The average agricultural wage also has been much lower than average earnings of non-agriculture (table 2.6). This lower wage means that in terms of cost of production agriculture labor costs have been relatively low compared to other sectors.

### **2.4.3. Capital**

As indicated earlier, the large-scale commercial sector is heavily mechanized, relying on vehicles, tractors and equipment such as combine harvesters, irrigation systems, milking equipment, and more recently mechanical cotton pickers. Almost all machinery is imported. Since independence, approximately 800 tractors (agricultural) per annum have been imported and assembled (Government of Zimbabwe, 1996). To date there are 20,000 tractors in the large-scale commercial sector. Most imports were aid-funded through schemes run by the World Bank, export retention schemes, or through the Zimbabwe Tobacco Association. Prior to the initiation of the structural adjustment program, prices of tractors were controlled by the government which set a 30 percent markup on the cif value. With the economic reforms currently underway, the government has decontrolled tractor prices.

In the small-scale commercial farming sector, about 4,500 tractors are available. However, animals are still the most reliable source of draft power because of the poor state of tractor repair. In resettlement areas, the main source of draft power is supposed to be animals, but since most of the settlers do not own any animals, these farmers hire state tractors from a state hire service operated by the District Development Fund (DDF). In communal areas, about 90 percent of draft power is from cattle or donkeys, with the remainder from tractors hired from DDF. The state tractor hire service is subsidized. While data on investment in the smallholder sector is scarce, investment in commercial agriculture shows an overall increase in real terms since 1983 (see table 2.7). The data indicate that the major investment is for irrigation works followed by tobacco barns.

#### **2.4.4. Variable Inputs**

The amount of fertilizer used by farmers has increased dramatically since 1980 (table 2.8). Of significance is the increase in fertilizer use by the smallholder sector. However use of fertilizer is generally lower in the smallholder sector because it is less profitable because of low fertilizer productivity under low levels of rainfall and high fertilizer costs because of high transport and credit costs (Rukuni, 1995). The dramatic increase in fertilizer sales to the smallholder farmers in 1981 was due to several factors including exceptionally good weather in 1981, a return to rural peace, favorable pricing and the post-independence credit thrust aimed at smallholder farmers (Masters, 1994). Fertilizer use in the large scale-commercial sector is, by contrast, high as shown in table 2.8.

Table 2.7. Total Real Investment in Commercial Agriculture (Z\$ million, 1990 base)

	1983	1990	1992
Housing & Facilities	5.38	2.10	1.5
Tobacco Barns	3.52	6.12	7.27
Other Buildings	4.71	6.35	5.41
Fencing	2.97	2.85	1.95
Irrigation Works	7.09	9.84	12.75
Land Conservation	2.07	1.42	1.28
Orchards & Plantations	1.43	2.44	2.29
Fishery	.01	.19	0
Other	.54	3.01	3.29
Total	27.73	34.33	35.72

Note: Deflated by Building Materials Price Index.

Source: Ministry of Agriculture, 1995.

Table 2.8. Fertilizer Sales By Farming Sector and Percent of Farmers Applying Fertilizer:  
1974 - 1992

Year	Communal		Large Scale Commercial		Small Scale Commercial		Resettlement	
	`000 t	%	`000 t	%	`000 t	%	`000 t	%
1974/75*	24.0		425.0					
1979/80*	27.0		328.0					
1986/87	79.7	17	338.1	73	11.9	3	32.5	7
1989/90	92.4	19	364.9	77	7.9	2	10.6	2
1991/92	60.4	14	368.6	83	6.2	1	9.4	2

\* Data for communal includes small scale sector.

Source: Rukuni *et. al.*, 1995, p441.

According to a study by Vudzijena, fertilizer use by smallholder households is concentrated in the high rainfall areas. The low levels of fertilizer adoption in the low rainfall areas reflect the high incidence of drought associated with increased production risk.

Since 1940, the seed industry has been supported by research and plant breeding carried out by government and statutory boards. For most of the field crops in Zimbabwe, there are locally-bred, well-adapted varieties for particular ecological and farming conditions (Tattersfield *et. al.*). However while the large-scale commercial farmers are able to get the seed of the right varieties when they require it, the smallholder sector still faces several limitations such as lack of funds, poor seed distribution in the rural areas, and lack of suitable seed varieties.

Agricultural chemicals (pesticides, insecticides, herbicides, fungicides, bactericides, nematocides and plant growth regulators) are produced under a high degree of competitive pressure. The industry blends and packages imported materials, with a local value added generally under 20 percent. Virtually all sales (over 98%) are to the large-scale commercial sector (Masters, 1991). In total about 4,312 tons of crop chemicals are sold each year; insecticides account for 67.4 percent, herbicides 23.4 percent, and fungicides about 9.2 percent (Government of Zimbabwe, 1995).

The foregoing section has highlighted the marked differences in input availability and affordability by the different farm types, implying that each farm type has unique research requirements, and justifying the need to set priorities by farm type.

## **2.5. Investment in Agriculture**

This section presents the major types of public and private investment in agriculture, including credit, irrigation, transport, extension, agricultural research, and marketing.

### **2.5.1. Credit**

There are three formal sources of finance for farmers: the government parastatal Agricultural Finance Corporation (AFC), commercial banks, and commercial firms accounting for 25; 52, and 23 percent respectively. The AFC provides short-term (for variable inputs), medium-term (for investment like machinery, irrigation) and long-term loans (for major capital investment). In the rural areas, formal financial markets are not well developed. As a result, the government parastatal is the only formal lending institution in the rural areas.

Prior to 1980, the large-scale commercial farmers received the lions share of credit from the AFC (ie. >98%). Since then, the communal farmers have also received loans as presented in table 2.9. Communal farmers repayments are recovered through stop orders on their sales through the marketing boards. However, between the period 1979 and 1989, AFC's loans to farmers totaled Z\$1295.4 million, of which 6.5% became bad debt and about 5.8% of the loans had to be paid by the government (Government of Zimbabwe, 1991).

Table 2.9. Number and Value of loans granted by Sector by the Agricultural Finance Corporation (current market prices)

Year <sup>1</sup>	Large Scale Commercial		Small Scale Commercial		Resettlement		Communal	
	Number	Value (Z\$m)	Number	Value (Z\$m)	Number	Value(Z\$m)	Number	Value Z\$m
1981	2526	86.9	3333	3.7			18000	4.2
1982	2103	88.8	3649	4.6	911	.5	30150	10.1
1983	1645	88.7	2953	4.5	4154	1.5	38912	13.2
1984	1400	110.2	3052	8.1	19874	10.6	50036	23.4
1985	1484	110.3	2744	8.7	19926	10.7	65793	32.0
1986	1308	114.0	2569	11.5	13866	8.5	77526	38.9
1987	1007	94.9	1910	9.6	11800	8.6	77384	60.0
1988	990	111.2	1542	6.8	11217	9.0	69885	49.4
1989	900	117.4	140	5.3	7022	5.9	57679	41.3
1990	969	136.3	844	4.5	5193	5.9	43846	33.4
1991	1133	195.1	761	3.6	4658	4.7	30190	26.4
1992	1499	358.2	727	6.8	6307	10.5	27344	29.7
1993	1340	248.5	376	7.6	4624	13.7	15973	34.0

<sup>1</sup> Year ended March.

Source: Chimedza, 1994.

Some communal farmers were selling through markets other than the marketing boards to avoid paying stop orders. As a result, the AFC has adopted stringent rules. It now loans to groups instead of individuals in order to reduce administrative costs and to put group pressure on borrowers to keep up repayments. This pressure has resulted in a decline in the number of seasonal loans to the smallholder sector which has led to a general decrease in the fertilizer market share of the smallholder sector (Chimedza, 1994). There also exists informal or semi-formal financial initiatives in the rural areas which include savings clubs, rotating savings and credit associations.

### **2.5.2. Irrigation**

Zimbabwe receives seasonal rainfall, and moisture is probably the primary constraint on soil productivity in the dry season or during occasional drought periods. There is thus a need for water storage and irrigation. In 1991, land under irrigation was estimated at 104,500 hectares. Of this: 68 percent was for large-scale commercial farms, 20 percent for corporate estates, and 7 percent for land under the state farming agency ADA. The remaining 4 percent comprised smallholder irrigation schemes run by Department of Agricultural, Technical and Extension services (AGRITEX), (Rukuni, 1995). Within the large-scale sector, the proportion of land irrigated varies widely by crop with wheat, cotton, groundnuts, soybeans, sugar, coffee, maize and tobacco the major irrigated crops. The bulk of irrigation facilities in the large-scale commercial sector have been privately developed and are privately owned by individual large-scale commercial farmers or a partnership of neighbors.

Government efforts to improve food security in drought-prone areas before and after independence led to the establishment of smallholder irrigation schemes in communal lands. By 1991, 4,775 hectares of irrigation land were farmed on 70 schemes by 7,900 families on communal lands (Rukuni *et. al.*, 1995). In 1985 a special credit facility for construction and irrigation equipment aimed at development of new private irrigation (The National Irrigation Fund), was established. The fund was intended to assist both large-scale commercial and smallholder farmers to expand the area under irrigation at a subsidized interest rate. The fund had an initial allocation of Z\$18 million of which about Z\$6 million was earmarked for smallholder schemes that were appraised as financially viable. Because of various constraints which include the small size of individual farms, communal land tenure, distance from markets, lack of electricity where pumping is needed etc., none of the Z\$6 million was tapped by smallholders in 1985 and 1986, and less than Z\$50 000 had been allocated by 1990 (Rukuni *et. al.* 1995).

Large-scale commercial farmers are required to produce wheat to qualify for the irrigation fund. This facility has been highly successful among large-scale commercial farmers who have found the interest rates attractive. Once these farmers have established their physical facilities, they have generally found that wheat is not profitable, so they have diversified into tobacco, cotton, and horticulture (Rukuni *et. al.* 1995).

### **2.5.3. Transport infrastructure**

Transport infrastructure is an important input affecting farm costs. The state and availability of transport determines the costs of moving inputs and outputs. The road network is well developed for the large-scale commercial farms because of the preferential treatment given to commercial farmers during the colonial era. According to Masters, the large-scale commercial farms have a road density that in per capita terms rivals that of the United States, while the rural areas have a road network that is among the best in Africa and better than that in Asia in per capita terms. While the major roads leading to most rural areas are well developed and well maintained, the road network connecting points within the communal areas are not well developed.<sup>8</sup> A large proportion are earth tracks and are not easily accessible particularly during the wet season, hindering the timely delivery of inputs and outputs. Since the road infrastructure in rural areas is still relatively undeveloped, transport is a major cost for agricultural production and marketing in rural areas.

### **2.5.4. Agricultural Extension**

Agricultural extension, a main form of research technology transfer, can play an important role in transmitting information about farmers' needs to researchers. Until independence, the extension services of commercial farmers and smallholder farmers were separate, with smallholder farmers serviced by the Department of Agricultural Development, DEVAG, while the Department of Conservation and Extension, CONEX serviced commercial farmers. As with research services, the commercial farmers were better served than the African farmers. At independence the two departments merged to form the current Department of Agricultural,

Technical and Extension services (AGRITEX). The objective of AGRITEX is to provide the country's diversified agricultural sector with services which stimulate the adoption of proven agricultural practices leading to increased, sustainable and profitable production with a special focus on the smallholder sector in order to redress past inequities.

The services provided include crop and animal production, land use planning, agricultural management, soil and water conservation, agricultural engineering and irrigation. AGRITEX has an extensive network of field and technical services organized on a provincial, regional and district basis. At the field level the extension service provides more than just agricultural extension. It is involved in a number of coordinating roles for other public and private organizations. As of 1989, AGRITEX had a staff of 2500 of whom 1600 were extension agents. The diverse nature of the agricultural sector in both clientele characteristics and production systems has necessitated the use of a variety of extension approaches. These include group extension, master farmer training, and training and visit system. Because the ratio of extension workers to farming households is quite small, with a national average of 1:758, the group approach has been widely adopted (Pazvakawambwa, 1994).

Many informal linkages have been established between AGRITEX and DR&SS. All research institutes undertaking on-farm research have operated through the AGRITEX district network and have used AGRITEX officers to assist with identification of farmer participants, administration of surveys, management of on-farm trials and organization of field days and visits. This research-extension linkage is based on the Committee for On-Farm Research

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<sup>8</sup> According to Masters, 1991, average road density km/1000 persons was 20.3 in large-scale commercial

(COFRE). The commercial farmers union, a farmer organization for the commercial farmers, provides highly specialized advice to commercial farmers. Similarly, fertilizer, seed and crop chemical companies have a network of sale representatives who promote their products in an extension fashion.

### **2.5.5. National Agricultural Research System**

Research is the main source of technological innovations and is, thus, very important in strengthening the country's agricultural potential. It is only through continued agricultural technological breakthroughs that sustainable growth in agricultural productivity and hence the competitiveness of Zimbabwe's agricultural capability can be achieved or improved. According to the First Five year National Development Plan (1980-1985), the growth of agriculture was targeted at an average of 5 percent per year, but the actual growth rate was 2.7 percent. The current growth target is 3.3 percent. Such targeted growth in agricultural output can only be achieved with the help of improved technology.

Markets function best where goods are rival and exclusionary. Agricultural research, however, has properties of a public good because much of the knowledge produced by research has nonrivalness and nonexcludability characteristics. Therefore much research ends up being funded by government. Agricultural research in Zimbabwe comprises both private and government funded research organizations. Government funded research includes the Research and Specialist Services and the Veterinary Services Department. Private funded research include the Tobacco Research Board, Agricultural Research Trust, Zimbabwe Sugar

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farming areas compared to 4.9 in communal areas, for Zimbabwe in 1983.

Association research station, Pig Industry board and Zimbabwe seed companies. While private-funded research contributes considerably to national research, public-funded research is by far the greater contributor. The main public research organization in Zimbabwe is the Department of Research and Specialist Services (DR&SS). The following section gives an account of the historical evolution of DR&SS.

#### **2.5.5.1. Historical Evolution of The Department Of Research and Specialist Services<sup>9</sup>**

Formal agricultural research in Zimbabwe started in 1903 with the establishment of the Department of Agriculture. The key task of the department was to foster the development of the agricultural industry in the young colony. Initially the department's research involved testing newly introduced plants and conducting simple agronomic investigations. The prime concern was on increasing production of the export commodities (ie. cotton, tobacco, and beef). The Department's first agricultural research station, the Salisbury (now Harare) Experimental Station, was established in 1909. Over the next forty years a network of research stations, and testing and demonstration farms were established to cover different agro-ecological regions.<sup>10</sup> At the same time the Department's research activities became increasingly sophisticated and oriented towards supporting the European farmers in their efforts to establish a commercial agricultural sector based on modern production practices.

Maize research was initiated at the Salisbury research station, focusing on screening maize varieties and on fertilizer use. In 1932, the station started a maize breeding program which

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<sup>9</sup> Based on Mudimu, (1989) DR&SS and ISNAR (1985), Kupfuma (1995), and Roseboom, et al. (1995).

emphasized developing inbred lines. Years of maize breeding research resulted in the release of its first hybrid variety, SR51 in 1940, and an improved variety, SR52 in 1961. Cotton research started in 1925 with the establishment of the Cotton Research Station at Kadoma (then Gatooma). In 1934, the newly formed Tobacco Research Board took over the tobacco research activities and research station from the Department of Agriculture. The Department of Agriculture also made research progress on small grains, groundnuts, wheat and horticultural crops. Research work was devoted to testing and screening varieties for the local environment.

After the second world war, the lucrative markets for agricultural exports that opened up in Europe and the influx of European settlers gave rise to an increase in demand for new farm technology (Kupfuma, 1995). As a result, the Department of Research and Specialist Services (DR&SS) was created from the Department of Agriculture in 1948. A diversified commercial agriculture emerging from mainly the European settlers required systematic agricultural research and for provision of advisory services. DR&SS became the primary public agricultural research organization in Zimbabwe entrusted with the promotion of technical progress in agriculture. The DR&SS was organized into commodity- and discipline-based branches; tobacco, pastures, horticulture, dairy and poultry, animal husbandry, botany, conservation, crop production, entomology, extension., plant pathology and soil chemistry. During the period 1948 to 1970, DR&SS released improved crop varieties (maize, cotton, tobacco) and crop and livestock production practices, and established a tradition of excellence in research. (Tawonezvi, 1994). In 1950, the branch

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<sup>10</sup> See Mudimu, (1989) for a complete listing of the research stations.

of Conservation and Extension (CONEX<sup>11</sup>) was set up as a separate department responsible for extension to serve the commercial farmers. In the same year, the tobacco branch was taken over by the Tobacco Research Board (TRB). In 1968, DR&SS was reorganized into six branches, namely: crop production, animal production, biology and ecology, chemistry and soils, plant protection and agricultural education.

In 1970, the Agricultural Research Council (ARC) was established to give farmers a greater role in the planning and setting of research priorities. The formation of the ARC was a response to farmers' demand for direct involvement in research policy formulation and a tactical movement by the government to have farmers contribute towards research costs (Mudimu, 1989). The ARC had twelve members, of which five were representatives of commercial farmer associations', three were directors of DR&SS, CONEX, and Tobacco Research Board, and representatives from the University of Zimbabwe. Initially the ARC mandate was an advisory role. In 1973/74, following ARC's influence, DR&SS was reorganized into a divisional structure of Crops Research, Livestock and Pastures, and Research Services. This last reorganization represents the current structure of DR&SS (See Appendix 2). The research stations and institutes were given specific mandates based on a particular commodity, agro-ecological region and discipline.

In 1976, following government's amendments to the ARC mandate, the ARC assumed direct responsibility for agricultural research within DR&SS. This reorganization was in

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<sup>11</sup> CONEX was the then Department of Conservation and Extension which was merged with DEVAG (Department of Agricultural Development) to form AGRITEX (Department of Agricultural and Extension Services) in 1981.

line with the commercial farmers' demand to play a greater role in the determination of research priorities and expenditures. All expenditures on research (excluding salaries) by the Ministry of Agriculture were to be channeled through the ARC. Several commercial agricultural producers associations also agreed to make annual grants to the Council. This enabled the producers through the ARC to influence directly the formulation of agricultural research policies and programs that mainly addressed the needs of the large-scale commercial sector. Under this new arrangement DR&SS continued to receive funds for salaries and capital expenditures from the Ministry of Agriculture but got their operating funds from ARC.

After independence in 1980, there was a policy shift to place more emphasis on the research needs of communal farmers who had been left out by the research system which had served the commercial farmers so well. Since communal farmers face production and institutional constraints that are more technically challenging to researchers than those faced by commercial farmers, DR&SS's institutes and stations initiated on-farm research programs in 1981 (Kupfuma, 1995).

The arrangement of having ARC control the research funds only lasted until 1982. In that year the government reverted the ARC to its former advisory role and created a separately administered Agricultural Research Fund (ARF) with grants received from producer associations and donors. (Roseboom et al. 1995). Commercial farmers associations responded by creating their own Agricultural Research Trust (ART) farm, which conducts research, demonstration and training for commercial farmers. The contribution of

commercial farmers to DR&SS research activities declined sharply. There was a 25 percent reduction in the DR&SS's real budget from 1980 to 1989 (Kupfuma). This forced administrators to scale back on-farm research activities that were meant to reach and, in the long run, benefit small farmers.

Currently DR&SS is the main public research organization in Zimbabwe responsible for government research in agricultural science and crop and pastoral production. The Department also provides dairy and meat grading services and several regulatory functions with respect to animal feeds, fertilizers, seeds, and pesticides. The Department runs The National Herbarium and Botanic Garden and offers an information service publishing research journals and annual reports. The ARC currently plays an advisory role and now includes equal representation from the commercial and smallholder farmers. DR&SS mandate is to promote and sustain a viable agricultural sector by generating and providing appropriate technology and support services that will: (i) increase the productivity and efficiency with special emphasis to the smallholder farmers, and (ii) promote sustainable natural resource management.

#### **2.5.5.2 DR&SS Resources**

The department has thirteen research stations sited in different natural regions and with sizes ranging from 2,000 to 28,000 hectares. Land is not fully utilized on most of the research stations because of financial constraints and the stations have limited transport and irrigation facilities. Thus research activities are confined to the land nearest the offices for easy access. The staffing structure of DR&SS is presented in table 2.10. The department has 2,024 total staff, of which about a quarter are researchers and technical

officers, while the rest are support staff. The table shows that the number of research personnel peaked in the 1986-1990 period but declined back to almost the 1984 level. The educational status of researchers is pyramid shaped, with about 6 percent having Ph. D, 25 percent Msc, and 69 percent bachelors degree.

DR&SS expenditures by category over recent years is presented in table 2.11. As noted in the historical section, the government provides the bulk of funds for the maintenance and development of research facilities in the department. In 1992, government funds to DR&SS accounted for 76 percent of all support, with donors accounting for the remainder.

### **2.5.5.3 Other Public Research Organizations**

Other government research organizations include: the Department of Veterinary Services which is responsible for livestock disease control, and research and extension on livestock diseases, the Institute of Agricultural Engineering - run by AGRITEX, whose research focus is on mechanization, and the Ministry of Natural Resources which conducts research on fisheries, and the Forestry Commission conducts research on forestry.

Table 2.10. The Department of Research and Specialist Services Total Number of staff

Staff Category	1984	1986-90	1991	1992-1995
Researchers	128	174	158	127
Support Staff				
Technical	na	360	361	359
Administrative	na	13	13	13
Other	na	1537	1537	1535
Subtotal	1496	1910	1911	1907
Total Staff	1624	2083	2051	2024

*Source:* DR&SS, and Roseboom et. al., 1995.

*Note:* The numbers are reported as head count of staff, not FTE research staff.

**Table 2. 11. Real Government Expenditure, (1980 Z\$ '000s.)**

Fiscal Year Ending	Total Govt. Expend.	Total Expend. On. Agric.	% of Agric. to Govt. Expend.	Research	Extension	Veterinary Services	Admin. & Subsidies
1967	160674	15417	10	1678	3071	2109	8559
1968	178756	70400	39	1916	3288	2148	63048
1969	398309	75855	19	4363	7132	4721	59639
1970	419058	65451	16	4697	3688	4855	5210
1971	430803	98812	23	5111	3741	5008	84951
1972	492012	98627	20	5477	4078	5471	83600
1973	530927	103296	19	6178	4062	6435	86621
1974	622182	117279	19	5942	3884	6798	100656
1975	672222	68242	10	6297	4007	6014	51924
1976	662781	39193	6	6138	3934	6671	22451
1977	766383	62887	8	5895	3762	7304	45927
1978	880452	124734	14	5491	3476	5102	110665
1979	898013	112288	13	5559	3494	5899	97335
1980	1027229	89851	9	5930	3734	6082	74105
1981	1062990	77850	7	7045	3610	7763	59431
1982	1254971	101468	8	7197	7958	13719	72593
1983	1305679	129336	10	5159	9655	12259	102263
1984	1313163	168687	13	4949	9132	11480	143126
1985	1314714	189978	14	5343	10260	12190	162185
1986	1361133	180280	13	6035	11330	12061	150853
1987	1479716	183446	12	5780	11576	13010	153080
1988	1277889	206644	16	5867	12037	12974	175767
1989	1416246	164607	12	6331	12348	13569	132359
1990	2115797	115549	5	5963	12936	17281	79368
1991	2251126	118418	5	6091	12985	14723	84619
1992	2695077	240801	9	5841	13995	16096	204868
1993	1674660	158927	9	3367	8564	10068	136928
1994	1534716	68038	4	3401	10092	9857	44687
1995	1585131	79762	5	3305	11683	10096	54677

Up to 1989, deflated by low income CPI, 1990 onwards deflated by a national CPI which replaces the traditional higher and lower income urban families CPI resulting from the change in CSO statistical reporting.

SOURCE: Masters, up to 1989, 1990 onwards CSO and MOA.

#### **2.5.5.4. The Role of Private Research Institutions in Zimbabwe**

Zimbabwe is serviced by well-organized private sector research in the form of the Agricultural Research Trust (ART) Farm, and the Seed Co-op's Rattray Arnold Research Station, and other seed, fertilizer and chemical companies. The importance of private sector research has grown rapidly since independence.

ART Farm is privately funded by the large-scale commercial grains, cereal, and oilseeds producers. Its major aim is to service the 4,500 subscribing commercial farmer members with applicable research (ART farm winter Report, 1994). Its research section is actively involved in agronomic research on maize, soybeans, groundnuts, sorghum, wheat and barley, irrigation techniques for wheat, and machinery testing and development. Seed Co-op's Rattray Arnold Research station conducts its own crop breeding and agronomic research on grains and oilseeds. The other seed companies Cargill, and PANNAR, are actively involved in breeding research on maize, while fertilizer and chemical companies run research trials on their products.

As government's funds become more scarce, thus limiting DR&SS activities, it is important for DR&SS to take full advantage of the existence of private sector research. DR&SS must be modeled to complement private sector research which concentrates on research aspects that are excludable and promise short to medium term profits.

### **2.5.6. International Technology Availability**

The DR&SS has close interactions with international agricultural research organizations especially in plant breeding research with the International Crop Research Institute for Semi-Arid Tropics (ICRISAT) for sorghum and the International Maize and Wheat Improvement Center (CIMMYT). Both CIMMYT and ICRISAT have research stations in Zimbabwe.

### **2.5.7. Agricultural Training**

Zimbabwe has six agricultural training institutions: two colleges that provide training leading to a diploma in agriculture and four others that offer courses leading to the certificate in agriculture. Most of the diploma graduates join AGRITEX to become extension officers, DR&SS to become technicians, teach high school agriculture, or secure jobs in other organizations. The certificate graduates become extension workers or research assistants. In addition to the agricultural colleges, the government also runs two technical colleges and 14 major youth training centers which also provide training in agriculture.

The University of Zimbabwe offers an agricultural degree in four majors; soil science, crop science, animal science and agricultural economics. The university also offers a veterinary degree. A newly opened (1992) private university, Africa University, funded by the Methodist church also offers an agricultural degree. There is limited graduate training in agriculture in Zimbabwe. Most students still go out of the country for graduate studies.

## 2.6. Marketing and Pricing Policies

Up until 1990, pricing and marketing of major agricultural products, with the exception of tobacco, fruits and vegetables, was subject to a high degree of government control, with the government directly involved in the setting of producer, wholesale, and retail prices. The marketing system and pricing policy resulted in a single channel marketing system based on government marketing boards. The major policy instruments used included regulation of producers, pan-seasonal pricing, and pan-territorial pricing<sup>12</sup> (Takavarasha, 1991). The marketing system evolved from the early 1930s so that by 1990, most agricultural commodities were either controlled or regulated and marketed through one of the parastatal marketing boards, including the Grain Marketing Board (GMB), Cotton Marketing Board (CMB), Dairy Marketing Board (DMB) and Cold Storage Commission involved in the trade of grains and oilseeds, cotton, milk and beef respectively. The Zimbabwe government maintained an extensive system of price controls in order (i) to ensure the supply of basic and essential commodities at reasonable prices, (ii) to ameliorate restrictive trade practices, and (iii) to secure remunerative prices for farmers. (Government of Zimbabwe, 1991).

All four marketing boards operated as monopolies in purchasing, processing, selling and exporting their commodities. They were centralized under the Agricultural Marketing Authority (AMA), which was subsequently dissolved in 1994 due to the economic liberalization program. Prior to 1991, the price fixing<sup>13</sup> procedure was a complex mix of analysis of market conditions and of lobbying by farmer's unions. Issues of market conditions

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<sup>12</sup> Pan-territorial pricing involves offering uniform government guaranteed prices for commodities in all parts of the country regardless of distance from the market outlet. Pan-seasonal pricing involves offering the same government guaranteed prices for commodities throughout the year.

included costs of production, size of stock holding, expected domestic demand and supply, financial conditions of marketing boards, and trade prospects. After extensive discussions between the producer organizations and the Economic Policy Committee of the AMA, the proposed prices were reviewed by the Ministry of Agriculture (MOA) who submitted the ministry's recommendations to the working party of the Ministerial Economic and Coordinating Committee (MECC)<sup>14</sup>. The working party had the power to modify the recommendations made by the MOA. MECC finally made recommendations to the cabinet, which made the final decision on both producer and consumer prices for the controlled crops. In many years producer prices were announced post planting.

The agricultural pricing system described above had several shortcomings. First, there were problems of synchronization of producer, wholesale, and retail price adjustments leading to severe marketing board losses<sup>15</sup>. Second, although multiple criteria was used in setting the prices, the costs of production for many years received a larger weight. Usefulness of the cost of production information is severely reduced by the diversity of the production systems, ecological conditions and technological levels among the producers in the country. Third, there was a lack of detailed economic analysis involving estimation of the relevant price elasticities and price distortions resulting from the proposed price increases. Fourth, pan-territorial and pan-seasonal pricing meant that the marketing board bore all the transport and storage costs

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<sup>13</sup> Based on Takavarasha, 1995.

<sup>14</sup> Chaired by the Ministry of Finance Economic Planning and Development, MECC is made up of Ministries of Agriculture, Industry and Commerce, Transport, Mines, Labor and Social Welfare, Political Affairs, Defense and Energy.

<sup>15</sup> In many years the controlled prices at which marketing boards sell to processors and to consumers were not decided at the same time as the producer price at which the boards purchase.

from depots to selling centers leading to increased board losses. The pricing and marketing policy of the country thus resulted in very high parastatal operating costs and losses. These costs resulted in the government paying substantial amounts as subsidies to the marketing boards. These costs were increased by the rapid expansion of the boards' services that has taken place since independence in an effort to provide marketing services to the small marginal producers. In spite of this expansion, market integration has remained poor in the communal areas because of inadequacies in market information, transport, feeder roads and storage facilities (Takavarasha, 1991).

With the onset of an economic structural adjustment program, agricultural pricing and marketing policy is directed towards meeting the following objectives (according to the government's document on the Economic Reform Program, 1991); (1) to reduce and then entirely eliminate the financial deficits of the marketing boards, (2) to increase the efficiency of the marketing boards, (3) to commercialize fully the operations of the agricultural marketing boards so that the boards operate in competition alongside other marketing channels, and (4) to increase the participation of private traders in agricultural marketing with the hope of replacing administered prices by market led prices in a competitive environment.

Zimbabwe's markets have dramatically opened up since 1991. All agricultural commodities have been decontrolled and deregulated. The CMB, CSC and DMB have been privatized. The AMA has been eliminated. The GMB has commercialized its activities; however the marketing board was tasked by government to manage a strategic maize stockpile. Prior to 1990, agricultural pricing and marketing was subject to a high degree of control and regulation. The

new pricing and marketing policy has resulted in the decontrol of agricultural prices and commercialization of the marketing boards operations. This means that most of the product markets are free from direct government distortions. The impact of the changes in the marketing arrangements has been the emergence of small-scale maize millers who represent an efficient alternative of marketing and processing channel for maize meal and provide a staple food to the urban consumers at relatively low prices, without necessitating Government expenditures (World Bank, 1995).

## **2.7. Government spending on agriculture**

Real government spending on agriculture is shown in table 2.11. The percentage of the budget allocated to agriculture has declined substantially since the period 1966/74, with annual allocations ranging from 5 to 16 percent. A large part of the allocation to agriculture is taken up by subsidies and losses associated with the marketing of controlled crops, livestock and dairy. The effective allocation after the subsidy losses is thus very small. (See table 2.12) Little resources were therefore left for research and development, extension, veterinary services and investment into rural infrastructure. This analysis of public sector expenditure patterns suggests that the government set a low priority on investment in in these agricultural prime movers, which are the engines of agricultural growth (Rukuni, 1995). The government since independence is putting relatively more resources into extension than into research (tables 2.11 and 2.12).

Table 2.12. Zimbabwe Proportion Of Agricultural Expenditure on Research, Extension, Veterinary Services and Administration and Subsidies (annual average %)

	Research	Extension	Veterinary Services	Administration & Subsidies
1967 - 70	7	10	8	58
1971 -75	6	4	6	83
1976 - 80	8	5	9	78
1981 - 85	5	6	9	79
1986 - 90	4	7	9	80
1991 - 95	4	10	11	75

Calculations based on table 2.11.

## 2.8. Trade and Exchange Rate Policies

The real value of agricultural exports is shown in table 2.13. The traditional picture of Zimbabwe's foreign trade is one in which agricultural products, raw materials and semi-processed raw materials are exchanged for electricity, machinery, transport equipment and manufactured products. Agricultural exports are dominated by tobacco. The second major export is cotton lint followed by horticultural crops, then maize. Most of the maize is exported through tripartite agreements in exchange for wheat from U.S.A, Canada, and Australia. Zimbabwe has a quota of 25000 tons of sugar per year and 9100 tons of beef per year under Lome II. After 1980, Zimbabwe continued to implement the pre-independence trade and exchange rate policies characterized by import substitution industrialization policy. Although in the 1980s Zimbabwe's foreign accounts looked balanced outwardly, inwardly foreign exchange shortages became a major problem strangling agricultural and economic growth (Rukuni et. al, 1995).

Since 1980 the exchange rate has been maintained at a level that has tended to overvalue the domestic currency,<sup>16</sup> and this overvaluation has acted as a serious disincentive to producers of agricultural exports and exports (Masters, 1994). A number of programs<sup>17</sup> were introduced to offset some of the disincentives of the foreign exchange allocation. Jansen and Muir conclude

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<sup>16</sup> The domestic currency was changed from a Rhodesian dollar to a Zimbabwean dollar Z\$ in 1980 which was fixed to a trade-weighted basket of about 12 major convertible currencies which include among others the US\$, British pound, South African rand, DM, lira.

<sup>17</sup> The Export Revolving Fund (allowed exporters to retain 25% of increases in export earnings), the Export Promotion Program (Z\$140 million allocated to agriculture for importing chemicals, fertilizers, spare parts and livestock), Export incentive scheme (gives exporters of processed or semi-processed commodities a 9% rebate on FOB value of exports), and numerous donor-funded Commodity Import Programs.

that these special programs only partially offset the implicit tax on agriculture, and did so at substantial administrative, budgetary, and equity costs.

The major agricultural crop exports in an average year are tobacco (50%), cotton (13%), sugar (13%), tea and coffee (5%) and maize (9%), while wheat is the only major food import. In independent studies on the impact of trade policy on the level and structure for total and individual agricultural exports in Zimbabwe, Jansen and Muir, 1995, Zvinavashe, 1995, Masters, 1994, and Rukovo and Takavarasha, 1991, found that the agricultural sector had a lower level of protection than the manufacturing sector. Within the agricultural sector itself, assistance varied from subsector to subsector and from crop to crop. The large-scale commercial sector was relatively more protected than their small-scale counterparts. Calculations by Jansen and Muir indicate that in the period 1980-1989, producers of maize, wheat, beef, cotton, tobacco, groundnuts and soyabeans were taxed by government's trade and pricing policies.

The current government objective is to significantly alter its trade and exchange rate policies as part of the economic reform program. The government has, since 1990, already implemented a series of exchange rate devaluations and liberalization of the foreign exchange market aimed at lowering and eventually eliminating the implicit tax on agricultural producers. The official exchange rate was depreciated by 35%, 20%, and 17% in 1991, 1993, and 1994 respectively.

Table 2.13. Major Agricultural Exports Real Value Z\$ million (Averages)

	1981-85	1986-1990	1991-92
Beef	9.3	12.3	12.1
Other meats	4.5	7.2	14.5
Maize	20.9	48.7	15.2
Barley	2.4	3.0	4.7
Tea	8.7	10.0	11.7
Coffee	15.0	28.2	10.9
Raw Sugar	30.2	29.7	1.5
Refined Sugar	7.9	9.5	2.8
Other Food	5.4	21.2	68.2
Burley Tobacco	1.2	1.1	15.6
Virginia Tobacco	165.4	248.9	498.6
Other Tobacco	1.7	16.5	33.4
Cattle Hides	4.5	4.3	11.4
Cotton Lint	58.0	61.7	36.9
Groundnuts	0.9	3.3	2.2
Maize Seed	1.6	4.8	13.4
Horticultural <sup>1</sup>	0.3	9.1	23.2
TOTAL	337.9	519.6	776.4

<sup>1</sup> Include flowers, citrus and fruits and vegetables.

Deflated by CPI, 1980b.

Source: Central Statistical Office, 1995 files.

The trade reform has made progress in achieving a unified market-based exchange rate in 1995 (World Bank, 1995). The trade reform has succeeded in stimulating increased horticultural exports in a few years, Zimbabwe has become the third largest supplier of imported cut roses into Europe, and the fourth largest supplier of all imported cut flowers (World Bank, 1995). Similarly, there has been significant increase in the export of fresh off-season vegetables such as mange-tout peas, cherry tomatoes and baby sweetcorns. However due to their superior access to finance, their more favored location, their effective producer associations and other factors, it has been primarily the large-scale commercial farmers who have been able to respond to the new export trade environment.

## **2.9. Summary of Chapter**

Agricultural research is a driving force behind increased agricultural production. Agricultural research can serve to maintain or improve the competitiveness of the sector in the world markets. The economy in Zimbabwe, both in pre-independence and post independence times, was highly controlled and regulated. All three macro resources, (labor, foreign exchange and capital) were subject to some form of direct government control. In 1990, the government embarked on an economic reform program which was aimed at stimulating investment and removing impediments to growth. Major steps have been undertaken in removing price controls, liberalizing trade, and deregulating the markets. On the positive side, the liberalization of foreign exchange allocations and the free availability of foreign exchange to pay for current import requirements generated a greater degree of competition among the farm input suppliers.

This chapter has shown how diverse Zimbabwe's agricultural sector is due to the existence of different farmer types, and different agro-ecological regions. This diversity implies that the farmer and regional categories may demand different types of technology. In applying agricultural research priority setting to Zimbabwe, the following factors should be considered: differences in the farmer groups, different agro-ecological regions of the country, and the multiple goals of agricultural research.

## **CHAPTER 3**

### **THEORETICAL FRAMEWORK**

#### **3.1. Introduction**

The aim of this chapter is to provide a theoretical framework for measuring economic benefits arising from agricultural research and for allocating research resources amongst competing research programs given multiple research objectives. The first section introduces economic surplus estimation of research benefits and provides a review of previous studies which used economic surplus to measure benefits from agricultural research. The second section outlines the economic surplus model used in this study and presents modifications required to make the model suit Zimbabwean conditions. The third section discusses how mathematical programming can be used to calculate the optimal allocation of research resources given multiple research objectives.

## **3.2. Economic Surplus Method of Measuring Research Benefits**

### **3.2.1. Conceptual Issues**

Changes in agricultural production resulting from research-induced changes in knowledge (technical change) are reflected as a shift in commodity supply. The impact of the change is a dynamic relationship between today's research investment and future production, supply and prices. The stream of the research benefits can be measured in terms of changes to consumer and producer surplus. Annual net benefits are then compared with the annual costs of research using cost benefit analysis. This method has been used widely as an empirical tool for public policy evaluation.

Consumer surplus is based on the concept of the consumer's willingness to pay for consumption. Jules Dupuit<sup>18</sup>, who coined the term consumer surplus in 1844, claimed that a buyer may receive a surplus from a transaction. He postulated that the price associated with any quantity demanded is the maximum price the consumer would be willing to pay for the last unit consumed. Therefore, a demand curve is essentially a willingness-to-pay curve, with the consumer willing to pay less and less for each additional unit consumed. Thus the demand curve is a measure of the incremental benefit derived by the consumers from another unit of the commodity. The consumer surplus therefore is the savings the consumer realizes by not having to pay higher prices for the earlier units consumed. Dupuit is said to have proposed that this surplus can be measured by the area below the demand curve and above the price line.

Producer surplus can be thought of in a similar manner. Marshall as cited in Currie, Murphy, and Schmitz introduced the concept to formalize the notion that a seller also receives some sort of surplus from a transaction (direct or indirect utility is greater than

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<sup>18</sup>cited in Currie, Murphy, and Schmitz 1971.

the utility of the item given up). The supply curve (marginal cost) may be viewed as the opportunity cost or incremental value to society foregone by use of resources for producing and consuming that commodity rather than other goods and services. The supply curve rises because the first units of a farm commodity can be produced at low cost on very productive land. As more units are produced, less productive land and other resources are brought into production, hence incremental costs rise. The industry supply curve is a lateral sum of the marginal cost curves of the individual firms.

The theoretical basis for using the long-run supply curve in measuring economic surplus is developed by Currie, Murphy and Schmitz. "The long-run supply curve of a perfectly competitive industry does represent the average costs of each firm in the industry....in an industry with fixed supply of land and with all other factors available at constant prices.... the supply curve is then a long-run average cost curve including rent to land and a long run marginal cost curve excluding rent to land." Thus as Varian puts it, "The cost function summarizes all economically relevant information about the technology of the firm."

Graphically this can be illustrated by looking at Figure 3.1. The industry demand and supply curves are  $D$  and  $S$  respectively. In a competitive market,  $Q_0$  is the market equilibrium and it follows that such a competitive allocation maximizes both revenue and net social benefit. If  $P_0$  is the market price, the consumer will want to consume  $Q_0$  units. The consumer is willing to pay higher prices for any level of consumption less than  $Q_0$ , but does not have to since the market price was  $P_0$ . Therefore, the area under the demand curve and above the price  $P_0$ , represents the consumer surplus (area  $P_0XZ$ ), i.e. what the consumer is willing to pay but doesn't have to.

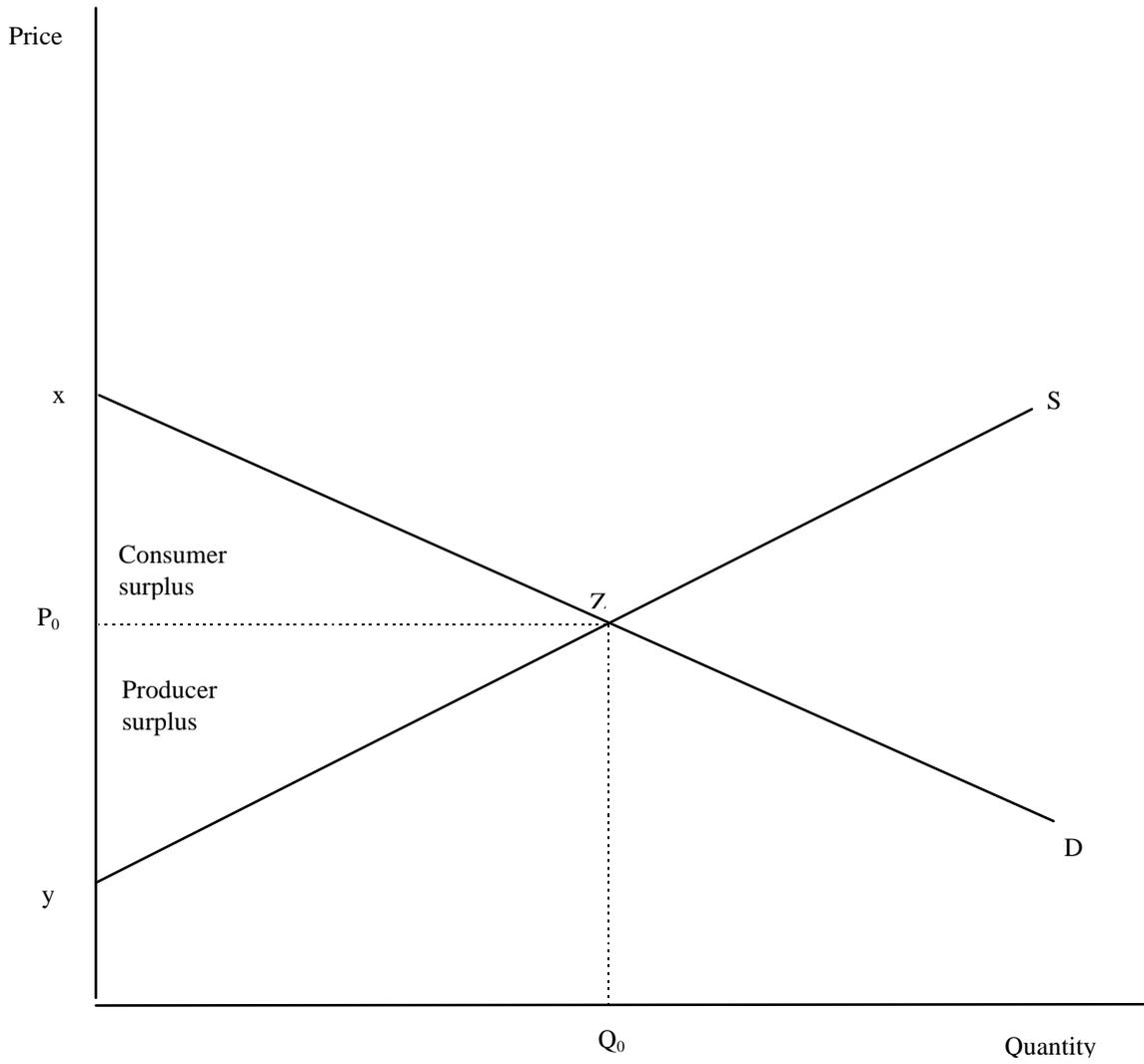


Figure 3.1 Consumer and producer surplus

The area under the industry's supply curve represents the total costs of all the variable inputs of production, and the area above the industry's supply curve and below the prevailing price of the product is a return to all other inputs (all fixed factors of production and entrepreneurship). Thus producer surplus, is a return to all fixed factors of production and can be represented by the area above the supply curve and under the output price  $P_0$  (area  $P_0YZ$ ).

In considering the benefits that accrue from research, one can consider how much change there is in total surplus. As mentioned above, research causes a reduction in costs or an increase in yields and the adoption of a new technology results in an outward shift of the commodity supply curve. This shift results in a change in consumer and producer surplus.

The Marshallian concepts of producer surplus and consumer surplus have shortcomings. Major criticisms according to various sources<sup>19</sup> include: measurement error, the partial equilibrium nature of the analysis, and incomplete markets. Consumer surplus must be estimated from a demand curve which ordinarily is estimated from time series data. The historic price-quantity data used to estimate the demand curve are likely to be narrow in range. The shape of the demand curve outside the range of historic price-quantity data is unknown. Therefore consumer surplus outside the historic price-quantity data range can be measured imperfectly at best. The model as presented above involves partial equilibrium analysis, ie. market equilibrium in a single market ignoring any effects of changes in other markets. Alston *et al* reiterate the need for a more encompassing economic surplus method developed in a general equilibrium framework. Such a framework would enable the analysis to capture the complex interrelationships with other product and factor markets. Consumer and producer surplus, and neoclassical welfare economics in general, has been criticized for ignoring transaction costs that arise because

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<sup>19</sup> Currie *et al*, 1971, Hertford *et al*, 1977, Norton *et al*, 1981, Alston *et al*, 1995 .

of asset fixity (sunk cost), imperfect information (bounded rationality), and the willingness of people to profit at the expense of other (Alston *et al*, 1995). Welfare analysis that ignores transaction costs will provide results that overstate the benefits of activities with high transaction costs both absolutely and relative to activities with relatively low transaction costs.

### **3.2.2. Review of Previous Empirical Studies of Economic Surplus Measurements of Agricultural Research Benefits**

Several studies have used the concept of economic surplus to measure benefits of agricultural research. Shultz made the first attempt to empirically apply the economic surplus approach to evaluate agricultural research investments. He calculated the value of inputs saved in agriculture because of improved, more efficient production techniques and compared this with the cost of research and development. As illustrated by figure 3.2, Shultz estimated the increase in consumer surplus,  $a$ , resulting from the savings in inputs assuming inelastic demand. The area under the supply curve,  $S_1$ , and to the left of the demand curve,  $D$ , represents the total cost of producing 1950 output with 1950 techniques and the area  $a$  represents the additional resources required to produce that output with 1910 techniques. Output per unit of input was estimated to be 32% higher in 1950 than in 1910.

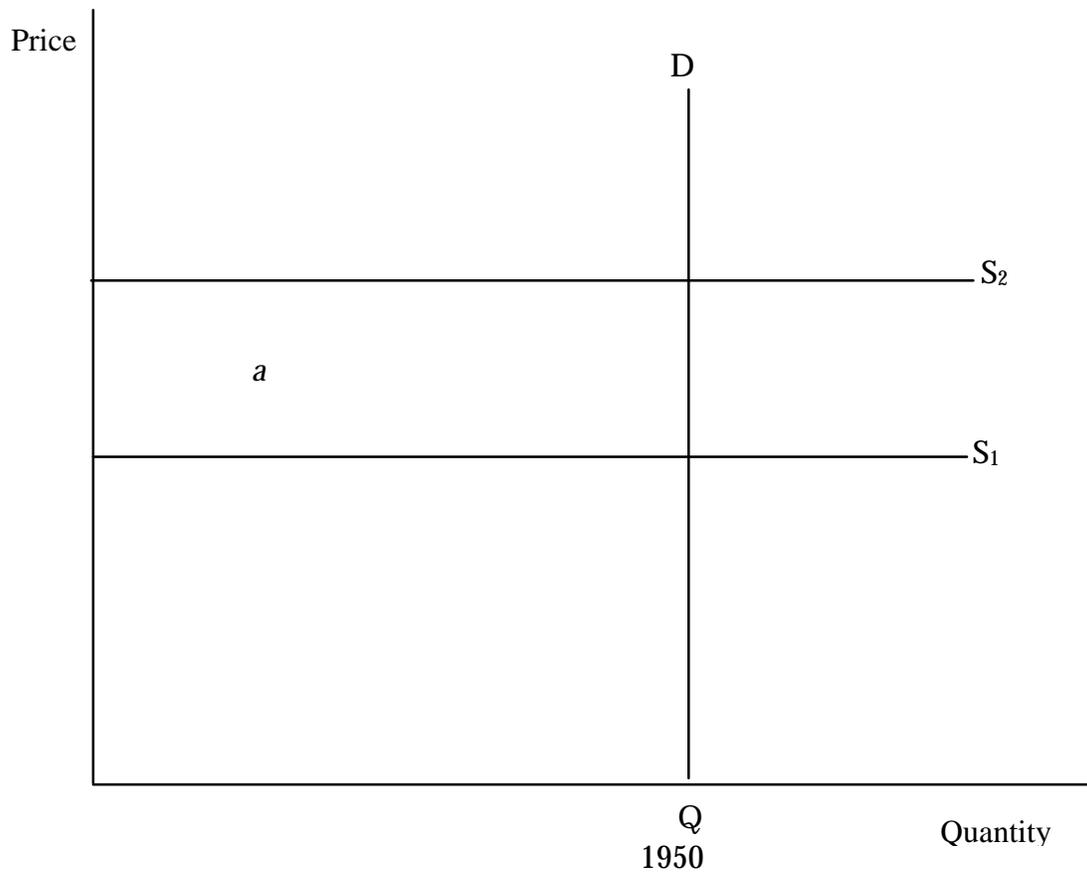


Figure 3.2 Effect of research on economic surplus

Griliches (1958), working at the commodity level, calculated the loss in net social surplus that would occur if hybrid corn were to disappear. He presented estimates of the rate of return to hybrid corn research and to total agricultural research in the United States. He assumed two cases: where the adoption of hybrid corn would shift the supply curve downward when supply is perfectly elastic (fig. 3.3), and where the supply would shift to the right when supply is perfectly inelastic (fig. 3.4). In each case he implicitly assumed that demand elasticity was minus one.

In fig. 3.3, the change in economic surplus is an increase in consumer surplus represented by A. To get A, Griliches measured  $A + B$  and then subtracted B. In order to measure the change in economic surplus in observable price and quantity, he developed a formula as follows:

$$A + B = kQ_1P_1,$$

where  $k = \Delta P/P$  (Proportionate change in price),

$$A = kQ_1P_1 - B,$$

$$B = \frac{1}{2} \Delta Q \Delta P = \frac{1}{2} \Delta Q/Q_1 * \Delta P/P_1 * Q_1P_1, \text{ and}$$

$n =$  the demand elasticity  $= \Delta Q/\Delta P * P/Q,$

$$\text{so } \Delta Q/Q = n\Delta P/P = nk.$$

Therefore,

$$\begin{aligned} B &= \frac{1}{2} (\Delta P/P)^2 * n Q_1P_1 \\ &= \frac{1}{2} k^2 n Q_1P_1 \end{aligned}$$

and

$$\begin{aligned} A &= kQ_1P_1 - \frac{1}{2} k^2 n Q_1P_1 \\ &= kQ_1P_1 (1 - \frac{1}{2} kn). \end{aligned}$$

Therefore the gain in consumer surplus is  $k Q_1P_1 (1 - \frac{1}{2} kn).$

Similarly for fig. 3.4, the change in consumer surplus is  $A + B$ ,

$$\text{change in producer surplus} = -A + C, \text{ and}$$

$$\begin{aligned} \text{change in net economic surplus} &= A + B - A + C \\ &= kP_1Q_1(1 + \frac{1}{2} k/n), \end{aligned}$$

where  $k = \Delta Q/Q_1$  (Proportionate change in quantity).

This method of calculating changes in economic surplus does not require knowledge of the supply elasticity.

In 1967, Willis Peterson used the economic surplus method to calculate the rate of return on investment in poultry research in the United States. The formula he developed to measure change in net economic surplus eliminated Griliches supply elasticity restrictions. Further, demand and supply curves need not always be linear. He used two measures of productivity, (a) a measure of feed efficiency (that resulted from improvements in inherent egg and meat producing ability of the birds, improvement in feed quality, housing and management), and (b) a measure of total productivity that is derived from the increase in poultry input prices relative to poultry output prices. The two measures of productivity were converted to the  $K$  values (proportionate change in quantity) and applied to the formula to obtain a measure of consumer surplus.  $K$  was defined as the percentage shift in the supply function of poultry products that would occur if the new inputs used by poultry farmers to obtain greater efficiency.

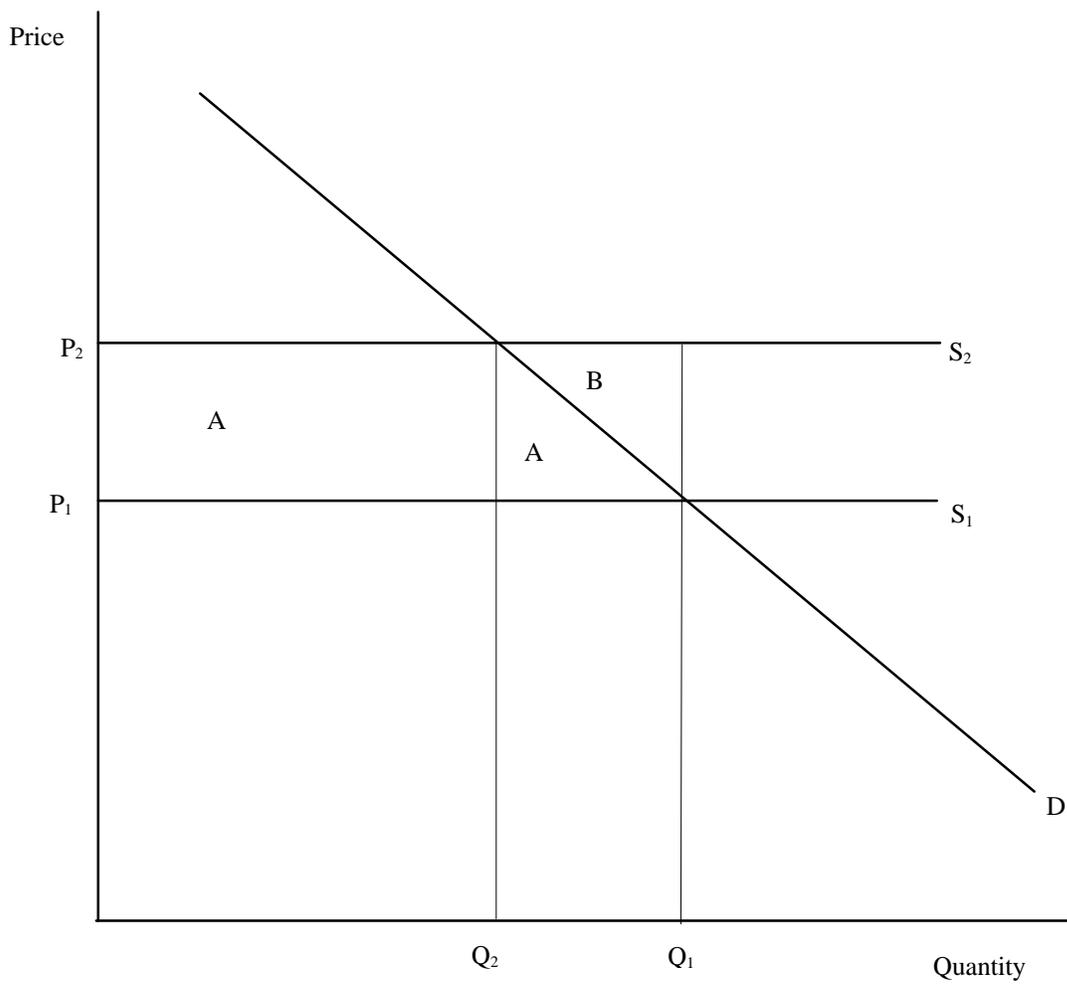


Figure 3.3 Benefits from agricultural research - perfectly elastic supply

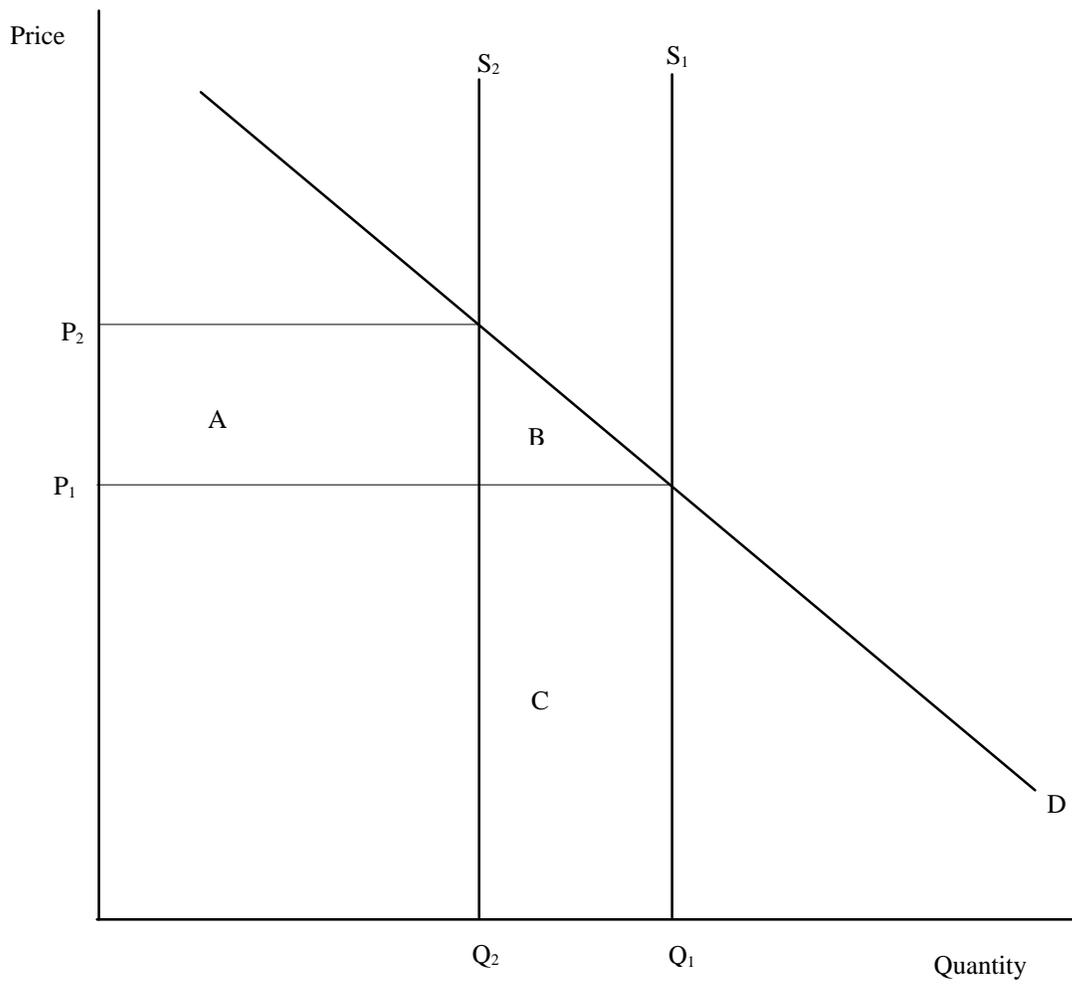


Figure 3.4 Benefits from agricultural research - perfectly inelastic supply

### 3.3. Economic Surplus Model Used in the Study

#### 3.3.1. The Basic Model

Since the early studies, several other evaluations of agricultural research have refined and applied economic surplus methods. Alston *et al* present the basic economic surplus model used for research evaluation and then elaborate several refinements to the model to account for trade, agricultural policies, research that affects production at various levels in the marketing chain, and environmental externalities. This basic model makes some simplifying assumptions. First, it assumes that the supply and demand curves are linear and the supply shift is parallel as a consequence of research induced technical changes. Second, a static, single-period model is used. Third, competitive market clearing is imposed.  $S_0$  and  $S_1$  represent the supply of the product before and after a research-induced technical change. The initial equilibrium price and quantity are  $P_0$  and  $Q_0$ ; after the shift they are  $P_1$  and  $Q_1$ .

In figure 3.5 total benefits from the research-induced supply shift ( $\Delta TS$ ) = area  $IoabI_1$  (the area below the demand curve and between the two long run supply curves). The change in consumer surplus ( $\Delta CS$ ) = area  $P_0abP_1$  and the change in producer surplus ( $\Delta PS$ ) = area  $P_1bI_1$  minus area  $P_0aI_0$ .

If a parallel shift is assumed, the area  $dCI_1 = P_0aI_0$  and the change in producer surplus is equal to the net benefit on current production (area  $P_1ecd$ ) plus the gain on the increment to production from  $Q_0$  to  $Q_1$  (area  $bce$ ) for a total producer surplus gain of area  $P_1bcd$ .

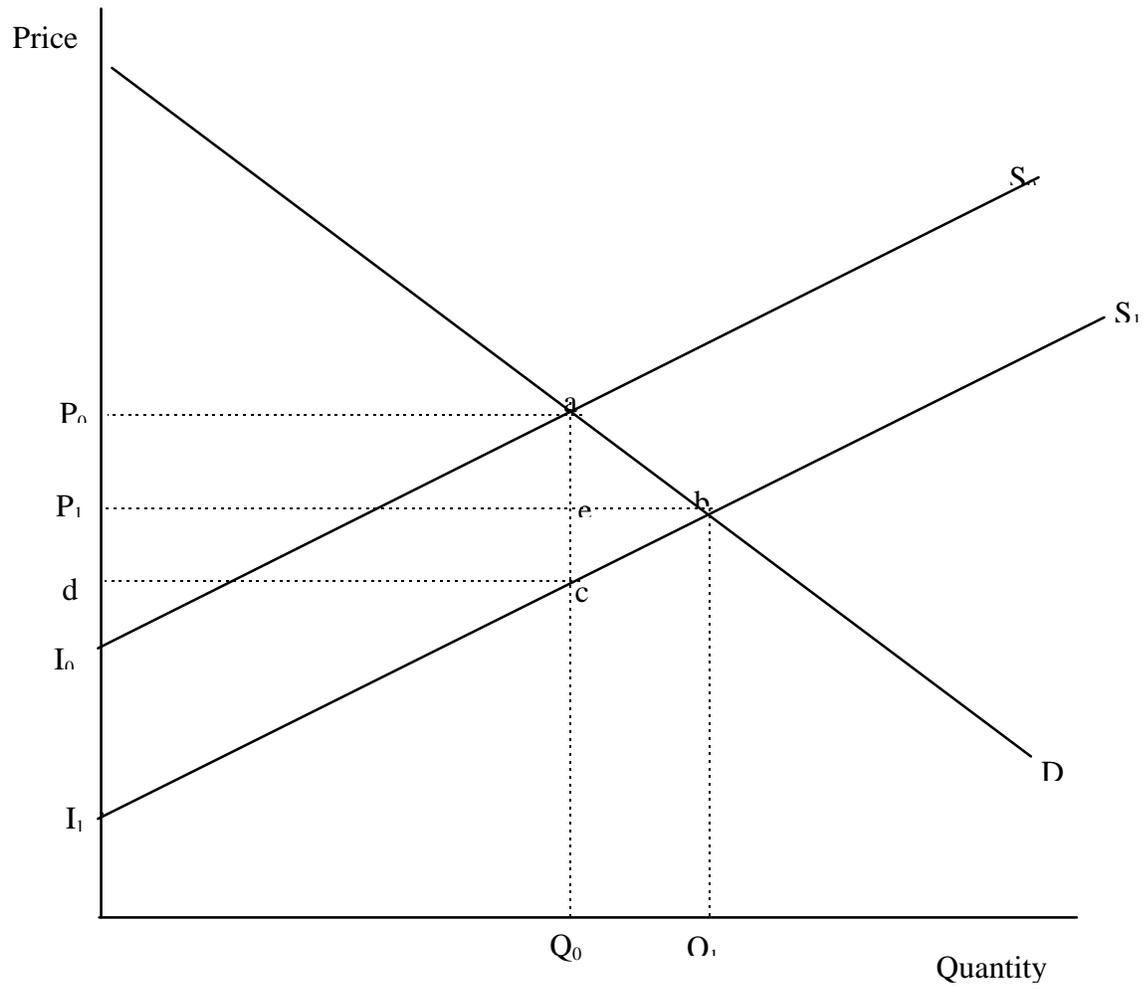


Figure 3.5 Economic surplus distribution in the basic model of research benefits

These gains can be expressed algebraically as follows:

$$\begin{aligned} &\text{Change in consumer surplus, area } P_0abP_1 = P_0aeP_1 + abe \\ &= (P_0 - P_1) Q_0 + 0.5(P_0 - P_1)(Q_1 - Q_0), \text{ and} \end{aligned} \quad (3.1)$$

$$\begin{aligned} &\text{Change in producer surplus, } P_1bI_1 - P_0aI_0 = P_1bcd + dcI_1 - P_0aI_0 = P_1bcd \\ &\text{(assuming a parallel shift } dcI_1 = P_0aI_0) \\ &= (P_1 - d) Q_0 + 0.5(P_1 - d)(Q_1 - Q_0). \end{aligned} \quad (3.2)$$

With linear demand and supply,

$$\text{Supply: } Q_s = b + b(P+k) = (b + bk) + bP, \text{ and}$$

$$\text{Demand: } Q_d = a + aP,$$

where  $k$  is the shift down of the supply due to cost saving induced by research.

The competitive equilibrium price and quantity after research can be obtained by solving the supply and demand at equilibrium  $Q_s = Q_d = Q$ .

$$P_1 = P_0 (1 - Z), \text{ and} \quad (3.3)$$

$$Q_1 = Q_0 (1 + \eta Z), \quad (3.4)$$

where  $Z$  is the relative reduction in price defined as  $Z = k\varepsilon/(\varepsilon+\eta)$ ,  $k$  is the supply shift relative to the initial equilibrium price  $k/P_0$ ,  $\varepsilon$  is the supply elasticity and  $\eta$  is the absolute value of the price elasticity of demand. Substituting equation (3) and (4) into (1) and (2) gives the following formulas for estimating economic surplus:

$$\Delta CS = P_0 Q_0 Z (1 + .5Z\eta), \text{ and} \quad (3.5)$$

$$\Delta PS = (k - Z)(1 + .5Z\eta). \quad (3.6)$$

Thus the change in total surplus is

$$\Delta TS = \Delta CS + \Delta PS = P_0 Q_0 k(1 + .5Z\eta). \quad (3.7)$$

This model applies primarily to products that are costly to transport and not traded. The model can be modified to include effects of trade because, in the real world, most products are exported or imported. Economic surplus models for a small open economy, a small importer and a small exporter are provided in Alston *et al.* Because Zimbabwe is small in the world market, the domestic price is heavily influenced by the world price (see figure 3.6).

In the case of either an importer or an exporter, all the benefits from research go to producers and are measured by the area  $I_0abI_1$ . The research benefits from a  $k$  proportionate and parallel shift in the supply curve is the same for both small importer and exporter.

$$\Delta PS = \Delta TS = P_w Q_0 k(1 + .5Zk\epsilon),$$

where  $P_w$  is the world price and other variables defined as before.

The basic economic surplus model can also be modified to account for cases where a country is a large exporter or a large importer. In the large exporter case, the country produces a commodity in quantities large enough to cause significant effects on the world price. This study will not examine these markets because Zimbabwe is not a major importer or exporter on the world market in any of its traded commodities.

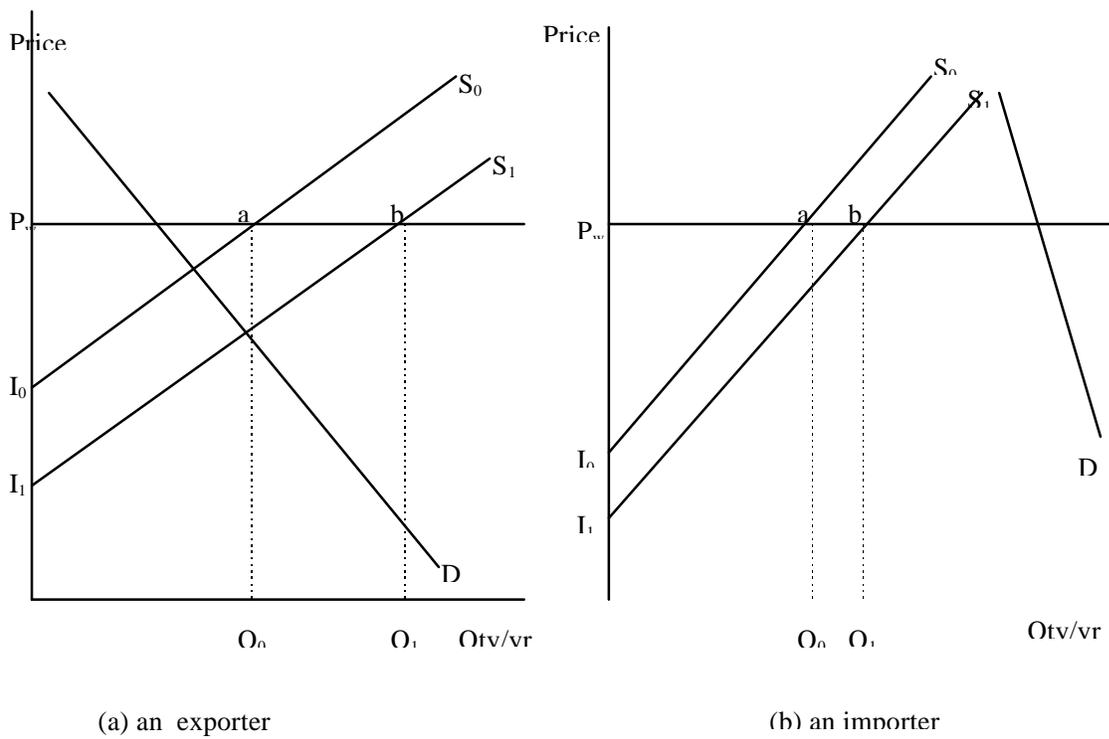


Figure 3.6. Research benefits in a small open economy

### **3.3.2. Analysis of market characteristics for Zimbabwe, and Basic**

#### **Model Modifications**

The level and distribution of benefits from agricultural research can be influenced by government policies that distort output and input prices. The major distortions are price policies such as price supports and price ceilings and trade policies such as quotas. Such interventions can distort input and output prices and thus significantly alter the distribution of the research benefits. This section analyzes commodity markets in Zimbabwe in order to identify the pricing and trade policies characterizing each product market. The aim is to identify market distortions resulting from government policies so that they can be included in the economic surplus analysis of returns to research on individual commodities. Main forms of distortions include price-fixing schemes, quantitative restrictions (on inputs, outputs, or trade), subsidies or taxes on production and inputs.

As mentioned in chapter 2, most of the commodities were controlled by government and marketed through government marketing boards. With the economic reforms underway, the government has decontrolled the marketing of agricultural commodities and the marketing boards have turned into private companies or commercialized their marketing activities. The market characteristics of the major agricultural commodities to be analyzed in this study are summarized in table 3.1. There are no major distortions currently present in any of the markets as indicated by the table. The markets of most of the commodities can be characterized as small open economies with the exception of indigenous fruits and vegetables and draught power which can be characterized as closed.

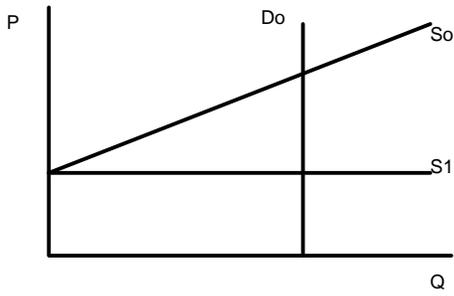
Table 3.1. Summary Table of Product Market Characteristics

Commodity	Market Type	Quantitative Restriction	Subsidy or Tax
1. Maize	Small - open	none	none
2. Sorghum	Small - open	none	none
3. Pearl Millet	Small - open	none	none
4. Finger Millet	Small - open	none	none
5. Beans	Small - open	none	none
6. Bambara nuts	Small - open	none	none
7. Cowpeas	Small - open	none	none
8. Groundnuts	Small - open	none	none
9. Soybeans	Small - open	none	none
10. Cotton	Small - open	none	none
11. Sunflowers	Small - open	none	none
12. Castor beans	Small - open	none	none
13. Cabbage	Small - open	none	none
14. Tomato	Small - open	none	none
15. Potato	Small - open	none	none
16. Sweet Potato	Small - open	none	none
17. Onions	Small - open	none	none
18. Indigenous vegg	Closed	none	none
19. Wheat	Small - open	none	none
20. Peas	Small - open	none	none
21. Apples	Small - open	none	none
22. Strawberry	Small - open	none	none
23. Flowers	Small - open	none	none
24. Indigenous fruits	Closed	none	none
25. Beef	Small - open	none	none
26. Dairy	Small - open	none	none
27. Poultry	Small - open	none	none
29. Sheep	Small - open	none	none
30. Goats	Small - open	none	none
31. Fish	Small - open	none	none
32. Draught Power	Closed	none	none
33. Ostrich	Small - open	none	none

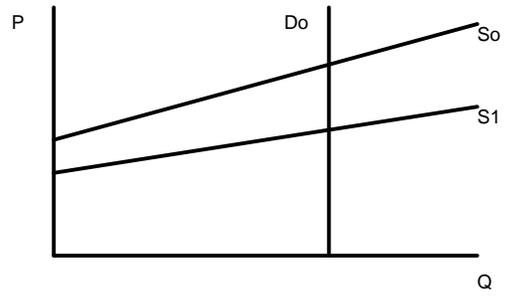
### **3.3.3. The Nature of the Research-induced Supply Shift**

Different types of technical change may result in different types of supply shifts, parallel, pivotal, proportional or convergent (Lindner and Jarrett, Rose). Examples of these different shifts are illustrated in figure 3.8. Such differences may affect the size and distribution of research benefits for example, total benefits from a parallel shift are nearly double those from a pivotal shift of equal size at the pre-research equilibrium. Because the change in economic surplus formulas outlined before presumes a parallel shift, an estimation error would result if the type of shift were not parallel. The premise is that the nature of supply shifts depends on the types of innovation (biological, chemical, mechanical, organizational) or on the structure of the average costs of marginal and inframarginal firms and the location of those firms on the industry supply curve. Inframarginal refers to more profitable lower cost firms.

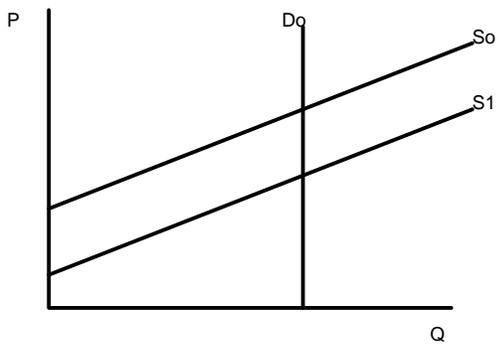
In their 1977 paper, Lindner and Jarrett distinguished three types of supply shift. The divergent shift illustrated by figure 3.7a and b includes all cases where the absolute vertical distance between the supply curves increases as quantity supplied increases, implying that absolute reductions in average cost are greater for marginal firms than inframarginal firms. A parallel shift results in a constant change in the vertical distance between the supply curves, while a convergent shift results in small shift at higher prices, implying that the absolute cost reduction at inframarginal levels of output is greater than at marginal levels.



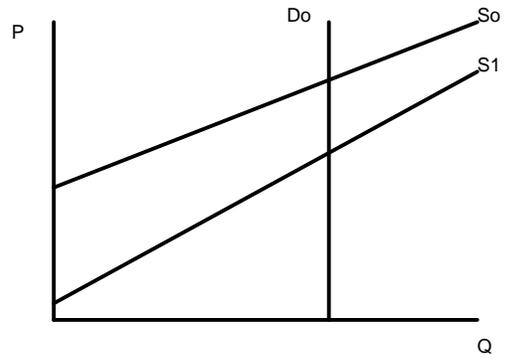
(a) Divergent-Pivotal



(b) Divergent-Proportional



(c) Parallel



(d) Convergent

Fig. 3.7 Different types of supply shift

Empirically incorporating the nature of the supply shift is difficult. Norton , Pardey and Alston, 1992, argue that although it is desirable to specify the nature of the research induced supply shift, economic theory is uninformative. They argue that shifts in the industry supply curve depend on the effects of new technologies on marginal costs of the existing firms and on entry and exit of firms. In order to predict which types of firms would benefit from a particular new technology, one would need to examine individual firms' characteristics that affect marginal costs and technology adoption. In addition, information on the number of firms of different types, and a complete theory of aggregation, would be needed to go from the firm to the industry. Because of these complexities, Norton *et al* contend that assumptions on the nature of the supply shift are unavoidable. They therefore suggest the Rose approach and consistently employ a vertically parallel shift. Under this assumption, the functional forms of supply and demand are relatively unimportant, and it is convenient to use local linear approximation. Calculations are simplified and consistency is introduced across the programs being evaluated.

#### **3.3.4. Price Elasticities**

Knowledge of the demand and supply elasticities will provide the basis for determining whether the flow of benefits from a given technical change will be realized as a producer surplus or consumer surplus. The larger the price elasticity of demand, the larger the producers' surplus. If demand is infinitely elastic, then producers will tend to benefit more. In such situations, an increase in research will mean an increase in the return to land for the “producers” (rent of land). This implies that research on more price elastic

commodities such as rubber, cotton, tobacco (due to trade) would benefit producers and input owners.<sup>20</sup> The less elastic demand is, the greater the benefits that will accrue to consumers. In the extreme case where demand is price inelastic, all benefits will go to consumers. As shown in figures 3.2, 3.3 and 3.4 for extreme cases of price elasticity of supply, the more elastic supply is, the greater are the gains to consumers. Thus price elasticities affect the distribution of research benefits between consumers and producers.

### **3.4. Mathematical Programming Model For Agricultural Research Resource**

#### **Allocation**

Several key issues related to agricultural research priority setting can not be treated satisfactorily by economic surplus analysis alone because this analysis does not indicate the amount and share of total resources to allocate to each program. Mathematical programming is an optimization procedure which provides a framework within which the following issues can be addressed:<sup>21</sup>

- the presence of multiple objectives and the need to quantify the nature of trade-offs among objectives (e.g. the economic efficiency sacrificed to meet a distributional objective),
- the desirability of incorporating a research response function that exhibits constant or diminishing returns to research so that, for a given objective, the mix of research programs can be optimized,
- the need to relate the marginal research benefit to the amount of funds going into research and their deployment,
- the implications of changing facility, human resource, and financial constraints on research

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<sup>20</sup> Hertford and Schmitz, and De Castro and Schuh, 1977.

<sup>21</sup> Alston, Norton and Pardey, 1995.

- short and long-run priorities by considering changes in constraints on resources that may be fixed in the short run but variable in the long run,
- the sensitivity of research priorities to estimated changes in research funding, market conditions, per unit cost reductions due to research, and other assumptions.

The advantage of using mathematical programming for allocating resources to research is its ability to consider simultaneously much of the complex nature of multiple objectives, resource constraints, and the trade-offs involved between objectives and programs. The use of mathematical programming in combination with the measures of research benefits calculated from economic surplus analysis, can give more precise answers to policy makers for their selection of a research portfolio. In addition, mathematical programming allows for incorporation of risk, making it a suitable framework to use in risky situations. Russell sums up the strength of mathematical programming to be “ a system facilitating selection of a portfolio of research projects such that the research outputs would provide society with the potential power to change the agricultural research system in ways that are expected to bring about the greatest improvement in social welfare.”

Mathematical programming is a computational technique for solving constrained optimization problems by maximizing (or minimizing) an objective function subject to a system of equations that represent equality and inequality constraints (Jaeger, 1986). In their simplest form, mathematical programming models are limited to optimizing a single linear objective function and are composed of production technologies exhibiting fixed input-output ratios, no factor substitution, and constant returns to scale. Work has been done to alleviate these limitations.

### **3.4.1. Trading-off Multiple Goals of Agricultural Research**

Agricultural research can have many economic and social goals or objectives. For example, the economic efficiency (growth) objective relates to whether the investment is the most efficient use of resources as far as the rate of return is concerned. Social objectives include increased equity and security which are concerned with the distribution of benefits and costs among different groups, locations and farm sizes in the society and the variability of those benefits. Zimbabwe has both economic and social objectives as indicated in chapter one. The question is how agricultural research can contribute more to economic efficiency and at the same time help meet other social objectives. In cases of multiple objectives, priority setting involves not only identifying the specific objectives and measuring the contributions of alternative research programs to each of them, but also requires trading off and weighting the alternative objectives. However weighting objectives is subjective, requiring value judgments of policy makers who may include research directors, ministers of agriculture and finance, and agricultural research councils.

The trade-off between economic efficiency and other objectives of research can be illustrated using a surplus transformation curve (Norton, Pardey, and Alston, 1992). Tradeoffs between two objectives, efficiency and equity, are illustrated in figure 3.8. The surplus transformation curve (STC) represents the range of maximum possible combinations of economic efficiency and equity that can be achieved by varying the mix of research programs in the portfolio. Also illustrated in figure 3.8 is a social indifference curve (SIC) or policy makers' willingness to substitute equity for efficiency. Point *a* represents a research portfolio where efficiency goal is maximized. Moving back to the

origin, the STC illustrates how much economic surplus has to be foregone in order to increase equity by shifting the research portfolio away from the one that maximizes economic efficiency. The optimal research portfolio is at point  $b$ ,  $(V^*, E^*)$  where the SIC is tangent to STC. To increase equity from  $V_{min}$  to  $V^*$  involves an opportunity cost of economic surplus foregone equivalent to  $E_{max} - E^*$ .

In general as noted by Alston *et al*, when multiple objectives are being pursued, it becomes particularly important to assess the comparative advantage of research relative to other policy instruments for meeting the social objectives because as many economists argue that agricultural research is a relatively poor instrument for achieving non-efficiency objectives. It is thus important to evaluate the costs of biasing the research portfolio in the pursuit of non-efficiency objectives. The next section presents a multiple-objective mathematical programming model that was used in this study.

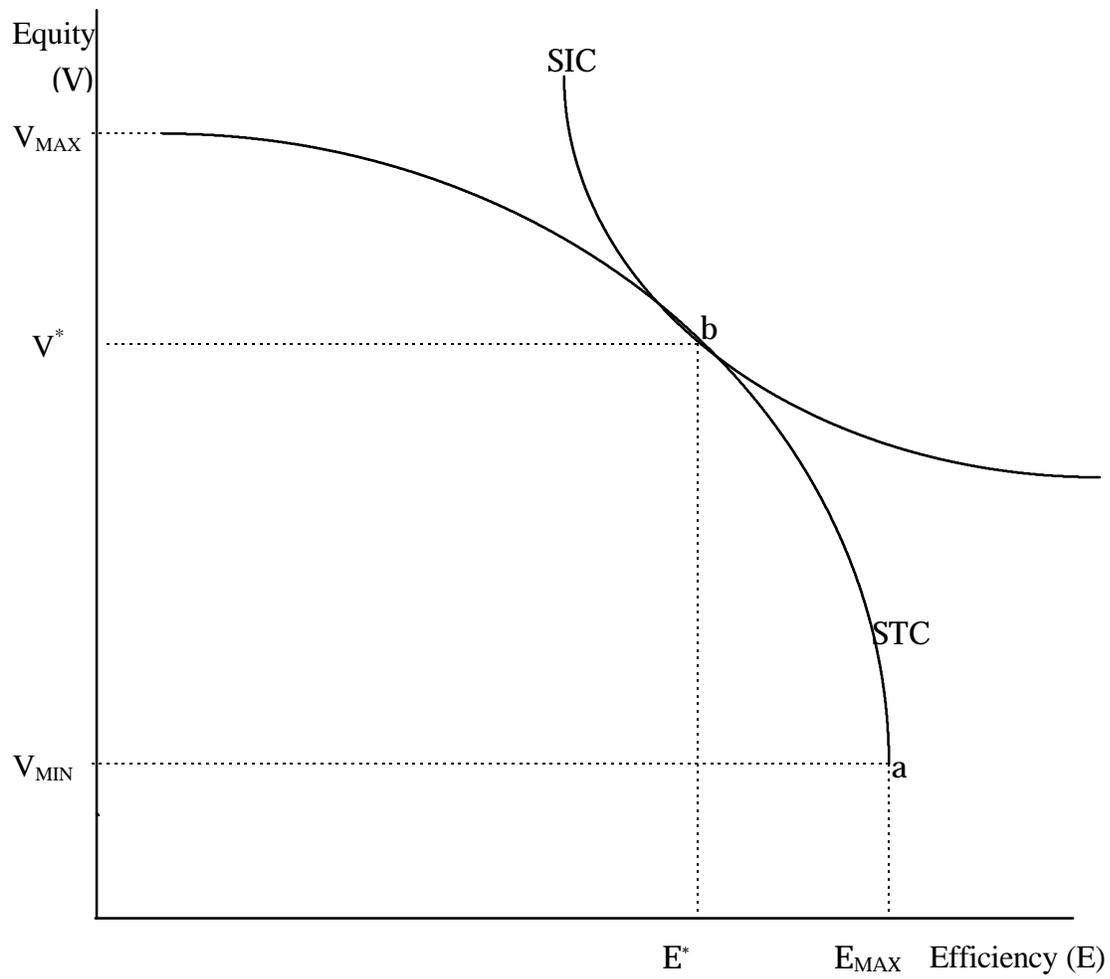


Figure 3.8. Illustration of the tradeoff between efficiency and equity objectives

### 3.4.2. The Multiple-Objective Mathematical Programming Model

The general form of a multiple-objective mathematical programming model for obtaining a set of feasible solutions that trade off the various objectives (Alston *et al*, 1995, and Russell, 1975) is as shown below;

$$\text{Max } z(\mathbf{x}) = G\{z_1(\mathbf{x}), z_2(\mathbf{x}), \dots, z_k(\mathbf{x})\}$$

Subject to

$$\mathbf{x} \in \mathbf{X}$$

$$x \geq 0$$

where  $z(\mathbf{x})$  is the objective function with  $k$  objectives,  $G$  is the goal operator (which defines the functional form of the objective function being maximized),  $\mathbf{x}$  is the  $n$ -dimensional vector of decision variables (the research programs to which resources are committed to achieve the stated objectives), and  $\mathbf{X}$  defines the decision space (the set of research resources available and any other constraints on the choices of  $\mathbf{x}$ ). The second equation is the set of constraints for the problem. and the third equation, the non-negativity conditions. The second equation is the set of constraints for the problem. and the third equation, the non-negativity conditions.

The following model (figure 3.9) adopted from Alston *et al* represents a summary of the model that was used in the study. The model includes two objectives: efficiency and distribution. Research resources are allocated across alternative activities to achieve the two objectives. There are  $n$  research activities and two levels of spending for each activity, the current level, and the current level plus fifty percent more.

**Figure 3.9. Multiple-objective, Mathematical Programming model**

Equation	Description	Research Activities									RHS
		Objectives		Activity 1		Activity 2		Activity n			
		$x_1$	$x_2$	$c_{11}$	$c_{12}$	$c_{21}$	$c_{22}$	...	$c_{n1}$	$c_{n2}$	
1	objective function	1	$w_2$								MAX
2	contributions to objectives	-1		$a_{11}$	$a_{12}$	$a_{21}$	$a_{22}$	...	$a_{n1}$	$a_{n2}$	= 0
3	total resource limit		-1	$b_{11}$	$b_{12}$	$b_{21}$	$b_{22}$	...	$b_{n1}$	$b_{n2}$	= 0
4	program resource limits			1	1	1	1		1	1	≤ R
				1							≤ R <sub>11</sub>
				1	1						≤ R <sub>12</sub>
						1					≤ R <sub>21</sub>
						1	1				≤ R <sub>22</sub>
								...			....
									1		≤ R <sub>n1</sub>
									1	1	≤ R <sub>n2</sub>

where:

- each activity correspond to research on a specific commodity for a specific farmer type as illustrated in table 3.2,
- $x_j$  = research system objective ( $x_1$  is efficiency objective and  $x_2$  is distributional objective). The model contains an objective function with weights of  $w_1 = 1.0$  placed on the efficiency objective and a weight of  $w_2$  placed on the distributional objective,
- $c_{ij}$  = The decision making variables reflecting the decision to fund research on the  $i$ th activity at a particular level of funding  $j$ , where  $j = \{ \text{current level} , \text{and current} + 50\% \text{ level} \}$
- $a_{ij}$  = the discounted marginal contributions of changes in research expenditure to the efficiency objective calculated in terms of net present value per dollar of research spending,
- $b_{ij}$  = the marginal contributions of changes in research expenditure to the distributional objective calculated in the same way as  $a_{ij}$  in terms of NPV per dollar of research spending,
- $R_{ij}$  = the research constraint represent the maximum funding levels for the  $i^{\text{th}}$  activity under the  $j^{\text{th}}$  level of funding ( $R_{11} < R_{12}$ ),
- $R$  = the total resources available for research, in the model it is initially equivalent to the current total DRSS research budget. The total expenditures on all research activities must be less than  $R$ .

Table 3.2 The list of actual research activities included in the multiple-objective mathematical programming model

Activity	Commodity	Farmer Type
1	Maize	Communal
2	Maize	Large Scale
3	Sorghum	Communal
4	Sorghum	Large Scale
5	Pearl Millet	Communal
6	Finger Millet	Communal
7	Wheat	Large Scale
8	Beans	Communal
9	Beans	Large Scale
10	Bambara nuts	Communal
11	Bambara nuts	Large Scale
12	Cowpeas	Communal
13	Cowpeas	Large Scale
14	Groundnuts	Communal
15	Groundnuts	Large Scale
16	Soybeans	Communal
17	Soybeans	Large Scale
18	Cotton	Communal
19	Cotton	Large Scale
20	Sunflower	Communal
21	Sunflower	Large Scale
22	Castor bean	Large Scale
23	Cabbage	Communal
24	Cabbage	Large Scale
25	Tomato	Communal
26	Tomato	Large Scale
27	Potato	Communal
28	Potato	Large Scale
29	Sweet Potato	Communal
30	Sweet Potato	Large Scale
31	Onions	Communal
32	Onions	Large Scale
33	Indigenous vegetables	Communal
34	Peas	Large Scale
35	Roses	Large Scale
36	Indigenous fruit	Communal
37	Macadamia	Large Scale
38	Coffee	Large Scale
39	Stonefruit	Large Scale
40	Apples	Large Scale
41	Strawberry	Large Scale
42	Beef	Communal

43	Beef	Large Scale
44	Dairy	Communal
45	Dairy	Large Scale
46	Broilers	Communal
47	Broilers	Large Scale
48	Layers	Communal
49	Layers	Large Scale
50	Sheep	Communal
51	Sheep	Large Scale
52	Goats	Communal
53	Ostriches	Large Scale
54	Cattle draft	Communal
55	Donkey draft	Communal
56	Fish	Communal

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The model contains an objective function with an initial weight of  $w_1 = 1.0$  placed on the efficiency objective,  $z_1(x)$ , and a weight of  $w_2 = 0$  placed on the distributional objective,  $z_2(x)$ . The NPVs for each objective are summed and transferred to the objective function for weighting. The weight on  $w_2$  can then be raised and efficiency trade-offs calculated for placing more weight on the other objective. At the low level of funding (current level),  $a_{ij}$  represent marginal products of research in terms of NPV per dollar research spending. Under a higher level of funding (current +50%),  $a_{12}$  is the marginal product of research measured in NPV per dollar of expenditures between  $R_{11}$  and  $R_{12}$ . The research response function is assumed to exhibit diminishing returns  $a_{11} > a_{12}$  implying that any additional increases in research spending on any research program results in smaller gains to productivity.

### **3.5. Summary of Chapter**

This chapter has provided the theoretical context for this study. The first section presented the conceptual issues on economic surplus estimation of benefits of research and gave a review of previous empirical studies. The second section indicated how the standard economic surplus model can be modified to incorporate trade and market characteristics to suit Zimbabwean conditions. The last section presented a discussion on how mathematical programming can be used to calculate optimal resource allocation given multiple research objectives. In the next chapter, the theoretical model will be transformed into an empirical one that can be used to estimate research benefit using survey and secondary data.

## CHAPTER 4

### THE EMPIRICAL MODEL

#### 4.1. Introduction

The major steps involved in the priority setting process include; defining the problem, measuring the research induced change in supply, compiling the market-related data, and analyzing the data<sup>22</sup>. Rather than taking these steps sequentially, this chapter begins by presenting a simple generalized version of the empirical model used to measure the value of the absolute reduction in costs resulting from research. This model is presented first so as to put into context the stages involved in empirically carrying out priority setting, focusing on the collection and measurement of the model variables.

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<sup>22</sup>Alston *et. al.* 1995

#### 4.2. Presentation of the model

As discussed in Chapter 3, change in total economic surplus for a small open economy, generalized for any particular commodity for a specific farmer type in a particular region in year  $t$ , is measured by the following formula:

$$\Delta TS_t = P_t Q_t K_t (1 + 0.5 K_t e_j) \quad (4.1)$$

where for a particular commodity  $j$ ,

$K_t$  is the shift down of the supply curve in period  $t$ , due to cost saving induced by research, measured as a percentage change in cost per ton of output.

$P_t$  is the pre-research price,

$Q_t$  is the pre-research quantity in year  $t$  (after accounting for exogenous or non-research shift effects), and,

$e_j$  is the supply elasticity for commodity  $j$ .

The crucial variable determining technical change,  $K_t$ , is measured as the percentage change in cost per ton of output.  $K_t$  can be obtained by dividing the absolute reduction in costs per ton,  $k_t$ , with the current producer price,  $PP_{j,0}$ .  $k_t$  is calculated by the following generalized formula (Alston *et al*, p 380):

$$k_{j,t} = \left[ \frac{E(Y_j)}{e_j} - \frac{E(C_j)}{(1 + E(Y_j))} - s_j E(F_j) \right] p_j A_{j,t} (1 - d_t)^t PP_{j,0} \quad (4.2)$$

where for a particular commodity,  $j$ , for any farmer type for a particular region:

$E(Y_j)$  = expected increase in value of output after the new technology has been adopted,

$e_j$  = the supply elasticity for commodity  $j$ ,

$E(C_j)$  = proportionate change in variable input costs per hectare to achieve the expected yield change,

$s_{ji}$  = fraction of fixed costs to pre-research costs per ton,

$E(F_j)$  = proportionate change in fixed costs,

$p_j$  = probability of research success, (ie. that research will achieve the expected yield change),

$A_j$  = the rate of adoption defined in relation to years,  $t$ , from commencement of research, and

$(1-d_j)$  = depreciation factor.

Formulae 4.1 and 4.2 can be used to calculate the streams of research benefits ( $\Delta TS_t$ ) over a number of years (Alston *et al*, p380). Given the projected research costs for the same years, net benefits are summarized using the net present value for each research program alternative. The NPV discounts all of the future benefits and costs into real value using the following formula:

$$NPV = \sum_{t=0}^{\infty} \frac{B_t - C_t}{(1+r)^t}$$

where  $r$  is the discount rate,  $B_t$  is the calculated value for annual research benefits  $t$  years in the future, obtained by calculating the total economic surplus for the year, and  $C_t$  is the annual research cost expended  $t$  years in the future. The calculated NPV per research program is expressed into  $a_{ij}$  or  $b_{ij}$  by dividing by the associated research expenditure to give NPV per dollar of research spending which is used in the mathematical programming model.

### **4.3. Defining the problem**

This step involves identifying the research system objectives and the relevant research programs. This identification is done to make sure that the identified research priorities are relevant to the research system.

#### **4.3.1. Objectives of the research system**

On the first trip to Zimbabwe, a meeting was held with research directors, institute and station heads, and the chair of the agricultural research council to determine the research objectives for the agricultural system. Identified research objectives are aimed at promoting and sustaining a viable agricultural sector by generating and providing appropriate technology and support services that will: (i) increase agricultural productivity and efficiency with special emphasis to the smallholder farmers, and (ii) promote sustainable natural resource management. After identifying the objectives, they were translated into operational objectives namely: (1) efficiency: to increase the total or average well-being of producers and consumers taken in aggregate, (2) equity: to improve the well-being of smallholder farmers, and (3) promote sustainable natural resource management.

#### **4.3.2. Research programs and program alternatives**

National and regional lists of commodities and non-commodity research program areas need to be developed when setting strategic research priorities (Norton, 1991). Research can also be prioritized by components of the commodity research programs which, for crops, can include programs such as plant breeding, plant protection or plant cultural practices and, for livestock, include animal health, animal nutrition and animal reproduction. Table 4.1 shows a list of commodity and non-commodity research programs for Zimbabwe.

The Department of Research and Specialist Services is not organized on a commodity basis (with the exception of cotton and coffee). Most of the research institutes were established on a discipline basis as per the non-commodity list shown in table 4.1. For example maize research is shared among the plant breeding institute, agronomy institute, plant protection and chemistry and soil research institute. The questionnaire was subsequently designed for Zimbabwe to capture the different contributions of each research institute to research on a particular commodity.

#### **4.3.3. Agro-ecological Zones**

Agro-ecological zones have been classified for Zimbabwe indicating where there is relatively homogenous physical response to the application of new technology. However, the actual (or realized) response is limited by infrastructural, institutional, cultural and other socio-economic conditions governing technology adoption and use. Thus in this study, a combination of agro-ecological zones and farmer type are used to try and capture anticipated research effects. However due to lack of agro-ecological specific data, an aggregation of natural regions 1 and 2 into a high potential region and natural regions 3, 4, and 5 into a low potential region provides a practical way of incorporating agro-ecological differences in the evaluation of returns to research.

#### **4.4. Measuring the research induced shifts in the supply curve**

To calculate the research induced shifts in the supply curve,  $K_t$ , information is required on the variables that quantify the knowledge production function. That function relates research costs to actual or expected per unit cost reductions or yield increases, to research adoption and depreciation lags, and to the probabilities of research success as shown in equations 4.1 and 4.2.

Table 4.1. List of Commodities and Non-Commodity Research Programs for DR&SS

Commodity	Non-Commodity
1. Maize	1. Plant Breeding
2. Sorghum	2. Plant Protection
3. Pearl Millet	3. Agronomy
4. Finger Millet	4. Chemistry and Soils
5. Beans	5. Farming Systems Research
6. Bambara nuts	6. Agro-forestry
7. Cowpeas	7. Botanical Gardens
8. Groundnuts	8. Livestock Breeding
9. Soybeans	9. Livestock Management
10. Cotton	10. Livestock Nutrition
11. Sunflowers	11. Pastures and Forages
12. Castor beans	12. Veld / rangeland
13. Cabbage	
14. Tomato	
15. Potato	
16. Sweet Potato	
17. Onions	
18. Indigenous vegs	
19. Wheat	
20. Peas	
21. Apples	
22. Strawberry	
23. Flowers	
24. Indigenous fruits	
25. Beef	
26. Dairy	
27. Poultry	
29. Sheep	
30. Goats	
31. Fish	
32. Draught Power	
33. Multi-purpose cattle	
34. Ostrich	
35. Coffee	

In particular the following data are needed:

- Expected yield increase and the probability of research success
- Anticipated change in input requirements and input costs
- Time required to complete the research
- Extent of adoption and research depreciation
- Effect of research on product quality
- Research costs

In this study, the above information was elicited from researchers, extension officers, and economists using an interview questionnaire. Sixty two scientists in DR&SS were interviewed from October to November 1995 and in April 1996 (see table 4.2.). Sixty of the scientists interviewed were knowledgeable (senior) research officers and two were research technicians in the respective research programs. In addition two AGRITEX extension officers and two Ministry of Agriculture economists were interviewed. This process included a pre-test in which two scientists participated and two senior scientists were consulted. The responses to the questionnaire were summarized into tables and in May - June, 1996, these responses were reviewed and assessed by other knowledgeable scientists, administrators, farmer's union representatives, and others. Suggested adjustments were made and presented to DR&SS knowledgeable scientists to recheck and validate the data. Based on these suggestions, refinements to the data were made before economic surplus analysis was conducted.

Published information including market-related data (quantities produced by farmer type, prices) and research costs per research program were obtained from DR&SS, the Central Statistical Office, farmer's unions, AGRITEX, Ministry of Agriculture, University of Zimbabwe, and other secondary sources. Appendix 3 shows the list of people contacted to validate technology related data and obtain secondary information.

Table 4.2. Summary of Scientists Interviewed

Institute Or Research Station	Discipline	Number of Scientists interviewed
Breeding Institute	Crop Breeding	11
Agronomy Institute	Agronomy	8
Chemistry and Soils	Soils	2
Plant Protection	Plant Protection	5
Farming System Research	Crops/livestock	3
Kadoma Research Station	Cotton	2
Matopos Research Station	Livestock	9
Marondera Horticultural Center	Horticulture	4
Grasslands Research Station	Livestock	4
Henderson Research Station	Livestock	5
Marondera Soil Productivity- Research Laboratory	Soils	2
Makoholi Research Station	Livestock	2
Chiredzi Research Station	Crops	3
Chipinge Research Station	Coffee/Horticulture	1
Nyanga Research Station	Horticulture	1
Total Number of Scientists interviewed		62.

The complete version of the questionnaire is presented in appendix 4 while a summary of the responses to the questionnaire is presented in appendix 5. The following section addresses each of the technology-related data requirements and integrates the questionnaire where relevant.

#### **4.4.1. Expected yield increase and Probability of research success**

Yield gain is the most common way of measuring the impact of technology developments on the agro-economy. However technology development, by nature of the research process, is uncertain and best represented as a distribution of possible outcomes. For simplicity this study assumes a triangular distribution of research outcomes from which the probability of success and expected yield increase values can be derived.

The expected yield gain from research is calculated by multiplying the expected yield gain by the probability that the research will be successful. Assuming that the yield gain from research,  $z$ , has a triangular distribution as shown in figure 4.1,  $z_h$ , is the highest possible yield,  $z_l$ , the lowest possible yield and,  $z_m$ , the most likely value (the modal). Scientists were asked to give estimates of  $z_h$ ,  $z_l$ , and,  $z_m$ , for three levels of funding (no funding, current funding, and 50% more funding) as shown in question 3, of questionnaire.

3. What will be the most likely (lowest, highest) expected yield per hectare in 5 - 10 years with continuation of current research funding for the next 5 years? With no funding? With 50 percent more funding?

Region:		Location:		
Research Funding Level		Yield (kg/ha)		
Scenario	I.D. No.	Lowest	Most Likely	Highest
Current	1			
No Research	2			
Current + 50%	3			

Data from the scientist's responses (shown in appendix 5) were used to calculate the percentage yield gain using the no funding scenario as the base. The probability of research success can be denoted by  $\Pr(z \geq z^*)$ , where  $z$  is the yield gain from research, and  $z^*$ , is the average yield gain calculated from the lowest, most likely, and highest. The probability of research success was calculated using two formulae:

$$\Pr(z \geq z^*) = \frac{(z_h - z^*)^2}{(z_h - z_l)(z_h - z_m)} \quad \text{where } (z_m \leq z^* \leq z_h),$$

$$\Pr(z \geq z^*) = 1 - \frac{(z^* - z_l)^2}{(z_h - z_l)(z_m - z_l)} \quad \text{where } (z_l \leq z^* \leq z_m)$$

Details on percentage yield increase for each triangular frequency distribution (calculated from the basic yield response data from given by scientists) are presented in appendix 6.

The resulting probabilities are shown in tables 4.3 and 4.4. and these figures represent  $P_j$  in equation 4.2.

#### **4.4.2. Anticipated change in input requirements and input costs**

Potential yield increases from adopting new technologies often involve the use of additional variable inputs (such as fertilizer, pesticides, hired labor) and fixed inputs (such as land) that effectively lower the yield increase attributable to new technology. Scientists were asked to provide estimates of changes in input requirements so that changes in input costs can be netted out in translating yield changes into cost changes.

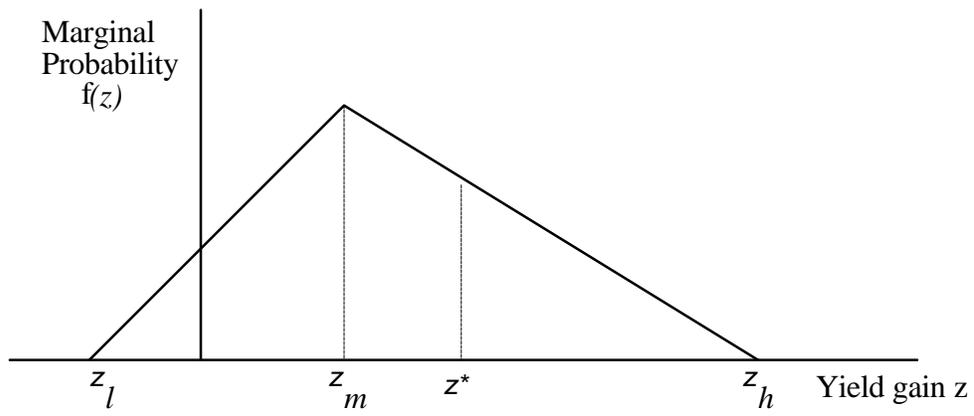


Figure 4.1. Triangular distribution of expected yield gain

Source: Adapted from Alston *et al* (1995) and Mills, (1995).

Table 4.3. Probability of Research Success Crop Commodities

Commodity	Communal Farmers				Small Scale Farmers				Large Scale Farmers			
	High Potential		Low Potential		High Potential		Low Potential		High Potential		Low Potential	
Commodity	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
Maize	0.50	0.46	0.45	0.53	0.45	0.45	0.46	0.54	0.50	0.50	0.46	0.46
Sorghum	0.46	0.48			0.46	0.48			0.45	0.45		
Pearl Millet	0.45	0.45										
Finger Millet	0.50	0.50			0.50	0.50						
Beans	0.53	0.53	0.47	0.50	0.54	0.53	0.53	0.52	0.54	0.53	0.53	0.48
Bambara nuts	0.46	0.50	0.54	0.47	0.46	0.49	0.50	0.52	0.47	0.50	0.54	0.54
Cowpeas	0.47	0.48	0.47	0.46	0.47	0.48	0.47	0.46	0.50	0.50	0.50	0.50
Groundnuts	0.50	0.50	0.47	0.50	0.50	0.50	0.47	0.50			0.50	0.50
Cotton	0.46	0.46	0.50	0.45	0.46	0.46	0.50	0.45	0.46	0.54	0.46	0.50
Sunflowers	0.50	0.50	0.44	0.50	0.50	0.50			0.44	0.50		
Castor Beans	0.59	0.54			0.54	0.52			0.53	0.53		
Indigenous Fruits	0.45	0.45										
Cabbage	0.50	0.53							0.50	0.46	0.50	0.46
Tomato	0.50	0.54							0.50	0.50	0.50	0.50
Potatoes	0.46	0.53							0.50	0.46	0.50	0.46
Sweet Potatoes	0.46	0.48			0.50	0.48			0.56	0.55	0.56	0.55
Onions	0.50	0.50							0.50	0.54	0.50	0.50
Indigenous vegetables	0.50	0.54										
Soybeans			0.50	0.51			0.54	0.54			0.47	0.50
Coffee			0.50	0.52			0.50	0.52	0.50	0.50	0.50	0.50
Apples			0.50	0.50								
Wheat					0.53	0.53	0.53	0.53	0.52	0.52	0.5	0.47
Macademia nuts							0.50	0.46			0.50	0.46
Strawberry											0.50	0.51
Apples											0.50	0.50
Peas											0.50	0.50
Roses stems/ha											0.50	0.59

Note: estimates calculated from scientists' responses (see appendices 5 and 6).

Level 1 refers to the current level of funding, and level 2 refers to the probability for research success from the additional 50% more funding.

Table 4.4. Probability of Research Success Livestock Commodities

Commodity	Communal Farmers		Small Scale Farmers		Large Scale Farmers	
	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
Beef	0.00	0.44	0.00	0.44	0.50	0.50
Dairy	0.50	0.46	0.50	0.54	0.50	0.50
Poultry Broilers	0.50	0.50	0.50	0.50	0.50	0.50
Poultry Layers	0.53	0.53	0.53	0.53	0.47	0.51
Sheep	0.54	0.45	0.59	0.45	0.50	0.50
Goats	0.50	0.50	0.50	0.50		
Fish kg/yr/100sq m	0.50	0.50				
Donkeys Draught Power ha/hr	0.44	0.50				
Cattle Draught Power ha/hr	0.50	0.54				
Ostriches					0.44	0.53

Note: estimates calculated from scientists' responses (see appendices 5 and 6).

Level 1 refers to the current level of funding, and level 2 refers to the probability for research success from the additional 50% more funding.

This netting out of input costs is needed because, conceptually, at the level of the individual farm firm, a research-induced supply shift may be decomposed into two components; (a) one part arising from changes in productivity that would occur if input use were held constant at the optimum that applied before the technological change and (b) one part associated with changes in the input mix to optimize input combinations under the new technology (Alston *et. al.*). Question 4 in the questionnaire captured the changes in variable and fixed costs resulting from adoption of new technologies.

4. What percent of total variable costs is currently represented by each variable input (hired labor, fertilizer, etc.); likewise for each allocatable fixed input (land, operator labor) for each agro-ecological region and farm type? What is your estimate of the **percent change** in cost (per hectare or per animal) (if any) for **each** of the major inputs needed to achieve the above yield increase?

<b>Region:</b>		<b>Farm Type:</b>		
		Most Likely Cost Change		
Input	Current Cost Share	Decrease Increase	No Change	Rate Of Change
Variable (\$/ha)	(%)	(Check One)		(%)
Hired labor				
Tractor operating				
Fertilizer				
Crop chemicals				
Irrigation				
Seed				
Marketing				
Other				
Total Variable	100%			$E(C)^1 = \%$
Allocatable/Fixed (\$/ton of Output)				
Land				
Operator labor				
Total Fixed	100%			$(F)^1 = \%$

#### 4.4.3. Time required to complete the research

The time required to complete the research is important in determining the value of benefits from research, i.e. the sooner the benefits are received, the more they are worth. In question 7 of the questionnaire, scientists were asked to estimate the length of time between incurring an expenditure on research and the release of new technologies. This time length measures the research lag,  $\lambda_R$ , which is an important input in calculation of adoption rate considered in the next section.

7. When will the key research results (transferable technologies) be available to farmers or to processors of this commodity?

Number of years until the results are available								
Region	Farm Type	Plant Breeding	Plant Protection	Agronomy	Chemistry & Soils	Agro-forestry	Botanical Gardens	FSR & Others

#### 4.4.4. Extent of adoption and Research depreciation

The realized commodity supply shift due to research will depend on the extent of adoption of the technology. The rate and extent of adoption depends on many factors which include agro-ecological factors such as rainfall, topography, soils, and temperature, and socio-economic factors such as land tenure, farmer education, quantity and quality of extension,

religion, transport infrastructure, availability of credit and communications (Alston *et. al.*, 1995). This study measures adoption rates by farmer type and agro-ecological regions.

The different components of a commodity research program will generate technologies that have different adoption paths in different locations. This study captures the spatial differences by specifying adoption patterns for each research discipline, for each commodity, by farmer type and agro-ecological location. This study assumes an adoption profile with a trapezoidal lag structure as shown in figure 4.2.(Adapted from Alston *et. al.*) The advantage of a trapezoidal lag structure is that it has a simple linear form for the growth or adoption phase and for the decline phase. The characteristic phases of the profile are noteworthy. These are labeled as;

- $\lambda_R$  - research lag; the research development phase, ending with the release of technology
- $\lambda_A$  - adoption lag: a phase of increasing adoption as a number of farmers in the target area become exposed to the technology and opt to use it, measured as years from initial adoption to maximum adoption
- $\lambda_M$  - maximum lag: an adoption plateau where most farmers have been exposed to the technology and have decided whether or not to adopt, measured as years from maximum adoption to eventual decline
- $\lambda_D$  - decline lag: a phase of declining adoption as the technology becomes obsolete.

Combined, these components determine the speed and magnitude by which research results are translated into an impact on farmers' fields. They form the shape of the time

path of  $K_t$ . A ceiling adoption rate,  $A^{MAX}$ , is measured as the proportion of output produced using the new technology, or as the maximum area sown to a new crop or cropped area produced with a new crop. Question 7 in the questionnaire elicited  $\lambda_R$ , while question 8, elicited  $\lambda_A$ ,  $\lambda_M$  and  $\lambda_D$ . The rate of adoption,  $A_t$ , is defined in relation to years,  $t$ , from commencement of research. For example, if research takes 5 years before technologies are available, then the adoption rate occurs on 5 percent of the land devoted to that commodity in year 6, 10 percent in year 7, 15 percent in year 8 and so on.

This study uses the straight-line depreciation, in which, at some point, the value of the technology declines linearly to zero, hence fitting into the trapezoidal lag structure assumption.

8 (a). What percentage of the farmers are expected to adopt the new technology (variety, practice, etc.) once it is released? (b). How many years after it is released do you expect to see maximum adoption? (c). Do you expect the technology to depreciate (become less effective or obsolete) over time? If yes, how many years after maximum adoption do you expect to see adoption begin to decline? Do you expect the decline to be rapid (3 to 7 years to no adoption) or slow (8 or more years to no adoption)?

Region	Farm Type	Adoption Lags	Plant Breeding	Plant Protection	Agronomy	Chemistry & Soils	Agro-forestry	Botanical Gardens	FSR & Others
		% Max Adopt							
		Years to Max Adopt							
		Years to Decline							
		Rapid Or Slow							

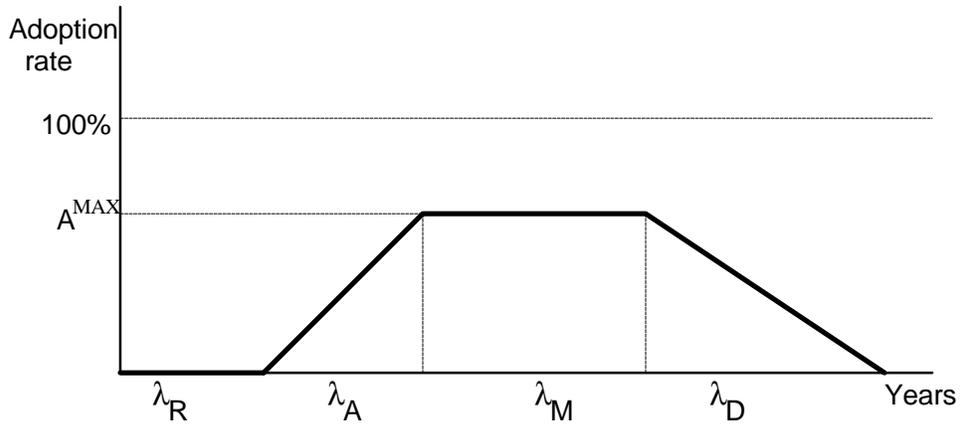


Figure 4.2. Trapezoidal adoption profile

#### **4.4.5. Research costs**

There is need to quantify the resources used in conducting research. The average annual expenditure (including operational or variable cost requirements, manpower, and capital) for each research program area was collected for the most recent 4 years. Because of the current organizational structure of DR&SS, costs are on a per research discipline basis and not by commodity (except for cotton and coffee).

To overcome this problem, DR&SS total research related cost was split across the different commodities based on the proportion of the scientist full-time equivalents, elicited from question 2 of the questionnaire. The research costs per commodity, farmer type, and agro-ecological region are shown in table 4.5. Research costs were further broken down across research disciplines based on the expected percentage contribution of each research program area to the percentage yield increase expected from research. Question 5 of the questionnaire captured this breakdown, and appendix 8 shows the research costs per commodity per research program.

2. How many scientists (full-time equivalents) currently conduct research at DR&SS on this commodity?

Disciplines or Research Program Areas			
Plant Breeding		Chemistry & Soils	
Plant Protection		Agro-forestry	
Agronomy		Botanical Gardens	
FSR & Others		Total Scientists	

5. What is the expected percentage contribution of each research program area to the percentage yield change listed above for this commodity in question 3?

Percent contribution to change in yield									
Region	Farm Type	Plant Breeding	Plant Protection	Agronomy	Chemistry & Soils	Agro-forestry	Botanical Gardens	FSR & Others	Total Percent
									100%
									100%
									100%

**Table 4.5. Estimate of Average Annual Expenditure Z\$ '000**

Commodity	Scientist full-time eq.	TOTAL COST	COMMUNAL		SMALL SCALE		LARGE SCALE	
			LP	HP	LP	HP	LP	HP
Maize	9.70	4514	752	752	752	752	752	752
Sorghum	2.95	1373	458		458		458	
Pearl Millet	1.30	605	605					
Finger Millet	1.00	466	233		233		0	
Beans	2.10	977	244	244	244		244	
Bambara nuts	1.18	549	137	137	137	137	137	137
Cowpeas	1.30	605	101	101	101	101	101	101
Groundnuts	3.10	1442	288	288	288	288		288
Soybeans	3.20	1489		372		372	372	372
Cotton	9.05	4211	702	702	702	702	702	702
Sunflowers	2.40	1117	279		279		279	
Castor Beans	0.50	233	78		78		78	
Cabbage	0.50	233	39	39	39	39	39	39
Tomato	1.90	884	147	147	147	147	147	147
Potatoes	1.20	558	93	93	93	93	93	93
Sweet Potatoes	0.75	349	58	58	58	58	58	58
Onions	1.30	605	101	101	101	101	101	101
Indigenous Fruits	0.60	279	279					
Indigenous vogs.	0.50	233	233					
Macadamia nuts	0.10	47				23		23
Coffee	2.90	900				0		900
Wheat	2.70	1256				419	419	419
Flowers	1.00	465						465
Apples	0.98	454		0		0		454
Stone fruit	0.90	419		0		0		419
Strawberry	0.08	35						35
Peas	0.20	93						93
Beef	11.55	5374	1792		1791		1791	
Dairy	7.25	3374	843		844		1687	
Broilers	1.00	465	155		155		155	
Layers	1.00	465	155		155		155	
Sheep	1.30	605	202		202		202	
Goats	5.72	2659	1330		1330			
Fish	0.50	233	233					
Multi-purpose	1.50	698	698					
Draught Power	1.34	624	624					
Donkeys	0.60	279	279					
Ostriches	1.00	465					465	
<b>TOTAL</b>	<b>86.14</b>	<b>40081</b>	<b>10293</b>	<b>3765</b>	<b>9030</b>	<b>3478</b>	<b>8436</b>	<b>5843</b>

Note: Amount allocated to each commodity calculated by the proportion of the scientists' fulltime equivalents spent on the commodity. The costs were subsequently proportionally divided between the farmer categories.

#### **4.5. Market related data**

The economic surplus analysis requires the following market related data:

- Quantities produced, consumed, exported, and imported for each commodity,
- Domestic output prices (farm level),
- Domestic price elasticities of demand and supply for each commodity,
- Government policy for each commodity,
- Interest rate for discounting research costs and benefits.

An ex-ante analysis, as in this study, requires a few years of price and quantity data, such as the most recent 3 to 4 years for a benchmark (Alston *et al*). The following passage discusses in detail the data requirements.

##### **4.5.1. Quantity data**

Appendix 7 shows the data on quantities produced disaggregated by farmer type and agro-ecological region. The most recent 3 to 4 year average is taken to reduce the effects of abnormal years.

##### **4.5.2. Prices**

Table 4.6 shows price data for the agricultural commodities considered in this study.

These prices reflect the producer market level.

**Table 4.6. Output Prices Z\$/mt**

COMMODITY	CURRENT PRICES Z\$/ton				REAL PRODUCER PRICES <sup>1</sup> Z\$/ton				AVERAGE
	1992	1993	1994	1995	1992	1993	1994	1995	Z\$/ton
Maize	550	900	900	1050	965	1311	1076	1050	1031
Sorghum	990	1620	1620	1890	1737	2360	1937	1890	1981
Pearl Millet	1155	1890	1890	2205	2026	2754	2260	2205	2311
Finger Millet	1485	2430	2430	2835	2605	3540	2906	2835	2972
Wheat	995	1450	1450	2250	1746	2113	1734	2250	1879
Beans	4200	4200	4200	4750	7368	6119	5022	4750	5815
Bambara nuts				4333				4333	4333
Cowpeas				4667				4667	4667
Groundnuts	1500	1800	2400	4500	2631	2622	2870	4500	3798
Soyabeans	1047	1323	1600	1600	1837	1927	1913	1600	1878
Seed Cotton	1630	2620	3200	4200	2860	3817	3826	4200	4040
Sunflower	995	1472	1472	1500	1746	2145	1760	1500	1894
Castor Beans	1200	1725	2150	2450	2105	2513	2571	2450	2410
Indigenous Fruit				2000				2000	2000
Cabbage		2680	2800	4290			3205	4290	3747
Tomato		4290	5030	7900			5130	7900	6515
Potatoes		4160	6360	6880			4974	6880	5927
Sweet Potatoes				2000				2000	2000
Onions		3430	4620	7430			4101	7430	5766
Indigenous vegetables				2000				2000	2000
Mac nuts				2100				2100	2100
Coffee				11650				11650	11650
Strawberry				18250				18250	18250
Apples		8570	11380	1689			10248	1689	5968
Peas				22150				22150	22150
Roses				6195000				6195000	6195000
Milk	720	1080	1410	1810	1263	1573	1686	1810	1814
Beef		3690	4610	14130		6473	6716	14130	10386
Goats				13000				13000	13000
Sheep				23000				23000	23000
Broilers				15000				15000	15000
Eggs /doz.				8				8	8
Ostriches				18000				18000	18000
Draft power cattle \$/ha				371				371	371
Draft power donkey \$/ha				371				371	371
Fish				22000				22000	22000

<sup>1</sup> 1980 base year.

Source: Ministry of Agriculture, The Farmer (various issues), CSO, and Horticultural Promotion Council.

Prices for sorghum and the millets reflect local rural market prices obtained from the National Early Warning Unit. Draft power prices are based on Ministry of Agriculture, Farm Management Data for Communal area farm units, 1989/90. Prices were deflated by the producer price index, 1995 base. Coffee and roses prices are f.o.b. prices less freight charges.

### **4.5.3. Elasticities**

Domestic price elasticities of supply and demand have to be determined for use in economic surplus calculation. Information on demand elasticities by region is not available in Zimbabwe. Basing on studies by Jayne *et. al.* (1993), Pinckney (1991), Bezuneh *et. al.* (1988) and Mills (1996), own price demand elasticities for the commodities were assumed to range from -0.3 for basic commodities to -2 for luxury commodities such as flowers (see table 4.7.).

According to Alston *et al*, most published elasticities of supply for agricultural products fall between 0.1 and 1.0. Literature on agricultural production in other African countries generally reveals a strong positive response by farmers to price incentives. An analysis carried out in Sub-Saharan Africa by W. Jaeger in 1992, revealed that price elasticities of 0.56 to 0.94 for export crops. Binswanger (1989) found that individual crops respond strongly to price factors in the short-run: even in a poor agro-climatic region in India he found that elasticities for single crops range from 0.25 to 0.77. He also discovered that "short-run supply elasticities for Sub-Saharan Africa are no lower than for other areas". Jayne estimated the maize price elasticities of supply in Zimbabwe to range between 0.76 and 0.48 depending on region. A

study on large-scale commercial farming in Zimbabwe by Muir-Leresche (1985), revealed the long run price elasticity of supply for maize to range between 0.93 and 1.2, and short run response to be 0.15 and 0.24. A study by Rodriguez (1986) on beef supply response in Zimbabwe, found the price elasticity ranging between 0.49 and 0.61. Therefore based on these studies, it is certainly reasonable to assume price elasticities of supply for Zimbabwe's agricultural products to be between 0.3 and 1.0 as shown in table 4.7.

Price elasticity of supply for resource poor smallholder farmers is expected to be lower than for large-scale commercial farmers for commodities which require high cost inputs such as beef, wheat, soybeans etc. who have better resource endowments. Price elasticity of supply for annual crops is higher than for fruit trees and livestock which have a longer growth period.

#### **4.5.4. Discount rate**

The discount rate to be used should be a real rate of interest (adjusted for inflation) and should reflect any restrictions placed on alternative uses of the funds. In many situations, the real discount rate will fall in 3-5% range, a rate corresponding to a long-term, risk-free rate of return, that is the real yield from long-term government bonds (Alston *et al*, 1995).

Zimbabwe has followed a relatively low interest rate policy which tends to discourage savings. Real interest rates on government bonds were negative in some years prior to the economic reforms. Since the beginning of economic structural adjustment, the government has adopted a very restrictive monetary policy which has led to the sharp increase in interest rates in order to control monetary expansion (aggregate demand) and therefore inflation. The real interest rate since 1990 has ranged between 3.6 and 8.8%. Based on this range this study assumes an interest rate of 5%.

Table 4.7. Price Elasticities of Supply and Demand

Commodity	Market Situation	Supply Elasticities			Demand Elasticities
		Communal	SSC	LSC	
Maize	Small Open	0.6	0.6	0.7	-0.3
Sorghum	Small Open	0.6	0.6	0.7	-0.4
Pearl Millet	Small Open	0.6			-0.3
Finger Millet	Small Open	0.6	0.6	0.7	-0.3
Beans	Small Open	0.6	0.6	0.7	-0.6
Bambara nuts	Small Open	0.6	0.6	0.6	-0.7
Cowpeas	Small Open	0.6	0.6	0.7	-0.4
Groundnuts	Small Open	0.6	0.6		-0.6
Soybeans	Small Open	0.6	0.6	0.7	-0.7
Cotton	Small Open	0.6	0.6		-0.5
Sunflowers	Small Open	0.6	0.6	0.7	-0.6
Castor Beans	Small Open	0.6	0.6	0.7	-0.6
Indigenous Fruits	Closed	0.7			-0.8
Indigenous Vegetables	Closed	0.5			-0.8
Cabbage	Small Open	0.6	0.6	0.7	-0.5
Tomato	Small Open	0.6	0.6	0.7	-0.5
Potatoes	Small Open	0.6	0.6	0.7	-0.4
Sweet Potatoes	Small Open	0.6	0.6	0.7	-0.4
Onions	Small Open	0.6	0.6	0.7	-0.5
Macadamia nuts	Small Open	0.3	0.3	0.3	-1
Coffee	Small Open	0.3	0.3	0.4	-0.5
Wheat	Small Open		0.6	0.6	-0.5
Flowers	Small Open			0.7	-2
Fruits	Small Open			0.4	-1.5
Export Vegetables	Small Open			0.7	-1.5
Beef	Small Open	0.4	0.4	0.5	-0.9
Dairy	Small Open	0.4	0.5	0.5	-0.9
Poultry	Small Open	0.4	0.5	0.5	-1
Sheep	Small Open	0.4	0.4	0.5	-1
Goats	Small Open	0.4	0.4		-0.9
Fish	Small Open	0.5			-1.1
Multi-purpose	Small Open	0.3			-0.5
Draught Power	Closed	0.3			-0.5
Ostriches	Small Open			0.5	-1.1

#### 4.5.5. Exogenous growth in demand and supply

For priority setting work, projections of population and income growth rates for the next 15 to 20 years are needed to project exogenous demand shifts. There is also need to project the change in the "without-research" quantity ie. growth in supply that is expected to occur regardless of whether the research program of interest is undertaken. Such growth may result from changes in area or herd size, price-induced changes in technology or the effect of research spillover. In practice current output may be projected forward using recent past changes in output to infer a growth rate and to obtain a first approximation of a benchmark stream of "without-research" quantities (Alston *et al*). Question 9 of the questionnaire captured expected changes in area or herd size.

**The following question should be asked of those people who are most familiar with the market for the commodity (not necessarily the scientists):**

9. Do you expect an increase (decrease) in area devoted to the commodity over the next 5 to 10 years? If so, by what percent per year?

Region	Farm Type	Increase or Decrease	Percent Change Per Year

#### 4.6. Analyzing the data

This study used a spreadsheet to calculate economic surplus measures of streams of benefits and costs given the data collected for the variables outlined in the foregoing passage. Data analysis included the conversion of benefits and costs into summary statistics using NPV, calculating contributions to efficiency and distribution objectives and implementing the mathematical programming model to help choose the best portfolio. Given equations 4.1 and 4.2, and data collected on all the variables, a spreadsheet template was set up to calculate the streams of research benefits and costs in a small open-economy and in a closed economy where relevant. The software package LINDO was then used to run the mathematical programming models. The following section details how the objective functions and constraints were calculated.

Two different research programs for each research activity are considered. There is a basic program allowing the current level of funding per research program per commodity and a second level allowing 50% additional funding. The total resource limit refers to the total budgeted research funds for the department in 1995/96 (see table 4.4). The objective function coefficients  $c_{ij}$ , represent the net benefits to society from funding research on commodity  $i$  at a particular level of funding  $j$ . Each  $c_{ij}$  is calculated as the gain in net present value (NPV) due to additional research expenditure i.e. dividing additional NPV by the additional costs resulting from the required increment in funding. Since it is thought that the research production function exhibits diminishing returns, the net returns to a higher level of funding should be diminishing, i.e.  $c_{i1} > c_{i2}$ . Chapter 5 gives further

explanation on how the variables for the mathematical programming model were calculated.

#### **4.7. Summary of chapter**

This chapter explained the methods used in this thesis. First the empirical model used to measure economic surplus changes from agricultural research was presented and explained. Second the steps and data requirements involved in priority setting were presented and discussed. These include identifying the research system objectives, and research programs, designing the scientist questionnaire used to capture information for measuring the research induced change in supply, compiling the market-related data, and analyzing the data. Details on calculation of the mathematical programming model's objective function coefficients and constraints were also presented. The next chapter presents the results of economic surplus estimation and mathematical programming.

## **CHAPTER FIVE**

### **RESULTS AND POLICY IMPLICATIONS**

#### **5.1. Introduction**

This chapter outlines the results of the economic surplus analysis and mathematical programming models. The chapter is divided into three parts. The first part presents priorities by commodity and major research disciplines, obtained from economic surplus analysis. The second section discusses the results obtained from mathematical programming analysis. Particular emphasis is placed on the sensitivity of the research portfolio to varying weights on the equity objective, the trade-off of equity and efficiency objectives, and the shadow prices of different research programs under different weights on the distributional objective. The agricultural research priorities have several important resource allocation and policy implications that are discussed in the last part of this chapter.

## **5.2. Economic Surplus Analysis**

Discounted net economic benefits were calculated for the years 1997 to 2011 using the methods detailed in chapter 4. Economic benefits were organized into tables showing the priorities derived in the analysis. First the priorities by commodities from aggregated benefits are discussed. In this section, commodities are ranked by their aggregate benefits from highest to lowest. The ranking criterion is based on the efficiency objective only. Second, the priorities are presented by farmer type and agro-ecological zone, thus capturing the distribution of benefits across farmer type and agricultural region. Third, priorities by major research areas for aggregate data are presented. Fourth, priorities by research area within major commodities are presented.

### **5.2.1. Aggregate Commodity Priorities**

A summary of the resulting aggregate commodity priorities based on economic benefits from research (1997-2011) if funding per program remains the same as in 1995/96 are presented in table 5.1. This table is derived from table 5.2 which shows detailed rankings of commodities by their aggregate benefits from highest to lowest for the current level of funding and with 50% additional funding for research. Commodities that are in the high, medium and low priority groups are indicated in table 5.1.

Maize, cotton, and groundnuts are by far the top priority commodities. The low priority group includes indigenous vegetables, sheep, donkey draft, indigenous fruits, export peas, macadamia nuts, strawberry, ostriches, castor beans and fish. An examination of appendix 5 and tables 4.1 to 4.6, which contain the underlying economic assumptions and

technology-related data, indicates that the top priority commodities, maize, cotton and groundnuts, have the highest benefits in part because they have higher production than the other commodities. In contrast, most of the commodities in the low priority group have a low total production ( e.g. castor beans), some have low projected yield increases and adoption levels, and others have a long period before results will be available.

Benefits obtained from an additional 50% funding for agricultural research are high for maize, cotton, groundnuts, beef, and dairy. This indicates that additional funding for these commodities generates more benefits than funding other commodities at their current levels. When resources are constraining, maize is funded up to 150 percent of the current level of funding before cotton, groundnuts and beef are funded at current levels. Cotton is allocated an additional 50 percent before allocating to wheat, dairy and bambara nuts current levels of funding (as shown in table 5.2). Allowing for two levels of funding therefore helps decisionmakers in deciding which programs to increase funding.

Table 5.1. Research Priorities resulting from ranking of economic benefits generated with the actual 1995/96 level of funding

High	Medium	Low
maize	pearl millet	apples
cotton	finger millet	beans
groundnuts	poultry	indigenous vegetable
beef	stone fruit	sheep
wheat	soybeans	donkey draft
dairy	onions	indigenous fruit
bambara nuts	sorghum	peas
sunflower	cattle draft	macadamia
coffee	cabbage	strawberry
goats	roses	ostriches
tomato	potatoes	castor beans
cow peas	sweet potatoes	

Table 5.2. Projected aggregate economic benefits (Net Present Value) from research (1997-2011) if funding per program remains the same as in 1995/96 for two levels of funding (current funding and additional funding equal to 50% of current funding)

Rank	Commodity	Level of Funding	Net Present Value 000 Z\$
1	Maize	Current	603703
2	Maize	Additional 50%	259128
3	Cotton	Current	147045
4	Groundnuts	Current	95362
5	Beef	Current	79579
6	Cotton	Additional 50%	66874
7	Wheat	Current	63252
8	Dairy	Current	62465
9	Bambara nuts	Current	50837
10	Groundnuts	Additional 50%	43039
11	Sunflower	Current	38835
12	Beef	Additional 50%	36951
13	Coffee	Current	34294
14	Goats	Current	31002
15	Dairy	Additional 50%	27289
16	Tomato	Current	26489
17	Cow peas	Current	25790
18	Pearl Millet	Current	25005
19	Finger Millet	Current	24767
20	Wheat	Additional 50%	24328
21	Broilers	Current	21246
22	Stonefruit	Current	20599
23	Bambara nuts	Additional 50%	19648
24	Soybeans	Current	19474
25	Onions	Current	18472
26	Sunflower	Additional 50%	18246
27	Sorghum	Current	18164
28	Cattle draft	Current	17711
29	Cabbage	Current	17566
30	Layers	Current	17272
31	Roses	Current	16133
32	Coffee	Additional 50%	15093
33	Potato	Current	14874
34	Sweet Potato	Current	14709
35	Apples	Current	13300
36	Goats	Additional 50%	12891
37	Finger Millet	Additional 50%	12309

38 Pearl Millet	Additional 50%	12294
39 Beans	Current	11915
40 Tomato	Additional 50%	11701
41 Stonefruit	Additional 50%	9992
42 Indigenous vegetables	Current	9614
43 Broilers	Additional 50%	9158
44 Soybeans	Additional 50%	8841
45 Sorghum	Additional 50%	8434
46 Onions	Additional 50%	8184
47 Cattle draft	Additional 50%	8025
48 Roses	Additional 50%	7613
49 Cow peas	Additional 50%	7566
50 Sheep	Current	7291
51 Sweet Potato	Additional 50%	6928
52 Layers	Additional 50%	6720
53 Donkey draft	Current	6718
54 Potato	Additional 50%	6039
55 Cabbage	Additional 50%	6016
56 Apples	Additional 50%	5802
57 Beans	Additional 50%	5244
58 Indigenous vegetables	Additional 50%	4738
59 Indigenous fruit	Current	3345
60 Peas	Current	3209
61 Sheep	Additional 50%	3174
62 Donkey draft	Additional 50%	2853
63 Macadamia	Current	1693
64 Indigenous fruit	Additional 50%	1620
65 Fish	Additional 50%	1598
66 Peas	Additional 50%	1213
67 Strawberry	Current	1067
68 Ostriches	Current	819
69 Macadamia	Additional 50%	780
70 Strawberry	Additional 50%	508
71 Ostriches	Additional 50%	298
72 Castor bean	Current	-280
73 Fish	Current	-1081

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Note: NPV from 50% additional funding refers to the incremental NPV obtained from adding 50% more funding to the current level.

### **5.2.2. Commodity Priorities by Farmer Type and Agro-Ecological Zone**

Priorities indicated in tables 5.1 and 5.2 do not reflect the distributional objective. The net economic benefits ranked by farmer type and agro-ecological zone, thus capturing both the efficiency and distributional objectives are presented in tables 5.3 and 5.4. In tables 5.3 and 5.4, priorities are arranged by farmer type and agro-ecological region. These tables examined together imply that maize, beef, cotton, groundnuts, coffee, wheat, sunflower, goats, bambara nuts, dairy, soybeans, cattle draft and sorghum are top priority commodities. Although beef, wheat, coffee and soybeans are top priority commodities, they only benefit the large-scale commercial sector. Investing research funds into these commodities may not have much impact on smallholder farmers in the short run. Research on smallholder beef is not profitable under the current level of funding because scientists indicated that without significantly more resources for off-station beef research, benefits to beef research for the communal sector will be minimal. However with 50% additional funds available for research, beef tends to become of high priority for smallholder farmers.

Large benefits accrue to smallholders in the low potential areas from research on maize, cotton, sunflower, millets, sorghum and pulses. Small-scale commercial production is low and, as a result, most of its commodities are in the low priority group.

Table 5.3 Ranking of Research Benefits By Farmer Type and Agro-ecological Region

RANKING OF RESEARCH BENEFITS FROM CURRENT LEVEL OF FUNDING					RANKING OF INCREMENTAL RESEARCH BENEFITS FROM 50% MORE FUNDING				
Rank	Commodity	Farmer Type	Region*	NPV'000 Z\$	Rank	Commodity	Farmer Type	Region	NPV'000 Z\$
1	Maize	Communal	LP	195123	1	Maize	Communal	LP	71769
2	Maize	Large Scale	HP	146271	2	Maize	Communal	HP	64513
3	Maize	Communal	HP	131516	3	Maize	Large Scale	HP	63416
4	Maize	Large Scale	LP	128373	4	Maize	Large Scale	LP	57734
5	Beef	Large Scale		79579	5	Beef	Communal		35294
6	Cotton	Communal	LP	62512	6	Cotton	Communal	LP	28804
7	Groundnuts	Communal	LP	47769	7	Groundnuts	Communal	LP	22205
8	Cotton	Large Scale	HP	36397	8	Cotton	Large Scale	HP	16661
9	Coffee	Large Scale	HP	34294	9	Coffee	Large Scale	HP	15093
10	Groundnuts	Communal	HP	34047	10	Groundnuts	Communal	HP	15029
11	Wheat	Large Scale	HP	33154	11	Sunflower	Communal	LP	14862
12	Sunflower	Communal	LP	31445	12	Cotton	Communal	HP	13898
13	Goats	Communal		31002	13	Wheat	Large Scale	HP	13414
14	Wheat	Large Scale	LP	30098	14	Goats	Communal		12891
15	Cotton	Communal	HP	29808	15	Dairy	Large Scale		12605
16	Bambara nuts	Communal	HP	29703	16	Finger Millet	Communal	LP	12309
17	Dairy	Large Scale		27695	17	Pearl Millet	Communal	LP	12294
18	Pearl Millet	Communal	LP	25005	18	Bambara nuts	Communal	LP	11737
19	Finger Millet	Communal	LP	24767	19	Wheat	Large Scale	LP	10914
20	Bambara nuts	Communal	LP	21110	20	Stonefruit	Large Scale	HP	9992
21	Stonefruit	Large Scale	HP	20599	21	Beef	Large Scale		9411
22	Dairy	Communal		18590	22	Soybeans	Large Scale	HP	8137
23	Soybeans	Large Scale	HP	17900	23	Cattle draft	Communal		8025
24	Cattle draft	Communal		17711	24	Bambara nuts	Communal	HP	7894
25	Cotton	Large Scale	LP	17047	25	Sorghum	Communal	LP	7882
26	Sorghum	Communal	LP	16583	26	Dairy	Small Scale		7723
27	Dairy	Small Scale		16180	27	Roses	Large Scale	HP	7613
28	Roses	Large Scale	HP	16133	28	Dairy	Communal		6961
29	Cowpeas	Communal	HP	13755	29	Cotton	Large Scale	LP	6901
30	Apples	Large Scale	HP	13300	30	Apples	Large Scale	HP	5802
31	Cowpeas	Communal	LP	11920	31	Indig. Veg.	Communal	LP	4738
32	Tomato	Communal	HP	9696	32	Tomato	Communal	HP	4372
33	Indig. Veg.	Communal	LP	9614	33	Cowpeas	Communal	LP	4087
34	Layers	Communal		8760	34	Layers	Communal		3734
35	Broilers	Communal		8599	35	Broilers	Large Scale		3621
36	Layers	Large Scale		8512	36	Tomato	Large Scale	HP	3593
37	Tomato	Large Scale	HP	8508	37	Groundnuts	Large Scale	HP	3409
38	Broilers	Large Scale		7847	38	Cowpeas	Communal	HP	3376
39	Groundnuts	Large Scale	HP	7793	39	Broilers	Communal		3170

40 Potato	Large Scale	HP	7241	40 Layers	Large Scale		2986
41 Donkey draft	Communal		6718	41 Onions	Communal	LP	2957
42 Onions	Communal	LP	6683	42 Potato	Large Scale	HP	2923
43 Beans	Communal	HP	6445	43 Donkey draft	Communal		2853
44 Sweet Potato	Communal	LP	5609	44 Sweet Potato	Communal	HP	2635
45 Sunflower	Communal	HP	5501	45 Beans	Communal	HP	2612
46 Sweet Potato	Communal	HP	5378	46 Sweet Potato	Communal	LP	2600
47 Cabbage	Communal	LP	5305	47 Beans	Communal	LP	2583
48 Beans	Communal	LP	5222	48 Sunflower	Communal	HP	2497
49 Broilers	Small Scale		4800	49 Broilers	Small Scale		2367
50 Onions	Large Scale	HP	4779	50 Onions	Large Scale	HP	2173
51 Tomato	Communal	LP	4641	51 Tomato	Communal	LP	2146
52 Onions	Communal	HP	3570	52 Sheep	Communal		1659
53 Sheep	Communal		3427	53 Indig. fruit	Communal	LP	1620
54 Cabbage	Large Scale	HP	3396	54 Fish	Communal		1598
55 Indig. fruit	Communal	LP	3345	55 Onions	Communal	HP	1568
56 Sheep	Large Scale		3291	56 Cabbage	Communal	HP	1451
57 Peas	Large Scale	HP	3209	57 Cabbage	Large Scale	HP	1430
58 Cabbage	Communal	HP	2908	58 Groundnuts	Small Scale	LP	1361
59 Groundnuts	Small Scale	HP	2889	59 Potato	Communal	LP	1273
60 Potato	Communal	LP	2887	60 Sheep	Large Scale		1256
61 Groundnuts	Small Scale	LP	2864	61 Peas	Large Scale	HP	1213
62 Cabbage	Large Scale	LP	2769	62 Cabbage	Communal	LP	1117
63 Potatoe	Large Scale	LP	2556	63 Cabbage	Large Scale	LP	1045
64 Tomato	Small Scale	HP	1960	64 Groundnuts	Small Scale	HP	1035
65 Sunflower	Small Scale	LP	1889	65 Potato	Large Scale	LP	976
66 Cabbage	Small Scale	LP	1809	66 Tomato	Small Scale	HP	950
67 Sweet Potato	Small Scale	HP	1776	67 Maize	Small Scale	LP	903
68 Sweet Potato	Small Scale	LP	1746	68 Sunflower	Small Scale	LP	887
69 Onions	Small Scale	LP	1718	69 Sweet Potato	Small Scale	HP	864
70 Macadamia	Large Scale	HP	1693	70 Maize	Small Scale	HP	793
71 Sorghum	Large Scale	LP	1581	71 Macadamia	Large Scale	HP	780
72 Soybeans	Large Scale	HP	1574	72 Onions	Small Scale	LP	743
73 Potato	Communal	HP	1448	73 Sweet Potato	Small Scale	LP	734
74 Cabbage	Small Scale	HP	1379	74 Soybeans	Large Scale	HP	704
75 Maize	Small Scale	HP	1325	75 Potato	Communal	HP	629
76 Cotton	Small Scale	LP	1281	76 Cotton	Small Scale	LP	610
77 Maize	Small Scale	LP	1095	77 Sorghum	Large Scale	LP	552
78 Strawberry	Large Scale	HP	1067	78 Strawberry	Large Scale	HP	508
79 Onions	Large Scale	LP	945	79 Cabbage	Small Scale	LP	501
80 Tomato	Large Scale	LP	903	80 Cabbage	Small Scale	HP	472
81 Ostriches	Large Scale		819	81 Tomato	Large Scale	LP	432
82 Tomato	Small Scale	LP	781	82 Onions	Large Scale	LP	420
83 Onions	Small Scale	HP	777	83 Onions	Small Scale	HP	323

84 Potato	Small Scale	LP	586	84 Ostriches	Large Scale		298
85 Sheep	Small Scale		573	85 Sheep	Small Scale		259
86 Beans	Large Scale	HP	248	86 Tomato	Small Scale	LP	208
87 Potato	Small Scale	HP	156	87 Potato	Small Scale	LP	161
88 Sweet Potato	Large Scale	HP	122	88 Cowpeas	Large Scale	HP	103
89 Cowpeas	Large Scale	HP	115	89 Potato	Small Scale	HP	77
90 Sweet Potato	Large Scale	LP	78	90 Sweet Potato	Large Scale	HP	60
91 Bambara nuts	Small Scale	HP	24	91 Beans	Large Scale	HP	49
92 Macadamia	Small Scale	HP	-46	92 Sweet Potato	Large Scale	LP	35
93 Castor bean	Communal	LP	-72	93 Bambara nuts	Small Scale	LP	21
94 Castor bean	Large Scale	LP	-86	94 Beans	Large Scale	LP	19
95 Bambara nuts	Small Scale	LP	-128	95 Bambara nuts	Small Scale	HP	17
96 Beans	Large Scale	LP	-231	96 Castor bean	Large Scale	LP	-38
97 Cowpeas	Large Scale	LP	-233	97 Castor bean	Communal	LP	-67
98 Castor bean	Small Scale	LP	-278	98 Macadamia	Small Scale	HP	-68
99 Cowpeas	Small Scale	LP	-287	99 Layers	Small Scale		-76
100 Cowpeas	Small Scale	HP	-313	100 Cowpeas	Small Scale	HP	-106
101 Layers	Small Scale		-436	101 Cowpeas	Large Scale	LP	-110
102 Soybeans	Communal	HP	-516	102 Finger Millet	Small Scale	LP	-111
103 Finger Millet	Small Scale	LP	-555	103 Cowpeas	Small Scale	LP	-126
104 Bambara nuts	Large Scale	HP	-566	104 Castor bean	Small Scale	LP	-142
105 Bambara nuts	Large Scale	LP	-586	105 Cotton	Small Scale	HP	-273
106 Cotton	Small Scale	HP	-780	106 Sunflower	Large Scale	LP	-323
107 Beans	Small Scale	HP	-872	107 Beans	Small Scale	HP	-402
108 Beans	Small Scale	LP	-885	108 Bambara nuts	Large Scale	LP	-408
109 Sunflower	Large Scale	LP	-969	109 Soybeans	Communal	HP	-414
110 Fish	Communal		-1081	110 Beans	Small Scale	LP	-457
111 Soybeans	Small Scale	HP	-1571	111 Bambara nuts	Large Scale	HP	-581
112 Sorghum	Small Scale	LP	-1725	112 Soybeans	Small Scale	HP	-785
113 Wheat	Small Scale	LP	-1791	113 Coffee	Small Scale	HP	-876
114 Coffee	Small Scale	HP	-1810	114 Wheat	Small Scale	LP	-887
115 Goats	Small Scale		-4822	115 Sorghum	Small Scale	LP	-934
116 Beef	Communal		-7754	116 Beef	Small Scale		-2374
117 Beef	Small Scale		-9152	117 Goats	Small Scale		-2643

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- Where LP and HP denotes low and high potential regions respectively.
  - Indig. Veg. and indig. fruit refer to indigenous vegetables and fruit respectively.

Table 5.4 Ranking of Research Benefits By Farmer Type and Agro-ecological Zone, and level of funding

SMALL SCALE FARMERS			COMMUNAL FARMERS			LARGE SCALE FARMERS								
Rank	Commodity	Zone*	Level of Funding	NPV '000 \$	Rank	Commodity	Zone	Level of Funding	NPV '000 Z\$	Rank	Commodity	Zone	Level of Funding	NPV '000 Z\$
1	Dairy		Current	16180	1	Maize	LP	Current	195123	1	Maize	HP	Current	146271
2	Dairy		50% more	7723	2	Maize	HP	Current	131516	2	Maize	LP	Current	128373
3	Broilers		Current	4800	3	Maize	LP	50% more	71769	3	Beef		Current	79579
4	Groundnuts	HP	Current	2889	4	Maize	HP	50% more	64513	4	Maize	HP	50% more	63416
5	Groundnuts	LP	Current	2864	5	Cotton	LP	Current	62512	5	Maize	LP	50% more	57734
6	Broilers		50% more	2367	6	Groundnuts	LP	Current	47769	6	Cotton	HP	Current	36397
7	Tomato	HP	Current	1960	7	Groundnuts	HP	Current	34047	7	Coffee	HP	Current	34294
8	Sunflower	LP	Current	1889	8	Sunflower	LP	Current	31445	8	Wheat	HP	Current	33154
9	Cabbage	LP	Current	1809	9	Goats		Current	31002	9	Wheat	LP	Current	30098
10	Sweet Pot.	HP	Current	1776	10	Cotton	HP	Current	29808	10	Dairy		Current	27695
11	Sweet Pot.	LP	Current	1746	11	Bambara N	HP	Current	29703	11	Stonefruit	HP	Current	20599
12	Onions	LP	Current	1718	12	Cotton	LP	50% more	28804	12	Soybeans	HP	Current	17900
13	Cabbage	HP	Current	1379	13	Pearl Millet	LP	Current	25005	13	Cotton	LP	Current	17047
14	Groundnuts	LP	50% more	1361	14	Finger Mill.	LP	Current	24767	14	Cotton	HP	50% more	16661
15	Maize	HP	Current	1325	15	Groundnuts	LP	50% more	22205	15	Roses	HP	Current	16133
16	Cotton	LP	Current	1281	16	Bambara N	LP	Current	21110	16	Coffee	HP	50% more	15093
17	Maize	LP	Current	1095	17	Dairy		Current	18590	17	Wheat	HP	50% more	13414
18	Groundnuts	HP	50% more	1035	18	Cattle draft		Current	17711	18	Apples	HP	Current	13300
19	Tomato	HP	50% more	950	19	Beef		Current	17647	19	Dairy		50% more	12605
20	Maize	LP	50% more	903	20	Sorghum	LP	Current	16583	20	Wheat	LP	50% more	10914
21	Sunflower	LP	50% more	887	21	Groundnuts	HP	50% more	15029	21	Stonefruit	HP	50% more	9992
22	Sweet Pot.	HP	50% more	864	22	Sunflower	LP	50% more	14862	22	Beef		50% more	9411
23	Maize	HP	50% more	793	23	Cotton	HP	50% more	13898	23	Layers		Current	8512
24	Tomato	LP	Current	781	24	Cowpeas	HP	Current	13755	24	Tomato	HP	Current	8508
25	Onions	HP	Current	777	25	Goats		50% more	12891	25	Soybeans	HP	50% more	8137
26	Onions	LP	50% more	743	26	Finger Mill	LP	50% more	12309	26	Broilers		Current	7847
27	Sweet Pot.	LP	50% more	734	27	Pearl Millet	LP	50% more	12294	27	Groundnut	HP	Current	7793
28	Cotton	LP	50% more	610	28	Cowpeas	LP	50% more	11920	28	Roses	HP	50% more	7613
29	Potato	LP	Current	586	29	Bambara N	LP	50% more	11737	29	Potato	HP	Current	7241
30	Sheep		Current	573	30	Tomato	HP	Current	9696	30	Cotton	LP	50% more	6901
31	Cabbage	LP	50% more	501	31	Indig. veg	LP	Current	9614	31	Apples	HP	50% more	5802
32	Cabbage	HP	50% more	472	32	Layers		Current	8760	32	Onions	HP	Current	4779
33	Onions	HP	50% more	323	33	Broilers		Current	8599	33	Broilers		50% more	3621
34	Sheep		50% more	259	34	Cattle draft		50% more	8025	34	Tomato	HP	50% more	3593
35	Tomato	LP	50% more	208	35	Bambara N	HP	50% more	7894	35	Groundnut	HP	50% more	3409
36	Potato	LP	50% more	161	36	Sorghum	LP	50% more	7882	36	Cabbage	HP	Current	3396
37	Potato	HP	Current	156	37	Dairy		50% more	6961	37	Sheep		Current	3291
38	Potato	HP	50% more	77	38	Donkey draft		Current	6718	38	Peas	HP	Current	3209
39	Bambara N	HP	Current	24	39	Onions	LP	Current	6683	39	Layers		50% more	2986
40	Bambara N	LP	50% more	21	40	Beans	HP	Current	6445	40	Potato	HP	50% more	2923
41	Bambara N.	HP	50% more	17	41	Sweet Pot.	LP	Current	5609	41	Cabbage	LP	Current	2769
42	Macadamia	HP	Current	-46	42	Sunflower	HP	Current	5501	42	Potato	LP	Current	2556
43	Macadamia	HP	50% more	-68	43	Sweet Pot.	HP	Current	5378	43	Onions	HP	50% more	2173
44	Layers		50% more	-76	44	Cabbage	LP	Current	5305	44	Macadama	HP	Current	1693
45	Cowpeas	HP	50% more	-106	45	Beans	LP	Current	5222	45	Sorghum	LP	Current	1581
46	Finger Mill	LP	50% more	-111	46	Indig.veg	LP	50% more	4738	46	Soybeans	HP	Current	1574
47	Cowpeas	LP	50% more	-126	47	Tomato	LP	Current	4641	47	Cabbage	HP	50% more	1430

48 Bambara N	LP	Current	-128	48 Tomato	HP	50% more	4372	48 Sheep	50% more	1256	
49 Castor bean	LP	50% more	-142	49 Cowpeas	LP	50% more	4087	49 Peas	HP	50% more	1213
50 Cotton	HP	50% more	-273	50 Layers		50% more	3734	50 Strawberry	HP	Current	1067
51 Castor bean	LP	Current	-278	51 Onions	HP	Current	3570	51 Cabbage	LP	50% more	1045
52 Cowpeas	LP	Current	-287	52 Sheep		Current	3427	52 Potato	LP	50% more	976
53 Cowpeas	HP	Current	-313	53 Cowpeas	HP	50% more	3376	53 Onions	LP	Current	945
54 Beans	HP	50% more	-402	54 Indig. fruit	LP	Current	3345	54 Tomato	LP	Current	903
55 Layers		Current	-436	55 Broilers		50% more	3170	55 Ostriches		Current	819
56 Beans	LP	50% more	-457	56 Onions	LP	50% more	2957	56 Macadami	HP	50% more	780
57 Finger M.	LP	Current	-555	57 Cabbage	HP	Current	2908	57 Soybeans	HP	50% more	704
58 Cotton	HP	Current	-780	58 Potato	LP	Current	2887	58 Sorghum	LP	50% more	552
59 Soybeans	HP	50% more	-785	59 Donkey draft		50% more	2853	59 Strawberry	HP	50% more	508
60 Beans	HP	Current	-872	60 Sweet Pot.	HP	50% more	2635	60 Tomato	LP	50% more	432
61 Coffee	HP	50% more	-876	61 Beans	HP	50% more	2612	61 Onions	LP	50% more	420
62 Beans	LP	Current	-885	62 Sweet Pot.	LP	50% more	2600	62 Ostriches		50% more	298
63 Wheat	LP	50% more	-887	63 Beans	LP	50% more	2583	63 Beans	HP	Current	248
64 Sorghum	LP	50% more	-934	64 Sunflower	HP	50% more	2497	64 Sweet Pot.	HP	Current	122
65 Soybeans	HP	Current	-1571	65 Tomato	LP	50% more	2146	65 Cowpeas	HP	Current	115
66 Sorghum	LP	Current	-1725	66 Sheep		50% more	1659	66 Cowpeas	HP	50% more	103
67 Wheat	LP	Current	-1791	67 Indig. fruit	LP	50% more	1620	67 Sweet Pot.	LP	Current	78
68 Coffee	HP	Current	-1810	68 Fish		50% more	1598	68 Sweet Pot.	HP	50% more	60
69 Beef		50% more	-2374	69 Onions	HP	50% more	1568	69 Beans	HP	50% more	49
70 Goats		50% more	-2643	70 Cabbage	HP	50% more	1451	70 Sweet Pot.	LP	50% more	35
71 Goats		Current	-4822	71 Potato	HP	Current	1448	71 Beans	LP	50% more	19
72 Beef		Current	-9152	72 Potato	LP	50% more	1273	72 Castorbean	LP	50% more	-38
				73 Cabbage	LP	50% more	1117	73 Castorbean	LP	Current	-86
				74 Potato	HP	50% more	629	74 Cowpeas	LP	50% more	-110
				75 Castor bean	LP	50% more	-67	75 Beans	LP	Current	-231
				76 Castor bean	LP	Current	-72	76 Cowpeas	LP	Current	-233
				77 Soybeans	HP	50% more	-414	77 Sunflower	LP	50% more	-323
				78 Soybeans	HP	Current	-516	78 BambaraN	LP	50% more	-408
				79 Fish		Current	-1081	79 BambaraN	HP	Current	-566
								80 BambaraN	HP	50% more	-581
								81 BambaraN	LP	Current	-586
								82 Sunflower	LP	Current	-969

Where LP and HP denotes low and high potential regions respectively.

Bambara N = bambara nuts, Sweet pot. = sweet potato, indig. veg. = indigenous vegetables.

Note: NPV from 50% more funding refers to the incremental NPV obtained from adding 50% more funding to the current level.

### **5.2.3. Priorities by Aggregate Research Areas**

Research priorities by research discipline are presented in table 5.5. This list is a ranking of aggregate research benefits for each research discipline for two levels of funding (current and incremental benefits from fifty percent more funding). The table indicates that plant breeding (varietal screening for horticultural crops), agronomy, plant protection, chemistry and soils, and livestock nutrition should receive the highest priority, while livestock management, pastures/ forages, veld and rangeland, and farming systems research are of intermediate priority. Livestock breeding, and agro-forestry are of lowest priority. Livestock breeding ranks low because of the long research lag before research results are available. Agro-forestry ranks low because it is currently limited to a few commodities.

Aggregate research priorities by farm type and agricultural region are presented in table 5.6. There are differences in research discipline priorities between smallholder farmers and large-scale commercial farmers. Smallholder farmers have agronomy ranked highest, followed by plant breeding in both low and high potential areas. Chemistry and soils is ranked higher in low potential areas than high potential areas for smallholder farmers. In the contrast, plant breeding ranks highest in both low and high potential areas for large-scale commercial farmers. Agronomy ranks second for large-scale farmers in low potential areas while plant protection ranks second in the high potential areas. Ranking of research disciplines for livestock is similar for smallholder and large-scale farmers, the only difference is that veld and rangeland ranks higher than livestock breeding for large-scale farmers than for smallholder farmers.

Table 5.5. Ranking of Aggregate Economic Benefits By Research Discipline

Benefits resulting from current level of funding		Incremental benefits resulting from 50% more funding	
Rank	Research Discipline	Rank	Research Discipline
	NPV '000Z\$		NPV '000Z\$
1	Plant Breeding	1	Plant Breeding
	534211		220225
2	Agronomy	2	Agronomy
	338104		152866
3	Plant Protection	3	Plant Protection
	238660		106113
4	Chemistry & soils	4	Chemistry & soils
	152854		74992
5	Livestock Nutrition	5	Livestock Nutrition
	118947		45656
6	Livestock Management	6	Pasture & Forage
	55793		28545
7	Farming System Res.	7	Farming System Res.
	47072		23415
8	Pasture & Forage	8	Livestock Management
	34855		21293
9	Veld / Rangeland	9	Veld / Rangeland
	15803		11277
10	Livestock Breeding	10	Livestock Breeding
	13604		4900
11	Agro-Forestry	11	Agro-Forestry
	6797		3485

Table 5.6. Ranking of Aggregate Economic Benefits Within Farm Types by Research Discipline in `000 Z\$

		CROPS IN LOW POTENTIAL REGIONS			CROPS IN HIGH POTENTIAL REGIONS			
Farmer Type	Research Discipline	Incremental		TOTAL NPV	Incremental		TOTAL NPV	
		NPV from Current Funding	NPV from additional 50% funding		NPV from Current Funding	NPV from additional 50% funding		
Small-holder	Agronomy	146314	62160	208474	Agronomy	82461	44344	126805
	Plant Breeding	135108	60701	195809	Plant Breeding	87263	15638	102901
	Chemistry& soil	89250	38946	128196	Plant Protection	46142	25336	71478
	Plant Protection	84467	34460	118927	Chemistry& soil	43645	27311	70956
	Farming System	29039	12390	41430	Farming System	13777	6458	20235
	Agroforestry	3720	1336	5055	Agroforestry	3073	2147	5220
	TOTAL	487898	209993	697891	TOTAL	276361	121234	397595
Large-Scale	Plant Breeding	122585	53391	175976	Plant Breeding	186415	83846	270261
	Agronomy	34424	13743	48166	Plant Protection	84319	35831	120150
	Plant Protection	21379	9311	30690	Agronomy	71488	30579	102067
	Chemistry& soil	5432	2408	7840	Chemistry& soil	13421	5841	19262
	Farming System	0	0	0	Farming System	0	0	0
	Agroforestry	0	0	0	Agroforestry	0	0	0
	TOTAL	183819	78852	262671	TOTAL	355643	156096	511739
LIVESTOCK ALL REGIONS								
Small-holder	Livestock Nutr.	50756	29752	80508				
	Livestock Mgt.	25729	12945	38674				
	Pasture&forage	10092	22638	32730				
	Livestock Breed	12469	4806	17275				
	Veld&rangeland	499	9525	10024				
	Farming System	3559	4362	7921				
	TOTAL	103104	84028	187132				
Large-Scale	Livestock Nutr.	65325	15904	81230				
	Livestock Mgt.	27333	7337	34670				
	Pasture&forage	22032	5703	27735				
	Veld&rangeland	13733	1549	15281				
	Livestock Breed	360	129	489				
	Farming System	0	0	0				
	TOTAL	128041	30206	158246				

Note: Small-scale commercial aggregated to communal to form smallholder.

#### **5.2.4. Priorities by Research problem area for the major commodities**

The results of the analysis of priorities by research problem area and agro-ecological region for each of the major commodity groups, and farm type are presented in tables 5.7, 5.8, and 5.9. The following is a summary of research problem area priorities for the major commodities.

- Maize: Agronomy, chemistry and soils, and breeding were identified as high priority areas for smallholder maize research in both low and high potential regions; while for the large-scale commercial farmers, plant breeding, agronomy and plant protection were identified as the priority areas.
- Cotton: Agronomy, plant breeding, and plant protection were identified as the areas of priority for smallholder cotton research, and plant protection and breeding for large-scale farmers.
- Oilseeds (sunflower, groundnuts, soybeans): The three most important research areas identified for oilseeds research were agronomy, plant breeding, and plant protection for both smallholder and large-scale farmers. However, soybeans and sunflower research gave negative research benefits for smallholder and large-scale farmers respectively.
- Small-grains (finger millet, pearl millet, and sorghum): Plant breeding, agronomy, and chemistry and soils were identified as the priority areas for small-grains research for

smallholder farmers, while for large-scale farmers, agronomy, plant breeding and plant protection were identified as the priority areas.

- Pulses (cow peas, beans, and bambara nuts): The three most important research areas identified for smallholder pulses research were plant breeding, agronomy and plant protection. Research on pulses for large-scale farmers yielded negative returns.
- Vegetables, fruits and export flowers: Plant breeding, agronomy, and plant protection were identified as the priority areas for vegetable and fruit research for both the smallholder and large-scale farmers. Plant breeding and agronomy were identified as priority areas for research on smallholder indigenous fruits and vegetables.
- Livestock (beef and dairy cattle, small ruminants, poultry): Identified priorities for smallholder livestock include livestock nutrition and management for poultry and dairy, pasture and forage, and veld and rangeland for beef, and livestock breeding for draft power cattle. Priorities for large scale livestock include nutrition, management for poultry and ostriches, nutrition, and pastures and forages for dairy and small ruminants, and nutrition, management and veld / range land for beef.

Table 5.7. Ranking Of Economic Benefits By Commodity, Farmer Type, Region and Research area

Benefits from Current Level Of Funding						Incremental benefits Resulting from 50% more Funding					
Rank	Farmer Type	Commodity	Region <sup>1</sup>	Research Area <sup>2</sup>	NPV 000 Z\$	Rank	Farmer Type	Commodity	Region <sup>1</sup>	Research Area <sup>2</sup>	NPV 000 Z\$
1	Large Scale	Maize	HP	PB	106,239	1	Large Scale	Maize	HP	PB	47,128
2	Large Scale	Maize	LP	PB	93,262	2	Large Scale	Maize	LP	PB	42,090
3	Smallholder	Maize	LP	AG	59,879	3	Smallholder	Maize	HP	AG	25,996
4	Smallholder	Maize	LP	CS	56,691	4	Smallholder	Maize	HP	CS	22,241
5	Large Scale	Beef		LN	41,370	5	Smallholder	Maize	LP	AG	22,206
6	Smallholder	Maize	HP	AG	36,262	6	Smallholder	Maize	LP	CS	21,046
7	Smallholder	Maize	LP	PP	35,873	7	Smallholder	Beef		PF	17,446
8	Smallholder	Maize	HP	PB	33,724	8	Smallholder	Maize	HP	PP	15,646
9	Large Scale	Coffee	HP	PP	31,421	9	Large Scale	Coffee	HP	PP	13,933
10	Smallholder	Maize	HP	CS	30,883	10	Smallholder	Maize	LP	PP	13,226
11	Smallholder	Maize	LP	PB	27,448	11	Smallholder	Draftpower		LN	11,438
12	Smallholder	Draftpower		LN	24,766	12	Smallholder	Cotton	LP	AG	11,086
13	Smallholder	Cotton	LP	AG	24,027	13	Smallholder	Maize	LP	PB	10,194
14	Smallholder	Maize	HP	PP	22,384	14	Smallholder	Pulses	LP	PB	9,563
15	Large Scale	Maize	HP	AG	22,063	15	Smallholder	Groundnut	LP	PB	9,260
16	Smallholder	Pulses	HP	PB	21,286	16	Smallholder	Smallgrain	LP	PB	9,260
17	Smallholder	Smallgrain	LP	PB	20,734	17	Smallholder	Cotton	LP	PB	9,018
18	Large Scale	Wheat	HP	PB	19,746	18	Smallholder	Beef		VR	8,983
19	Smallholder	Groundnut	LP	PB	19,722	19	Smallholder	Smallgrain	LP	CS	8,872
20	Smallholder	Cotton	LP	PB	19,536	20	Large Scale	Maize	LP	AG	8,618
21	Large Scale	Wheat	LP	PB	19,494	21	Large Scale	Fruits	HP	PB	8,531
22	Large Scale	Maize	LP	AG	19,338	22	Large Scale	Maize	HP	AG	8,431
23	Smallholder	Pulses	LP	PB	18,881	23	Smallholder	Cotton	LP	PP	8,126
24	Smallholder	Cotton	LP	PP	17,628	24	Large Scale	Wheat	HP	PB	7,995
25	Smallholder	Smallgrain	LP	AG	15,526	25	Large Scale	Wheat	LP	PB	7,100
26	Large Scale	Fruits	HP	PB	15,480	26	Smallholder	Smallgrain	LP	AG	6,980
27	Smallholder	Pulses	HP	AG	14,534	27	Smallholder	Sunflower	LP	AG	6,776
28	Smallholder	Sunflower	LP	AG	14,286	28	Large Scale	Cotton	HP	PP	6,292
29	Large Scale	Maize	HP	PP	13,972	29	Large Scale	Cotton	HP	PB	6,243
30	Smallholder	Groundnut	HP	AG	13,931	30	Smallholder	Pulses	HP	PB	6,212
31	Large Scale	Beef		LM	13,775	31	Large Scale	Maize	HP	PP	6,114
32	Large Scale	Cotton	HP	PP	13,733	32	Smallholder	Groundnut	HP	AG	6,084
33	Large Scale	Beef		VR	13,733	33	Smallholder	Dairy		LN	5,947
34	Smallholder	Dairy		LN	13,660	34	Smallholder	Groundnut	LP	AG	5,641
35	Large Scale	Cotton	HP	PB	13,620	35	Smallholder	Groundnut	HP	PB	5,639
36	Smallholder	Smallgrain	LP	CS	13,175	36	Large Scale	Dairy		LN	5,491
37	Smallholder	Groundnut	HP	PB	12,934	37	Large Scale	Beef		LN	5,489
38	Smallholder	Maize	LP	FSR	12,669	38	Large Scale	Maize	LP	PP	5,470
39	Smallholder	Groundnut	LP	AG	12,299	39	Large Scale	Fruits	HP	AG	5,328
40	Large Scale	Maize	LP	PP	12,270	40	Large Scale	Export hort	HP	PB	5,230
41	Large Scale	Dairy		LN	12,090	41	Smallholder	Beef		LN	5,213
42	Large Scale	Wheat	HP	AG	11,914	42	Smallholder	Sunflower	LP	PB	5,059
43	Large Scale	Beef		PF	11,429	43	Large Scale	Wheat	HP	AG	4,817
44	Large Scale	Export hort	HP	PB	11,328	44	Smallholder	Cotton	HP	PB	4,798
45	Smallholder	Poultry		LM	11,098	45	Smallholder	Poultry		LM	4,709

46	Smallholder	Sunflower	LP	PB	10,692	46	Smallholder	Maize	LP	FSR	4,685
47	Large Scale	Fruits	HP	PP	10,643	47	Smallholder	Maize	HP	FSR	4,543
48	Large Scale	Fruits	HP	AG	10,528	48	Large Scale	Dairy		PF	4,378
49	Smallholder	Cotton	HP	PB	10,212	49	Smallholder	Groundnuts	LP	PP	4,348
50	Smallholder	Dairy		LM	9,870	50	Smallholder	Cotton	HP	AG	4,317
51	Large Scale	Poultry		LN	9,795	51	Smallholder	Ind frt&vg	LP	PB	4,265
52	Smallholder	Vegetables	LP	PB	9,762	52	Smallholder	Vegetables	LP	PB	4,232
53	Large Scale	Vegetables	HP	PB	9,590	53	Large Scale	Poultry		LN	4,176
54	Large Scale	Dairy		PF	9,568	54	Smallholder	Vegetables	HP	PB	4,151
55	Smallholder	Groundnut	LP	PP	9,323	55	Smallholder	Dairy		LM	4,130
56	Large Scale	Wheat	LP	AG	9,267	56	Large Scale	Vegetables	HP	PB	3,958
57	Smallholder	Cotton	HP	AG	9,192	57	Smallholder	Vegetables	LP	AG	3,956
58	Smallholder	Vegetables	LP	AG	9,143	58	Smallholder	Pulses	HP	AG	3,889
59	Smallholder	Vegetables	HP	PB	9,080	59	Smallholder	Vegetables	HP	AG	3,808
60	Smallholder	Ind frt&vg	LP	PB	8,691	60	Smallholder	Cotton	HP	PP	3,725
61	Smallholder	Poultry		LN	8,402	61	Smallholder	Pulses	LP	AG	3,678
62	Smallholder	Vegetables	HP	AG	8,305	62	Smallholder	Poultry		LN	3,650
63	Smallholder	Cotton	HP	PP	7,934	63	Smallholder	Small grains	LP	FSR	3,426
64	Smallholder	Smallgrain	LP	PP	7,567	64	Large Scale	Vegetables	HP	AG	3,342
65	Smallholder	Small rum.		LM	7,491	65	Large Scale	Wheat	LP	AG	3,335
66	Smallholder	Pulses	LP	AG	7,435	66	Large Scale	Fruits	HP	PP	3,231
67	Large Scale	Vegetables	HP	AG	7,167	67	Smallholder	Vegetables	HP	PP	3,186
68	Smallholder	Smallgrain	LP	FSR	7,072	68	Smallholder	Small rum.		LM	3,112
69	Smallholder	Vegetables	HP	PP	6,951	69	Large Scale	Cotton	HP	AG	2,935
70	Smallholder	Small rum.		LN	6,793	70	Large Scale	Soybeans	HP	PB	2,927
71	Smallholder	Dairy		PF	6,661	71	Smallholder	Smallgrain	LP	PP	2,901
72	Smallholder	Maize	HP	FSR	6,566	72	Smallholder	Dairy		PF	2,866
73	Large Scale	Poultry		LM	6,564	73	Smallholder	Groundnuts	LP	CS	2,839
74	Large Scale	Cotton	LP	PP	6,473	74	Smallholder	Beef		FSR	2,797
75	Large Scale	Soybeans	HP	PB	6,425	75	Smallholder	Vegetables	LP	PP	2,766
76	Large Scale	Cotton	HP	AG	6,423	76	Large Scale	Dairy		LM	2,737
77	Smallholder	Vegetables	LP	PP	6,381	77	Smallholder	Small rum.		LN	2,706
78	Large Scale	Cotton	LP	PB	6,344	78	Large Scale	Cotton	LP	PP	2,630
79	Smallholder	Small rum.		PF	6,162	79	Large Scale	Cotton	LP	PB	2,569
80	Smallholder	Groundnut	LP	CS	6,101	80	Smallholder	Small rum.		PF	2,530
81	Large Scale	Dairy		LM	6,037	81	Large Scale	Poultry		LM	2,432
82	Smallholder	Groundnut	HP	PP	5,275	82	Smallholder	Groundnuts	HP	PP	2,285
83	Smallholder	Pulses	LP	PP	5,221	83	Smallholder	Pulses	LP	CS	2,209
84	Smallholder	Pulses	HP	PP	4,869	84	Large Scale	Soybeans	HP	PP	2,148
85	Large Scale	Soybeans	HP	PP	4,718	85	Smallholder	Maize	HP	AF	2,136
86	Smallholder	Dairy		LB	4,578	86	Smallholder	Ind frt&vg	LP	AG	2,094
87	Smallholder	Pulses	LP	CS	4,455	87	Smallholder	Vegetables	HP	CS	2,028
88	Large Scale	Vegetables	HP	PP	4,426	88	Large Scale	Soybeans	HP	AG	1,963
89	Smallholder	Small rum.		LB	4,415	89	Smallholder	Pulses	LP	PP	1,948
90	Smallholder	Vegetables	LP	CS	4,389	90	Smallholder	Vegetables	LP	CS	1,938
91	Smallholder	Vegetables	HP	CS	4,321	91	Large Scale	Export hort	HP	AG	1,875
92	Large Scale	Soybeans	HP	AG	4,319	92	Large Scale	Beef		LM	1,825
93	Smallholder	Indruit&vg	LP	AG	4,268	93	Large Scale	Vegetables	HP	PP	1,751
94	Large Scale	Exporthort	HP	AG	4,244	94	Large Scale	Maize	HP	CS	1,742

95	Smallholder	Small rum.		FSR	4,083	95	Smallholder	Dairy		LB	1,742
96	Smallholder	Pulses	HP	CS	4,066	96	Large Scale	Groundnuts	HP	PB	1,681
97	Large Scale	Maize	HP	CS	3,998	97	Smallholder	Small rum.		LB	1,648
98	Smallholder	Pulses	HP	FSR	3,935	98	Smallholder	Small rum.		FSR	1,633
99	Large Scale	Groundnuts	HP	PB	3,816	99	Smallholder	Sunflower	LP	FSR	1,578
100	Smallholder	Maize	LP	AF	3,658	100	Large Scale	Maize	LP	CS	1,556
101	Large Scale	Maize	LP	CS	3,503	101	Large Scale	Beef		VR	1,549
102	Large Scale	Vegetables	LP	PB	3,423	102	Smallholder	Groundnuts	LP	FSR	1,479
103	Smallholder	Sunflower	LP	FSR	3,367	103	Smallholder	Sunflower	HP	AG	1,396
104	Smallholder	Groundnuts	LP	FSR	3,187	104	Smallholder	Sunflower	LP	PP	1,371
105	Large Scale	Cotton	LP	AG	3,045	105	Large Scale	Vegetables	LP	PB	1,342
106	Smallholder	Maize	HP	AF	3,022	106	Smallholder	Maize	LP	AF	1,315
107	Smallholder	Sunflower	LP	PP	2,922	107	Large Scale	Cotton	LP	AG	1,235
108	Large Scale	Coffee	HP	AG	2,873	108	Smallholder	Groundnuts	HP	CS	1,221
109	Large Scale	Vegetables	HP	CS	2,862	109	Smallholder	Beef		LM	1,206
110	Smallholder	Groundnuts	HP	CS	2,848	110	Large Scale	Cotton	HP	CS	1,191
111	Large Scale	Cotton	HP	CS	2,622	111	Smallholder	Cotton	LP	CS	1,183
112	Smallholder	Cotton	LP	CS	2,601	112	Large Scale	Coffee	HP	AG	1,161
113	Smallholder	Sunflower	HP	AG	2,454	113	Smallholder	Pulses	HP	PP	1,136
114	Large Scale	Soybeans	HP	CS	2,437	114	Large Scale	Vegetables	HP	CS	1,129
115	Large Scale	Exporthort	HP	PP	2,366	115	Smallholder	Pulses	HP	CS	1,109
116	Smallholder	Poultry		LB	2,223	116	Large Scale	Soybeans	HP	CS	1,099
117	Smallholder	Pulses	LP	FSR	2,196	117	Large Scale	Exporthort	HP	PP	1,088
118	Large Scale	Vegetables	LP	AG	2,096	118	Smallholder	Pulses	HP	FSR	1,022
119	Large Scale	Groundnuts	HP	AG	2,083	119	Smallholder	Pulses	LP	FSR	987
120	Smallholder	Small rum.		VR	2,071	120	Smallholder	Sunflower	LP	CS	966
121	Smallholder	Sunflower	LP	CS	2,067	121	Large Scale	Beef		PF	929
122	Smallholder	Draft power		LB	2,027	122	Smallholder	Draft power		LB	925
123	Smallholder	Groundnuts	HP	FSR	1,948	123	Large Scale	Groundnuts	HP	AG	908
124	Smallholder	Cotton	HP	CS	1,690	124	Smallholder	Sunflower	HP	PB	891
125	Large Scale	Groundnuts	HP	PP	1,661	125	Large Scale	Vegetables	LP	AG	842
126	Smallholder	Sunflower	HP	PB	1,560	126	Smallholder	Poultry		LB	836
127	Large Scale	Wheat	HP	PP	1,494	127	Smallholder	Groundnuts	HP	FSR	835
128	Large Scale	Exporthort	HP	CS	1,404	128	Smallholder	Fish		LN	799
129	Large Scale	Wheat	LP	PP	1,337	129	Smallholder	Fish		LM	799
130	Large Scale	Cotton	LP	CS	1,185	130	Smallholder	Cotton	HP	CS	784
131	Smallholder	Sunflower	HP	FSR	1,047	131	Smallholder	Small rum.		VR	746
132	Large Scale	Small rum.		PF	1,035	132	Large Scale	Groundnuts	HP	PP	725
133	Large Scale	Small rum.		LN	1,035	133	Large Scale	Export hort	HP	CS	633
134	Large Scale	Ostrich		LN	1,035	134	Large Scale	Wheat	HP	PP	602
135	Large Scale	Vegetables	LP	CS	906	135	Large Scale	Wheat	LP	PP	478
136	Large Scale	Small rum.		LM	861	136	Large Scale	Cotton	LP	CS	469
137	Large Scale	Vegetables	LP	PP	826	137	Large Scale	Small grains	LP	PB	437
138	Large Scale	Small grains	LP	AG	823	138	Large Scale	Small rum.		PF	397
139	Large Scale	Soybeans	LP	PB	643	139	Large Scale	Small rum.		LN	397
140	Smallholder	Vegetables	LP	FSR	609	140	Large Scale	Vegetables	LP	CS	374
141	Large Scale	Soybeans	LP	PP	502	141	Large Scale	Ostrich		LN	352
142	Smallholder	Vegetables	HP	FSR	392	142	Large Scale	Vegetables	LP	PP	350
143	Large Scale	Soybeans	LP	AG	368	143	Large Scale	Small Rum		LM	333

144	Large Scale	Small grains	LP	PB	363	144	Large Scale	Soybeans	LP	PB	293
145	Large Scale	Small rum.		LB	360	145	Large Scale	Small grains	LP	PP	288
146	Large Scale	Small grains	LP	PP	278	146	Smallholder	Vegetables	LP	FSR	263
147	Large Scale	Groundnuts	HP	CS	232	147	Large Scale	Soybeans	LP	PP	229
148	Smallholder	Sunflower	HP	CS	229	148	Smallholder	Vegetables	HP	FSR	169
149	Smallholder	Sunflower	HP	PP	211	149	Large Scale	Soybeans	LP	AG	164
150	Large Scale	Pulses	HP	PB	171	150	Large Scale	Pulses	HP	PB	153
151	Large Scale	Small grains	LP	CS	117	151	Smallholder	Sunflower	HP	CS	137
152	Large Scale	Ostrich		LM	97	152	Large Scale	Small Ruminants		LB	129
153	Smallholder	Pulses	LP	AF	65	153	Smallholder	Sunflower	HP	PP	120
154	Large Scale	Soybeans	LP	CS	61	154	Large Scale	Small grains	LP	CS	106
155	Smallholder	Pulses	HP	AF	51	155	Large Scale	Groundnuts	HP	CS	96
156	Large Scale	CastorBean	LP	CS	13	156	Smallholder	Pulses	LP	AF	22
157	Large Scale	CastorBean	LP	AG	11	157	Large Scale	Soybeans	LP	CS	18
158	Large Scale	CastorBean	LP	PB	4	158	Smallholder	Pulses	HP	AF	11
159	Smallholder	Fruits	HP	AG	-11	159	Large Scale	Ostrich		LM	11
160	Large Scale	Ostrich		LB	-15	160	Large Scale	CastorBean	LP	CS	7
161	Smallholder	CastorBean	LP	FSR	-21	161	Large Scale	CastorBean	LP	AG	7
162	Smallholder	Fruits	HP	PP	-34	162	Large Scale	CastorBean	LP	PB	5
163	Smallholder	CastorBean	LP	CS	-51	163	Smallholder	Fruits	HP	AG	-5
164	Smallholder	CastorBean	LP	PP	-65	164	Smallholder	Fruits	HP	PP	-12
165	Smallholder	Wheat	HP	PP	-90	165	Smallholder	CastorBean	LP	FSR	-12
166	Smallholder	CastorBean	LP	AG	-106	166	Large Scale	Sunflower	LP	AG	-27
167	Smallholder	CastorBean	LP	PB	-109	167	Smallholder	CastorBean	LP	CS	-27
168	Smallholder	Soybeans	HP	FSR	-111	168	Large Scale	Ostrich		LB	-37
169	Large Scale	Castor Bean	LP	PP	-114	169	Smallholder	CastorBean	LP	PP	-40
170	Large Scale	Pulses	HP	PP	-115	170	Smallholder	Wheat	HP	PP	-45
171	Large Scale	Pulses	HP	AG	-126	171	Smallholder	Sunflower	HP	FSR	-47
172	Large Scale	Pulses	HP	CS	-133	172	Large Scale	Pulses	HP	CS	-49
173	Smallholder	Draft power		FSR	-134	173	Large Scale	Sunflower	LP	CS	-50
174	Large Scale	Sunflower	LP	AG	-161	174	Large Scale	Pulses	HP	PP	-53
175	Large Scale	Pulses	LP	CS	-171	175	Large Scale	CastorBean	LP	PP	-57
176	Large Scale	Sunflower	LP	CS	-181	176	Smallholder	CastorBean	LP	AG	-62
177	Large Scale	Pulses	LP	PP	-193	177	Smallholder	Soybeans	HP	FSR	-63
178	Large Scale	Pulses	LP	PB	-322	178	Smallholder	CastorBean	LP	PB	-67
179	Large Scale	Pulses	LP	AG	-364	179	Smallholder	Draft power		FSR	-67
180	Smallholder	Soybeans	HP	PB	-371	180	Large Scale	Pulses	LP	CS	-70
181	Smallholder	Beef		FSR	-390	181	Large Scale	Pulses	LP	PP	-78
182	Smallholder	Soybeans	HP	CS	-391	182	Large Scale	Pulses	LP	AG	-152
183	Smallholder	Draft power		VR	-407	183	Large Scale	Pulses	HP	AG	-181
184	Smallholder	Draft power		PF	-407	184	Large Scale	Pulses	LP	PB	-200
185	Smallholder	Soybeans	HP	PP	-471	185	Smallholder	Draft power		PF	-203
186	Smallholder	Wheat	HP	AG	-538	186	Smallholder	Draft power		VR	-203
187	Smallholder	Fish		LN	-540	187	Smallholder	Soybeans	HP	CS	-209
188	Smallholder	Fish		LM	-540	188	Smallholder	Soybeans	HP	PB	-222
189	Large Scale	Sunflower	LP	PB	-626	189	Large Scale	Sunflower	LP	PB	-246
190	Large Scale	Beef		LB	-727	190	Smallholder	Wheat	HP	AG	-267
191	Smallholder	Soybeans	HP	AG	-743	191	Large Scale	Smallgrain	LP	AG	-279

192	Smallholder	Beef		LB	-775	192	Smallholder	Soybeans	HP	PP	-281
193	Smallholder	Beef		LM	-775	193	Smallholder	Beef		LB	-346
194	Smallholder	Coffee	HP	PP	-886	194	Large Scale	Beef		LB	-380
195	Smallholder	Coffee	HP	AG	-924	195	Smallholder	Soybeans	HP	AG	-423
196	Smallholder	Wheat	HP	PB	-1,162	196	Smallholder	Coffee	HP	PP	-424
197	Smallholder	Beef		VR	-1,165	197	Smallholder	Coffee	HP	AG	-452
198	Smallholder	Draft power		LM	-1,416	198	Smallholder	Wheat	HP	PB	-576
199	Smallholder	Beef		PF	-2,325	199	Smallholder	Draft power		LM	-1,011
200	Smallholder	Beef		LN	-2,325	200	Smallholder	Maize	HP	PB	-5,255

<sup>1</sup> LP Low potential, HP High potential

<sup>2</sup> PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry

LB = Livestock breeding, LM = Livestock Management, LN=Livestock Nutrition, PF = Pastures and Forages, VR = Veld and Rangeland and FSR Farming Systems research.

Indigfr&veg = indigenous fruits and vegetables, small rum = small ruminants, export hort = export horticultural crops.

Table 5.8. Ranking Of Economic Benefits By Research discipline and agricultural region for major commodities for smallholder farmers

Benefits from Current Level Of Funding				Incremental benefits Resulting from 50% more Funding			
Commodity	Region	Research Area	NPV 000 Z\$	Commodity	Region	Research Area	NPV 000 Z\$
Maize	LP	AG	59,879	Maize	HP	AG	25,996
	LP	CS	56,691		HP	CS	22,241
	HP	AG	36,262		LP	AG	22,206
	LP	PP	35,873		LP	CS	21,046
	HP	PB	33,724		HP	PP	15,646
	HP	CS	30,883		LP	PP	13,226
	LP	PB	27,448		LP	PB	10,194
	HP	PP	22,384		LP	FSR	4,685
	LP	FSR	12,669		HP	FSR	4,543
	HP	FSR	6,566		HP	AF	2,136
	LP	AF	3,658		LP	AF	1,315
	HP	AF	3,022		HP	PB	-5,255
Cotton	LP	AG	24,027	Cotton	LP	AG	11,086
	LP	PB	19,536		LP	PB	9,018
	LP	PP	17,628		LP	PP	8,126
	HP	PB	10,212		HP	PB	4,798
	HP	AG	9,192		HP	AG	4,317
	HP	PP	7,934		HP	PP	3,725
	LP	CS	2,601		LP	CS	1,183
	HP	CS	1,690		HP	CS	784
Groundnuts	LP	PB	19,722	Groundnuts	LP	PB	9,260
	HP	AG	13,931		HP	AG	6,084
	HP	PB	12,934		LP	AG	5,641
	LP	AG	12,299		HP	PB	5,639
	LP	PP	9,323		LP	PP	4,348
	LP	CS	6,101		LP	CS	2,839
	HP	PP	5,275		HP	PP	2,285
	LP	FSR	3,187		LP	FSR	1,479
	HP	CS	2,848		HP	CS	1,221
	HP	FSR	1,948		HP	FSR	835
Sunflower	LP	AG	14,286	Sunflower	LP	AG	6,776
	LP	PB	10,692		LP	PB	5,059
	LP	FSR	3,367		LP	FSR	1,578
	LP	PP	2,922		HP	AG	1,396
	HP	AG	2,454		LP	PP	1,371
	LP	CS	2,067		LP	CS	966
	HP	PB	1,560		HP	PB	891
	HP	FSR	1,047		HP	CS	137
	HP	CS	229		HP	PP	120
	HP	PP	211		HP	FSR	-47
Vegetables	LP	PB	9,762	Vegetables	LP	PB	4,232
	LP	AG	9,143		HP	PB	4,151
	HP	PB	9,080		LP	AG	3,956
	HP	AG	8,305		HP	AG	3,808

	HP	PP	6,951		HP	PP	3,186
	LP	PP	6,381		LP	PP	2,766
	LP	CS	4,389		HP	CS	2,028
	HP	CS	4,321		LP	CS	1,938
	LP	FSR	609		LP	FSR	263
	HP	FSR	392		HP	FSR	169
Smallgrains	LP	PB	20,734	Small grains	LP	PB	9,260
	LP	AG	15,526		LP	CS	8,872
	LP	CS	13,175		LP	AG	6,980
	LP	PP	7,567		LP	FSR	3,426
	LP	FSR	7,072		LP	PP	2,901
Pulses	HP	PB	21,286	Pulses	LP	PB	9,563
	LP	PB	18,881		HP	PB	6,212
	HP	AG	14,534		HP	AG	3,889
	LP	AG	7,435		LP	AG	3,678
	LP	PP	5,221		LP	CS	2,209
	HP	PP	4,869		LP	PP	1,948
	LP	CS	4,455		HP	PP	1,136
	HP	CS	4,066		HP	CS	1,109
	HP	FSR	3,935		HP	FSR	1,022
	LP	FSR	2,196		LP	FSR	987
	LP	AF	65		LP	AF	22
	HP	AF	51		HP	AF	11
Indig frt&veg	LP	AG	4,268	Indig frt&veg	LP	PB	4,265
	LP	PB	8,691		LP	AG	2,094
Poultry		LM	11,098	Poultry		LM	4,709
		LN	8,402			LN	3,650
		LB	2,223			LB	836
SmallRumin		LM	7,491	SmallRumin		LM	3,112
		LN	6,793			LN	2,706
		PF	6,162			PF	2,530
		LB	4,415			LB	1,648
		FSR	4,083			FSR	1,633
		VR	2,071			VR	746
Draft power		LN	24,766	Draft power		LN	11,438
		LB	2,027			LB	925
		FSR	-134			FSR	-67
		PF	-407			VR	-203
		LM	-1,416			LM	-1,011
Dairy		LN	13,660	Dairy		LN	5,947
		LM	9,870			LM	4,130
		PF	6,661			PF	2,866
		LB	4,578			LB	1,742
Beef		VR	-1,165	Beef		PF	17,446
		PF	-2,325			VR	8,983
		FSR	-390			LN	5,213
		LM	-775			FSR	2,797
		LB	-775			LM	1,206
		LN	-2,325			LB	-346

Table 5.9. Ranking Of Economic Benefits By Research discipline and agricultural region for major commodities for large-scale farmers

Benefits from Current Level Of Funding			Incremental benefits Resulting from 50% more Funding				
Commodity	Region	Research Area	NPV 000 Z\$	Commodity	Region	Research Area	NPV 000 Z\$
Maize	HP	PB	106,239	Maize	HP	PB	47,128
	LP	PB	93,262		LP	PB	42,090
	HP	AG	22,063		LP	AG	8,618
	LP	AG	19,338		HP	AG	8,431
	HP	PP	13,972		HP	PP	6,114
	LP	PP	12,270		LP	PP	5,470
	HP	CS	3,998		HP	CS	1,742
	LP	CS	3,503		LP	CS	1,556
Cotton	HP	PP	13,733	Cotton	HP	PP	6,292
	HP	PB	13,620		HP	PB	6,243
	LP	PP	6,473		HP	AG	2,935
	HP	AG	6,423		LP	PP	2,630
	LP	PB	6,344		LP	PB	2,569
	LP	AG	3,045		LP	AG	1,235
	HP	CS	2,622		HP	CS	1,191
	LP	CS	1,185		LP	CS	469
Coffee	HP	PP	31,421	Coffee	HP	PP	13,933
	HP	AG	2,873		HP	AG	1,161
Wheat	HP	PB	19,746	Wheat	HP	PB	7,995
	LP	PB	19,494		LP	PB	7,100
	HP	AG	11,914		HP	AG	4,817
	LP	AG	9,267		LP	AG	3,335
	HP	PP	1,494		HP	PP	602
	LP	PP	1,337		LP	PP	478
Vegetables	HP	PB	9,590	Vegetables	HP	PB	3,958
	HP	AG	7,167		HP	AG	3,342
	HP	PP	4,426		HP	PP	1,751
	LP	PB	3,423		LP	PB	1,342
	HP	CS	2,862		HP	CS	1,129
	LP	AG	2,096		LP	AG	842
	LP	CS	906		LP	CS	374
	LP	PP	826		LP	PP	350
Sunflower	LP	AG	-161	Sunflower	LP	AG	-27
	LP	CS	-181		LP	CS	-50
	LP	PB	-626		LP	PB	-246
Soybeans	HP	PB	6,425	Soybeans	HP	PB	2,927
	HP	PP	4,718		HP	PP	2,148
	HP	AG	4,319		HP	AG	1,963
	HP	CS	2,437		HP	CS	1,099
	LP	PB	643		LP	PB	293
	LP	PP	502		LP	PP	229
	LP	AG	368		LP	AG	164
	LP	CS	61		LP	CS	18
Small grains	LP	AG	823	Small grains	LP	PB	437

	LP	PB	363		LP	PP	288
	LP	PP	278		LP	CS	106
	LP	CS	117		LP	AG	-279
Pulses	HP	PB	171 Pulses		HP	PB	153
	HP	PP	-115		HP	CS	-49
	HP	AG	-126		HP	PP	-53
	HP	CS	-133		LP	CS	-70
	LP	CS	-171		LP	PP	-78
	LP	PP	-193		LP	AG	-152
	LP	PB	-322		HP	AG	-181
	LP	AG	-364		LP	PB	-200
Groundnuts	HP	PB	3,816 Groundnuts		HP	PB	1,681
	HP	AG	2,083		HP	AG	908
	HP	PP	1,661		HP	PP	725
	HP	CS	232		HP	CS	96
Fruits	HP	PB	15,480 Fruits		HP	PB	8,531
	HP	PP	10,643		HP	AG	5,328
	HP	AG	10,528		HP	PP	3,231
Export hort	HP	PB	11,328 Export hort		HP	PB	5,230
	HP	AG	4,244		HP	AG	1,875
	HP	PP	2,366		HP	PP	1,088
	HP	CS	1,404		HP	CS	633
Castor Beans	LP	CS	13 Castor Beans		LP	CS	7
	LP	AG	11		LP	AG	7
	LP	PB	4		LP	PB	5
	LP	PP	-114		LP	PP	-57
Dairy		LN	12,090 Dairy		LN	LN	5,491
		PF	9,568			PF	4,378
		LM	6,037			LM	2,737
Poultry		LN	9,795 Poultry		LN	LN	4,176
		LM	6,564			LM	2,432
Ostrich		LN	1,035 Ostrich		LN	LN	352
		LM	97			LM	11
		LB	-15			LB	-37
Small Rumin		LN	1,035 Small Rumin			PF	397
		PF	1,035			LN	397
		LM	861			LM	333
		LB	360			LB	129
Beef		LN	41,370 Beef		LN	LN	5,489
		LM	13,775			LM	1,825
		VR	13,733			VR	1,549
		PF	11,429			PF	929
		LB	-727			LB	-380

<sup>1</sup> LP Low potential, HP High potential

<sup>2</sup> PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry

LB = Livestock breeding, LM = Livestock Management, LN=Livestock Nutrition, PF = Pastures and Forages, VR = Veld and Rangeland and FSR Farming Systems research.

### **5.3. Results of the Mathematical programming model**

Given that the DR&SS budget is limited, it is important to decide on a possible optimal allocation of research funds across the different commodities. The economic benefits calculated from the economic surplus analysis were used to run first a single-objective (efficiency or total benefits) and then a multiple-objective (efficiency and small farm objectives) model. This section first presents the results of the aggregate single-objective mathematical programming model. Secondly, results of the two-objective mathematical programming model with different weights on the equity objective are presented. Thirdly, shadow prices of the different research programs are presented, and fourthly, the opportunity costs of placing more weight on smallholder farmers are presented.

#### **5.3.1. Results of Aggregate single-objective model**

The results of the mathematical programming analysis help answer two questions; (i) how much to invest, and (ii) where resources should be invested. The objective function coefficients and resource constraints for the efficiency-objective mathematical programming model are presented in table 5.10. As shown in the table, objective function coefficients are expressed as the NPV per dollar of cost. This rate is the measure used for comparing across commodities and for allocating resources. NPVs per dollar of research spending range from -1.5 for castor beans to 133.8 for maize in the aggregate, and from -4.6 for fish to 45.7 for broilers in the aggregate at the current level of funding. One reason for the differences between the livestock and crop commodities is the longer lag between research inputs and outputs for livestock than for crop research. But within the livestock sector, there are differences between returns to poultry compared to returns to other commodities. Poultry

NPV return per dollar cost is higher because it has a shorter pay-off period than that for other livestock commodities like beef.

The results from running the one-objective mathematical programming model are summarized in table 5.11 and details are presented in table 5.12. The results indicate that the high-priority commodities are maize, cotton, dairy, beef, groundnuts, coffee, wheat, sunflower and tomato. These high-priority commodities are the same as those identified in section 5.2.1. Similarly, the medium- and low-priority commodities correspond closely to the ones identified in 5.2.1. However some of the medium and low priority commodities from 5.2.1. (soybeans, sorghum, beans, indigenous fruit, castor beans, sheep, goats and ostriches) are not selected in the optimal solution. Thus, based on the efficiency objective, these commodities would not be funded because their returns are not high relative to returns for the other commodities. The commodities selected in the optimal portfolio are funded at both the current and additional 50% levels, with the exception of dairy and beef which are funded at the current level. It is, however, important to note that 50% of total funds is shared among four commodities (maize, cotton, dairy and beef), 45% among 16 commodities, and the remaining 5% among 7 commodities.

Table 5.10 Resource constraints and objective function coefficients for the efficiency-objective aggregate linear programming model

COMMODITY	AGGREGATE NPV '000 Z\$		Research Funding		NPV/\$cost	
	Current	Incremental	Current	Current +50%	Current	Incremental
Maize	603703	259128	4514	6770.4	133.8	114.8
Sorghum	18164	8434	1273	1910.1	13.2	12.3
Pearl Millet	25005	12294	605	907.4	41.3	40.6
Finger Millet	24767	12309	465	698.0	53.2	52.9
Wheat	63252	24328	1256	1884.6	50.3	38.7
Beans	11915	5244	977	1465.8	12.2	10.7
Bambara nuts	50837	19648	549	823.6	92.6	71.6
Cow peas	25790	7566	605	907.4	42.6	25.0
Groundnuts	95362	43039	1442	2163.7	66.1	59.7
Soybeans	19474	8841	1489	2233.5	13.1	11.9
Cotton	147045	66874	4211	6316.8	34.9	31.8
Sunflower	38835	18246	1117	1675.2	34.8	32.7
Castor bean	-350	-209	233	349.0	-1.5	-1.8
Cabbage	17566	6016	233	349.0	75.5	51.7
Tomato	26489	11701	884	1326.2	30.0	26.5
Potato	14874	6039	558	837.6	26.6	21.6
Sweet Potato	14709	6928	349	523.5	42.1	39.7
Onions	18472	8184	605	907.4	30.5	27.1
Indigenous veg	9614	4738	233	349.0	41.3	40.7
Peas	3209	1213	93	139.6	34.5	26.1
Roses	16133	7613	465	698.0	34.7	32.7
Indigenous fruit	3345	1620	279	418.8	12.0	11.6
Macadamia	1693	780	47	69.8	36.4	33.5
Coffee	34294	15093	1349	2024.2	25.4	22.4
Stonefruit	20599	9992	454	680.5	45.4	44.0
Apples	13300	5802	419	628.2	31.8	27.7
Strawberry	1067	508	35	52.3	30.6	29.1
Beef	79579	36951	5374	8061.7	14.8	13.8
Dairy	62465	27289	4071.6	6107.4	15.3	13.4
Broilers	21246	9158	465	698.0	45.7	39.4
Layers	17272	6720	465	698.0	37.1	28.9
Sheep	7291	3174	605	907.4	12.1	10.5
Goats	31002	12891	2659	3989.0	11.7	9.7
Ostriches	819	298	465	698.0	1.8	1.3
Cattle draft	17711	8025	624	935.3	28.4	25.7
Donkey draft	6718	2853	279	418.8	24.1	20.4
Fish	-1081	1598	233	349.0	-4.6	4.6

Table 5.11 Summary results of research priorities based on allocation of research funding with efficiency as the only objective

High	Medium	Low	None
maize	cattle draft	stone fruit	beans
cotton	pearl millet	apples	indigenous fruit
dairy	onions	sweet potatoes	sorghum
beef	cow peas	donkey draft	soybeans
groundnuts	potatoes	cabbage	castor beans
coffee	bambara nuts	indigenous vegetable	sheep
wheat	finger millet	peas	goats
sunflower	poultry	macadamia	ostriches
tomato	roses	strawberry	

Table 5.12 Optimal Level of Research Spending with Efficiency Objective

RANK	COMMODITY	Current Level of funding	50% more funding	Total Expenditure '000 Z\$	Percentage of total cost
1	Maize	4514	2257	6770	16.89
2	Cotton	4211	2106	6317	15.76
3	Dairy	4072	0	4072	10.16
4	Beef	2527	0	2527	6.30
5	Groundnuts	1442	721	2164	5.40
6	Coffee	1349	675	2024	5.05
7	Wheat	1256	628	1885	4.70
8	Sunflower	1117	558	1675	4.18
9	Tomato	884	442	1326	3.31
10	Cattle draft	624	312	935	2.33
11	Pearl Millet	605	302	907	2.26
12	Onions	605	302	907	2.26
13	Cow peas	605	302	907	2.26
14	Potato	558	279	838	2.09
15	Bambara nuts	549	275	824	2.05
16	Finger Millet	465	233	698	1.74
17	Layers	465	233	698	1.74
18	Roses	465	233	698	1.74
19	Broilers	465	233	698	1.74
20	Stonefruit	454	227	681	1.70
21	Apples	419	209	628	1.57
22	Sweet Potato	349	174	523	1.31
23	Donkey draft	279	140	419	1.04
24	Cabbage	233	116	349	0.87
25	Indigenous vegetables	233	116	349	0.87
26	Peas	93	47	140	0.35
27	Macadamia	47	23	70	0.17
28	Strawberry	35	17	52	0.13
	TOTAL	28920	11161	40081	100

Note: commodities excluded from this optimal selection are sorghum, beans, soybeans, castor bean, indigenous fruit, sheep, goats, ostriches, and fish.

Thus the efficiency - objective MP model indicates that 50% of total resources should be allocated to maize, cotton, beef and dairy, while soybeans, sorghum, beans, indigenous fruit, castor beans, sheep, goats and ostrich are not funded. This “most efficient” portfolio has distributional implications that may not be acceptable as smallholder farmers will not benefit from beef research if the allocation is made at the current levels of funding, and some of priority commodities for smallholders, like sorghum, beans, and goats, are not funded at all. The next section presents results and discusses how the research portfolio changes when more weight is given to the equity objective (objective concerned with improving distribution of research returns to smallholder farmers).

### **5.3.2. Results of the two-objective mathematical Programming model**

Objective function coefficients and resource constraints for the two-objective mathematical programming model are presented in table 5.13. The table shows that objective function coefficients for large scale cow peas, bambara nuts, castor beans, and communal soybeans are negative at both the current and additional 50% funding levels. The total resource constraint, Z\$40 081 000, is the DR&SS 1995/96 actual research budget.

The two-objective mathematical programming model was run first with no additional weight on agricultural research for smallholder farmers, implying that only the efficiency criteria was used in selecting the optimal portfolio (Table 5.14). The model was then run with additional weights of 1.0 and 2.0 on smallholder farmers. The optimal research portfolios selected for each of these different weights are shown in tables 5.15 and 5.16.

The tables indicate the amount of research funds that should be allocated to each commodity for each farm type at the current level of funding and when an additional 50% more funding is made available for agricultural research. When no additional weight is placed on smallholder farmers, commodities that receive high funding include communal maize, and large scale cotton, dairy, beef and maize. Commodities which are not funded include smallholder castor beans, beef, indigenous fruit, goats, beans, dairy and fish, and large-scale sweet potatoes, castor beans, ostriches, sheep, cow peas, bambara nuts, beans, and sorghum. Placing a weight of 1.0 on the smallholder farmers results in a change in the optimal portfolio. Smallholder beef, goats, dairy and beans which were not in the optimal solution are included, while large-scale dairy and soybeans are dropped from the portfolio. Thus, disaggregating by farm type resulted in a change in priorities when compared to the single objective case. The low priority commodity communal sorghum, in the efficiency only-aggregate model now move into higher priority.

Placing an even higher weight (2.0) on equity objective results in a resource allocation similar to when the weight is 1.0 with the exception that large -scale commercial beef funding is reduced, large-scale cotton funding is dropped and communal funding for dairy, goats and beans is increased (table 5.16).

Table 5.13 Resource constraints and objective function coefficients for the multiple-objective linear programming model '000 Z\$

Commodity	Farmer Type	Level of Research Funding	Aggregate NPV '000 Z\$	Funding '000 Z\$ <sup>1</sup>	NPV/\$ cost <sup>2</sup>
Maize	Communal	current	329059	3009	109.4
Maize	Communal	incremental	137978	1505	91.7
Maize	Large Scale	current	274644	1504	182.6
Maize	Large Scale	incremental	81314	752	108.1
Sorghum	Communal	current	14858	915	16.2
Sorghum	Communal	incremental	6948	458	15.2
Sorghum	Large Scale	current	1581	458	3.5
Sorghum	Large Scale	incremental	552	229	2.4
Pearl Millet	Communal	current	25005	605	41.3
Pearl Millet	Communal	incremental	12294	303	40.6
Finger Millet	Communal	current	24212	466	52.0
Finger Millet	Communal	incremental	12100	233	51.9
Wheat	Large Scale	current	61461	1256	48.9
Wheat	Large Scale	incremental	23441	628	37.3
Beans	Communal	current	9910	977	10.1
Beans	Communal	incremental	4336	489	8.9
Beans	Large Scale	current	248	488	0.5
Beans	Large Scale	incremental	49	243	0.2
Bambara nuts	Communal	current	50709	548	92.5
Bambara nuts	Communal	incremental	19669	274	71.8
Bambara nuts	Large Scale	current	-1152	136	-8.4
Bambara nuts	Large Scale	incremental	-989	68	-14.3
Cow peas	Communal	current	25075	403	62.2
Cow peas	Communal	incremental	7231	202	35.8
Cow peas	Large Scale	current	-118	202	-0.6
Cow peas	Large Scale	incremental	-7	101	-0.1
Groundnuts	Communal	current	87569	1152	76.0
Groundnuts	Communal	incremental	39630	576	68.8
Groundnuts	Large Scale	current	7793	288	27.1
Groundnuts	Large Scale	incremental	3409	144	23.7
Soybeans	Communal	current	-516	372	-1.4
Soybeans	Communal	incremental	3409	186	18.3
Soybeans	Large Scale	current	19474	1117	17.4
Soybeans	Large Scale	incremental	8841	559	15.8
Cotton	Communal	current	92320	1404	65.8
Cotton	Communal	incremental	42702	702	60.8
Cotton	Large Scale	current	53444	2807	19.0
Cotton	Large Scale	incremental	23562	1404	16.8
Sunflower	Communal	current	38835	558	69.6
Sunflower	Communal	incremental	18246	279	65.4
Sunflower	Large Scale	current	-969	426	-2.3
Sunflower	Large Scale	incremental	-323	213	-1.5
Castor bean	Communal	current	-72	155	-0.5
Castor bean	Communal	incremental	-67	77	-0.9
Castor bean	Large Scale	current	-86	77	-1.1

Castor bean	Large Scale	incremental	-38	38	-1.0
Cabbage	Communal	current	8213	78	105.3
Cabbage	Communal	incremental	2568	39	65.8
Cabbage	Large Scale	current	6165	155	39.8
Cabbage	Large Scale	incremental	2475	78	31.7
Tomato	Communal	current	14337	294	48.8
Tomato	Communal	incremental	6518	147	44.3
Tomato	Large Scale	current	12152	589	20.6
Tomato	Large Scale	incremental	5183	295	17.6
Potato	Communal	current	4335	186	23.3
Potato	Communal	incremental	1902	93	20.5
Potato	Large Scale	current	10539	372	28.3
Potato	Large Scale	incremental	4137	186	22.2
Sweet Potato	Communal	current	10987	116	94.7
Sweet Potato	Communal	incremental	5235	58	90.3
Sweet Potato	Large Scale	current	3722	233	15.8
Sweet Potato	Large Scale	incremental	1693	117	14.5
Onions	Communal	current	10253	202	50.8
Onions	Communal	incremental	4525	101	44.8
Onions	Large Scale	current	8219	404	20.3
Onions	Large Scale	incremental	3659	202	18.1
Indigenous vegetables	Communal	current	9614	233	41.3
Indigenous vegetables	Communal	incremental	4738	117	40.5
Peas	Large Scale	current	3209	93	34.5
Peas	Large Scale	incremental	1213	47	25.8
Roses	Large Scale	current	16133	465	34.7
Roses	Large Scale	incremental	7603	233	32.6
Indigenous fruits	Communal	current	3345	233	14.4
Indigenous fruits	Communal	incremental	1620	117	13.8
Macadamia nuts	Large Scale	current	1693	47	36.0
Macadamia nuts	Large Scale	incremental	780	23	34.0
Coffee	Large Scale	current	32484	900	36.1
Coffee	Large Scale	incremental	14217	450	31.6
Stone fruit	Large Scale	current	20599	419	49.2
Stone fruit	Large Scale	incremental	9992	209	47.6
Apples	Large Scale	current	13300	454	29.3
Apples	Large Scale	incremental	5802	227	25.6
Strawberry	Large Scale	current	1067	35	30.5
Strawberry	Large Scale	incremental	508	18	28.2
Beef	Communal	current	-7754	1792	-4.3
Beef	Communal	incremental	35294	896	15.4
Beef	Large Scale	current	70427	3583	19.7
Beef	Large Scale	incremental	7037	1791	3.9
Dairy	Communal	current	18590	1541	12.1
Dairy	Communal	incremental	6961	771	9.0
Dairy	Large Scale	current	43875	2531	17.3
Dairy	Large Scale	incremental	20328	1266	16.1
Broilers	Communal	current	8599	155	55.5
Broilers	Communal	incremental	3170	78	40.6

Broilers	Large Scale	current	12647	310	40.8
Broilers	Large Scale	incremental	5988	155	38.6
Layers	Communal	current	8760	155	56.5
Layers	Communal	incremental	5988	78	76.8
Layers	Large Scale	current	8076	310	26.1
Layers	Large Scale	incremental	2910	155	18.8
Sheep	Communal	current	4000	202	19.8
Sheep	Communal	incremental	1918	101	19.0
Sheep	Large Scale	current	3864	403	9.6
Sheep	Large Scale	incremental	1515	202	7.5
Goats	Communal	current	26180	2660	9.8
Goats	Communal	incremental	10248	1330	7.7
Ostriches	Large Scale	current	819	465	1.8
Ostriches	Large Scale	incremental	298	233	1.3
Cattle draft	Communal	current	17711	624	28.4
Cattle draft	Communal	incremental	8025	312	25.7
Donkey draft	Communal	current	6718	283	23.7
Donkey draft	Communal	incremental	2853	141	20.2
Fish	Communal	current	-1081	233	-4.6
Fish	Communal	incremental	1598	117	2.2

<sup>1</sup> These are the resource constraints  $R_{ij}$  for each research activity.

<sup>2</sup> These are the objective function coefficients  $c_{ij}$  for each research activity.

Note:

- Communal includes small scale commercial for all commodities except wheat, pulses, groundnuts, sunflower, and goats, and large scale includes small scale commercial for all except those noted as included in communal.
- Incremental refers to 50% additional funding allowed per research activity.
- Communal beef and fish were treated differently since the current funding did not yield required benefits. An average of the benefits from current and additional level of funding was used to calculate the NPV/\$ cost used to calculate the objective function coefficient.

Table 5.14 Ranking of Optimal Resource allocation with no Additional Weight on Smallholder Farmers ('000 Z\$)

Rank	Commodity	Farmer Type	Current funding	50% additional funding	Total Funding 000 Z\$	Percentage of total cost
1	Maize	Communal	3009	1505	4514	11.3
2	Cotton	Large Scale	2807	1404	4211	10.5
3	Beef	Large Scale	3583	0	3583	8.9
4	Dairy	Large Scale	2531	310	2841	7.1
5	Maize	Large Scale	1504	752	2256	5.6
6	Cotton	Communal	1404	702	2106	5.3
7	Wheat	Large Scale	1256	628	1884	4.7
8	Groundnuts	Communal	1152	576	1728	4.3
9	Coffee	Large Scale	900	450	1350	3.4
10	Soybeans	Large Scale	1117	0	1117	2.8
11	Cattle draft	Communal	624	312	936	2.3
12	Sorghum	Communal	915	0	915	2.3
13	Pearl Millet	Communal	605	303	908	2.3
14	Tomato	Large Scale	589	294	883	2.2
15	Sunflower	Communal	558	279	837	2.1
16	Bambara nuts	Communal	548	274	822	2.1
17	Finger Millet	Communal	466	233	699	1.7
18	Roses	Large Scale	465	233	698	1.7
19	Apples	Large Scale	454	227	681	1.7
20	Stonefruit	Large Scale	419	210	629	1.6
21	Onions	Large Scale	404	202	606	1.5
22	Cowpeas	Communal	403	202	605	1.5
23	Potato	Large Scale	372	186	558	1.4
24	Broilers	Large Scale	310	155	465	1.2
25	Layers	Large Scale	310	155	465	1.2
26	Tomato	Communal	295	147	442	1.1
27	Groundnuts	Large Scale	288	144	432	1.1
28	Donkey draft	Communal	283	141	424	1.1
29	Indigenous veg	Communal	233	117	350	0.9
30	Onions	Communal	202	101	303	0.8
31	Sheep	Communal	202	101	303	0.8
32	Potato	Communal	186	93	279	0.7
33	Cabbage	Large Scale	155	78	233	0.6
34	Broilers	Communal	155	77	232	0.6
35	Layers	Communal	155	77	232	0.6
36	Sweet Potato	Communal	116	58	174	0.4
37	Peas	Large Scale	93	47	140	0.3
38	Cabbage	Communal	78	39	117	0.3
39	Macadamia	Large Scale	47	23	70	0.2

40 Strawberry	Large Scale	35	18	53	0.1
41 Ostrich	Large Scale	0	0	0	0.0
42 Fish	Communal	0	0	0	0.0
43 Beef	Communal	0	0	0	0.0
44 Indigenous fruit	Communal	0	0	0	0.0
45 Sheep	Large Scale	0	0	0	0.0
46 Goats	Communal	0	0	0	0.0
47 Dairy	Communal	0	0	0	0.0
48 Beans	Communal	0	0	0	0.0
49 Sweet Potato	Large Scale	0	0	0	0.0
50 Castor bean	Communal	0	0	0	0.0
51 Castor bean	Large Scale	0	0	0	0.0
52 Sunflower	Large Scale	0	0	0	0.0
53 Soybeans	Communal	0	0	0	0.0
54 Cowpeas	Large Scale	0	0	0	0.0
55 Bambara nuts	Large Scale	0	0	0	0.0
56 Beans	Large Scale	0	0	0	0.0
57 Sorghum	Large Scale	0	0	0	0.0
TOTAL		29228	10853	40081	100

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Where current refers to the current level of funding and additional refers to the 50% additional level of funding. Note that the overall budget was constrained to the 1995/96 DR&SS actual budget of Z\$40,081,000.

Table 5.15 Ranking of Optimal Resource allocation with 1.0 Additional Weight on  
Smallholder Farmers ('000 Z\$)

Rank	Commodity	Farmer Type	Current funding	50% additional funding	Total Funding 000 Z\$	Percentage of total cost
1	Maize	Communal	3009	1505	4514	11.3
2	Beef	Large Scale	3583	0	3583	8.9
3	Goats	Communal	2660	0	2660	6.6
4	Maize	Large Scale	1504	752	2256	5.6
5	Cotton	Communal	1404	702	2106	5.3
6	Wheat	Large Scale	1256	628	1884	4.7
7	Beef	Communal	1791	0	1791	4.5
8	Groundnuts	Communal	1152	576	1728	4.3
9	Dairy	Communal	1541	0	1541	3.8
10	Sorghum	Communal	915	458	1373	3.4
11	Coffee	Large Scale	900	450	1350	3.4
12	Cotton	Large Scale	1043	0	1043	2.6
13	Beans	Communal	977	0	977	2.4
14	Cattle draft	Communal	624	312	936	2.3
15	Pearl Millet	Communal	605	303	908	2.3
16	Sunflower	Communal	558	279	837	2.1
17	Bambara nuts	Communal	548	274	822	2.1
18	Finger Millet	Communal	466	233	699	1.7
19	Roses	Large Scale	465	233	698	1.7
20	Apples	Large Scale	454	227	681	1.7
21	Stonefruit	Large Scale	419	210	629	1.6
22	Cowpeas	Communal	403	202	605	1.5
23	Tomato	Large Scale	589	0	589	1.5
24	Potato	Large Scale	372	186	558	1.4
25	Broilers	Large Scale	310	155	465	1.2
26	Tomato	Communal	295	147	442	1.1
27	Groundnuts	Large Scale	288	144	432	1.1
28	Donkey draft	Communal	283	141	424	1.1
29	Onions	Large Scale	404	0	404	1.0
30	Indigenous veg	Communal	233	117	350	0.9
31	Indigenous fruit	Communal	233	117	350	0.9
32	Layers	Large Scale	310	0	310	0.8
33	Onions	Communal	202	101	303	0.8
34	Sheep	Communal	202	101	303	0.8
35	Potato	Communal	186	93	279	0.7
36	Cabbage	Large Scale	155	78	233	0.6
37	Broilers	Communal	155	77	232	0.6
38	Layers	Communal	155	77	232	0.6

39 Sweet Potato	Communal	116	58	174	0.4
40 Peas	Large Scale	93	47	140	0.3
41 Cabbage	Communal	78	39	117	0.3
42 Macadamia	Large Scale	47	23	70	0.2
43 Strawberry	Large Scale	35	18	53	0.1
44 Dairy	Large Scale	0	0	0	0.0
45 Soybeans	Large Scale	0	0	0	0.0
46 Ostrich	Large Scale	0	0	0	0.0
47 Fish	Communal	0	0	0	0.0
48 Sheep	Large Scale	0	0	0	0.0
49 Sweet Potato	Large Scale	0	0	0	0.0
50 Castor bean	Communal	0	0	0	0.0
51 Castor bean	Large Scale	0	0	0	0.0
52 Sunflower	Large Scale	0	0	0	0.0
53 Soybeans	Communal	0	0	0	0.0
54 Cowpeas	Large Scale	0	0	0	0.0
55 Bambara nuts	Large Scale	0	0	0	0.0
56 Beans	Large Scale	0	0	0	0.0
57 Sorghum	Large Scale	0	0	0	0.0
TOTAL		31018	9063	40081	100

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Table 5.16 Ranking of Optimal Resource allocation with 2.0 Additional Weight on Smallholder Farmers ('000 Z\$)

Rank	Commodity	Farmer Type	Current funding	50% additional funding	Total Funding 000 Z\$	Percentage of total cost
1	Maize	Communal	3009	1505	4514	11.3
2	Goats	Communal	2660	1330	3990	10.0
3	Dairy	Communal	1541	771	2312	5.8
4	Maize	Large Scale	1504	752	2256	5.6
5	Cotton	Communal	1404	702	2106	5.3
6	Beef	Large Scale	2036	0	2036	5.1
7	Wheat	Large Scale	1256	628	1884	4.7
8	Beef	Communal	1791	0	1791	4.5
9	Groundnuts	Communal	1152	576	1728	4.3
10	Beans	Communal	977	489	1466	3.7
11	Sorghum	Communal	915	458	1373	3.4
12	Coffee	Large Scale	900	450	1350	3.4
13	Cattle draft	Communal	624	312	936	2.3
14	Pearl Millet	Communal	605	303	908	2.3
15	Sunflower	Communal	558	279	837	2.1
16	Bambara nuts	Communal	548	274	822	2.1
17	Finger Millet	Communal	466	233	699	1.7
18	Roses	Large Scale	465	233	698	1.7
19	Apples	Large Scale	454	227	681	1.7
20	Stonefruit	Large Scale	419	210	629	1.6
21	Cowpeas	Communal	403	202	605	1.5
22	Tomato	Large Scale	589	0	589	1.5
23	Potato	Large Scale	372	186	558	1.4
24	Broilers	Large Scale	310	155	465	1.2
25	Tomato	Communal	295	147	442	1.1
26	Groundnuts	Large Scale	288	144	432	1.1
27	Donkey draft	Communal	283	141	424	1.1
28	Onions	Large Scale	404	0	404	1.0
29	Indigenous veg	Communal	233	117	350	0.9
30	Indigenous fruit	Communal	233	117	350	0.9
31	Layers	Large Scale	310	0	310	0.8
32	Onions	Communal	202	101	303	0.8
33	Sheep	Communal	202	101	303	0.8
34	Potato	Communal	186	93	279	0.7
35	Cabbage	Large Scale	155	78	233	0.6
36	Broilers	Communal	155	77	232	0.6
37	Layers	Communal	155	77	232	0.6
38	Sweet Potato	Communal	116	58	174	0.4
39	Peas	Large Scale	93	47	140	0.3
40	Cabbage	Communal	78	39	117	0.3
41	Macadamia	Large Scale	47	23	70	0.2
42	Strawberry	Large Scale	35	18	53	0.1
43	Cotton	Large Scale	0	0	0	0.0
44	Dairy	Large Scale	0	0	0	0.0

45 Soybeans	Large Scale	0	0	0	0.0
46 Ostrich	Large Scale	0	0	0	0.0
47 Fish	Communal	0	0	0	0.0
48 Sheep	Large Scale	0	0	0	0.0
49 Sweet Potato	Large Scale	0	0	0	0.0
50 Castor bean	Communal	0	0	0	0.0
51 Castor bean	Large Scale	0	0	0	0.0
52 Sunflower	Large Scale	0	0	0	0.0
53 Soybeans	Communal	0	0	0	0.0
54 Cowpeas	Large Scale	0	0	0	0.0
55 Bambara nuts	Large Scale	0	0	0	0.0
56 Beans	Large Scale	0	0	0	0.0
57 Sorghum	Large Scale	0	0	0	0.0
TOTAL		28428	11653	40081	100

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### **5.3.3. Shadow prices**

The shadow prices by commodity and farmer type when the farmer types are weighted equally are presented in table 5.17. The shadow prices are the effects on total economic benefits of spending an additional dollar on a particular commodity's research program. These shadow prices therefore indicate the commodity research programs that provide the most benefit to society from investing an additional dollar of research resources. The shadow prices also reflect the opportunity costs foregone by not investing additional resources. Themes with higher shadow prices imply higher foregone benefits per research dollar withheld. The commodities that give the highest additional benefits at current level of funding include communal maize, bambara nuts, cow peas, and cabbage and large-scale commercial maize. As expected, an increase in weight placed on smallholder farmers results in an increase in the shadow prices for the smallholder commodities relative to those of the large-scale commercial farmers.

### **5.3.4. Trade-off of Objectives**

As indicated in chapter 3, there is need to calculate the efficiency loss as more weight is placed on the equity objective. The calculated trade-off or opportunity cost of placing more weight on equity when total resource is constrained at different levels of the actual 1995/96 DR&SS budget is presented in table 5.18 and illustrated as trade-off curves in figure 5.1.

Table 5.17. Shadow Prices by commodity when farmer types are equally weighted

Commodity	Farmer Type	Funding Level <sup>1</sup>	Shadow Price Z\$
Maize	Communal	current	17.7
Maize	Communal	incremental	75.6
Maize	Large Scale	current	74.5
Maize	Large Scale	incremental	92.1
Sorghum	Communal	current	0.1
Sorghum	Communal	incremental	0.0
Sorghum	Large Scale	current	0.0
Sorghum	Large Scale	incremental	0.0
Pearl Millet	Communal	current	0.7
Pearl Millet	Communal	incremental	24.5
Finger Millet	Communal	current	1.0
Finger Millet	Communal	incremental	35.0
Wheat	Large Scale	current	11.6
Wheat	Large Scale	incremental	21.2
Beans	Communal	current	0.0
Beans	Communal	incremental	0.0
Beans	Large Scale	current	0.0
Beans	Large Scale	incremental	0.0
Bambara nuts	Communal	current	20.4
Bambara nuts	Communal	incremental	55.9
Bambara nuts	Large Scale	current	0.0
Bambara nuts	Large Scale	incremental	0.0
Cow peas	Communal	current	26.3
Cow peas	Communal	incremental	19.8
Cow peas	Large Scale	current	0.0
Cow peas	Large Scale	incremental	0.0
Groundnuts	Communal	current	7.2
Groundnuts	Communal	incremental	52.7
Groundnuts	Large Scale	current	3.4
Groundnuts	Large Scale	incremental	7.6
Soybeans	Communal	current	0.0
Soybeans	Communal	incremental	0.0
Soybeans	Large Scale	current	1.3
Soybeans	Large Scale	incremental	0.0
Cotton	Communal	current	5.0
Cotton	Communal	incremental	44.7
Cotton	Large Scale	current	2.2
Cotton	Large Scale	incremental	0.9
Sunflower	Communal	current	4.2
Sunflower	Communal	incremental	49.4
Sunflower	Large Scale	current	0.0
Sunflower	Large Scale	incremental	0.0
Castor bean	Large Scale	current	0.0
Castor bean	Large Scale	incremental	0.0
Cabbage	Communal	current	39.5
Cabbage	Communal	incremental	49.8
Cabbage	Large Scale	current	16.0

Cabbage	Large Scale	incremental	28.2
Tomato	Communal	current	4.5
Tomato	Communal	incremental	28.3
Tomato	Large Scale	current	3.0
Tomato	Large Scale	incremental	1.5
Potato	Communal	current	2.8
Potato	Communal	incremental	4.4
Potato	Large Scale	current	6.1
Potato	Large Scale	incremental	6.1
Sweet Potato	Communal	current	4.4
Sweet Potato	Communal	incremental	74.2
Sweet Potato	Large Scale	current	0.0
Sweet Potato	Large Scale	incremental	0.0
Onions	Communal	current	6.0
Onions	Communal	incremental	28.7
Onions	Large Scale	current	2.3
Onions	Large Scale	incremental	2.0
Indigenous veg	Communal	current	0.8
Indigenous veg	Communal	incremental	24.4
Peas	Large Scale	current	8.7
Peas	Large Scale	incremental	9.7
Roses	Large Scale	current	2.0
Roses	Large Scale	incremental	16.6
Indigenous	Communal	current	0.0
Indigenous	Communal	incremental	0.0
Macadamia	Large Scale	current	2.0
Macadamia	Large Scale	incremental	16.6
Coffee	Large Scale	current	4.5
Coffee	Large Scale	incremental	15.5
Stonefruit	Large Scale	current	1.5
Stonefruit	Large Scale	incremental	31.6
Apples	Large Scale	current	3.7
Apples	Large Scale	incremental	9.5
Strawberry	Large Scale	current	1.7
Strawberry	Large Scale	incremental	11.9
Beef	Communal	current	0.0
Beef	Communal	incremental	0.0
Beef	Large Scale	current	3.6
Beef	Large Scale	incremental	0.0
Dairy	Communal	current	0.0
Dairy	Communal	incremental	0.0
Dairy	Large Scale	current	1.2
Dairy	Large Scale	incremental	0.0
Broilers	Communal	current	14.9
Broilers	Communal	incremental	24.5
Broilers	Large Scale	current	2.8
Broilers	Large Scale	incremental	22.0
Layers	Communal	current	8.3
Layers	Communal	incremental	32.1

Layers	Large Scale	current	7.8
Layers	Large Scale	incremental	2.7
Sheep	Communal	current	0.8
Sheep	Communal	incremental	2.9
Sheep	Large Scale	current	0.0
Sheep	Large Scale	incremental	0.0
Goats	Communal	current	0.0
Goats	Communal	incremental	0.0
Ostriches	Large Scale	current	0.0
Ostriches	Large Scale	incremental	0.0
Cattle draft	Communal	current	2.7
Cattle draft	Communal	incremental	9.6
Donkey draft	Communal	current	3.6
Donkey draft	Communal	incremental	4.3
Fish	Communal	current	0.0
Fish	Communal	incremental	0.0

<sup>1</sup> Where current refers to the current level of funding and incremental refers to the 50% additional level of funding. Note that the overall budget was constrained to the 1995/96 DR&SS actual budget.

The table and figure indicates that when an additional weight on the equity objective is 1.0 to 2.0, the trade-off significantly increases. Thereafter as the weight increases, the trade-off remains unchanged and experiences another increase at a weight of 10. These findings indicate that there is a modest (3.8 percent maximum) opportunity cost of efficiency foregone when agricultural research is used as an instrument for meeting an income distribution objective when the budget is constrained at the actual 1995/96 DR&SS level. This finding implies that at the strategic level, DR&SS can invest resources into the research on smallholder farming without incurring major losses in efficiency.

One reason for the relatively low loss in efficiency is because the overall budget was not very constraining. When the resources are constrained by reducing the total budget by 20% and 50%, the loss in efficiency as the weight on the distributional objective is increased, increases to 8% and 11% respectively (table 5.18). Consequently the trade-off curve between the efficiency and the distributional objective is much steeper when the total budget is constrained to 50% of the actual 1995/96 budget as illustrated in figure 5.1.

It is important to identify which research programs lose and which programs benefit when the weight on the distributional objective is increased. A comparison of the distribution of benefits between the optimal solution with no weight on distributional objective and one with a weight of 2.0 on the distributional objective indicate that research on large scale commercial dairy, soybeans, sheep, and cotton are eliminated from the optimal portfolio, while research on large-scale commercial groundnuts, peas and onions experience cutbacks. Research on smallholder beef, beans, goats and dairy gain from increased

funding. Thus, the efficiency loss associated with increased weight on the distributional objective involves the loss of research on large-scale dairy, soybeans, sheep, and cotton. Previously underfunded research on smallholder beef, dairy and fish increases.

#### **5.4. Policy Implications**

The following policy implications can be drawn from the foregoing analysis about agricultural research priorities for Zimbabwe;

- Agricultural research investments in Zimbabwe have high rates of economic returns, and the government should continue to fund or increase investments into agricultural research.
- Research benefits from maize are very high, thus making maize research a high priority. Priorities resulting from economic surplus analysis and mathematical programming, show maize to be the dominant crop for both smallholder and large-scale farmers, for both high and low potential areas. When resources are allocated to research on smallholder farming, research on maize takes about 19% of total resources. Cotton comes second to maize as a major crop to be researched.
- If research priorities are to be tailored to meet both the efficiency and distributional objectives, then directing research efforts on commodity priorities indicated in tables 5.14, 5.15, and 5.16, may help achieve the objectives.

Table 5.18 Tradeoff of efficiency and equity objectives with the existing DR&SS total budget and when total resources are constrained ZS'000

Resources = 100% <sup>1</sup>				
Weight	Total research benefits (efficiency objective)	Benefits to smallholders	Trade-off	Percent trade-off
0	200570	112617	0	0.0
1	196211	122028	4359	2.2
2	193314	124181	7256	3.6
3	193314	124181	7256	3.6
4	193314	124181	7256	3.6
5	193314	124181	7256	3.6
6	193314	124181	7256	3.6
7	193314	124181	7256	3.6
10	192906	124232	7664	3.8
Resources = 20% less				
Weight	Total research benefits (efficiency objective)	Benefits to smallholders	Trade-off	Percent trade-off
0	186617	110943	0	0.0
1	183805	118683	2812	1.5
2	179272	121685	7345	3.9
3	175968	122949	10649	5.7
4	171483	124181	15134	8.1
5	171483	124181	15134	8.1
7	171483	124181	15134	8.1
9	171483	124181	15134	8.1
11	171483	124181	15134	8.1
Resources = 50% less				
Weight	Total research benefits (efficiency objective)	Benefits to smallholders	Trade-off	Percent trade-off
0	158089	105653	0	0.0
1	156368	110303	1721	1.1
2	155094	111296	2995	1.9
3	149536	113941	8553	5.4
4	149536	113941	8553	5.4
5	149536	113941	8553	5.4
7	142565	115099	15524	9.8
9	142565	115099	15524	9.8
11	139563	115375	18526	11.7

<sup>1</sup>Resources constrained to 100% of DR&SS actual 1995/96 research budget.

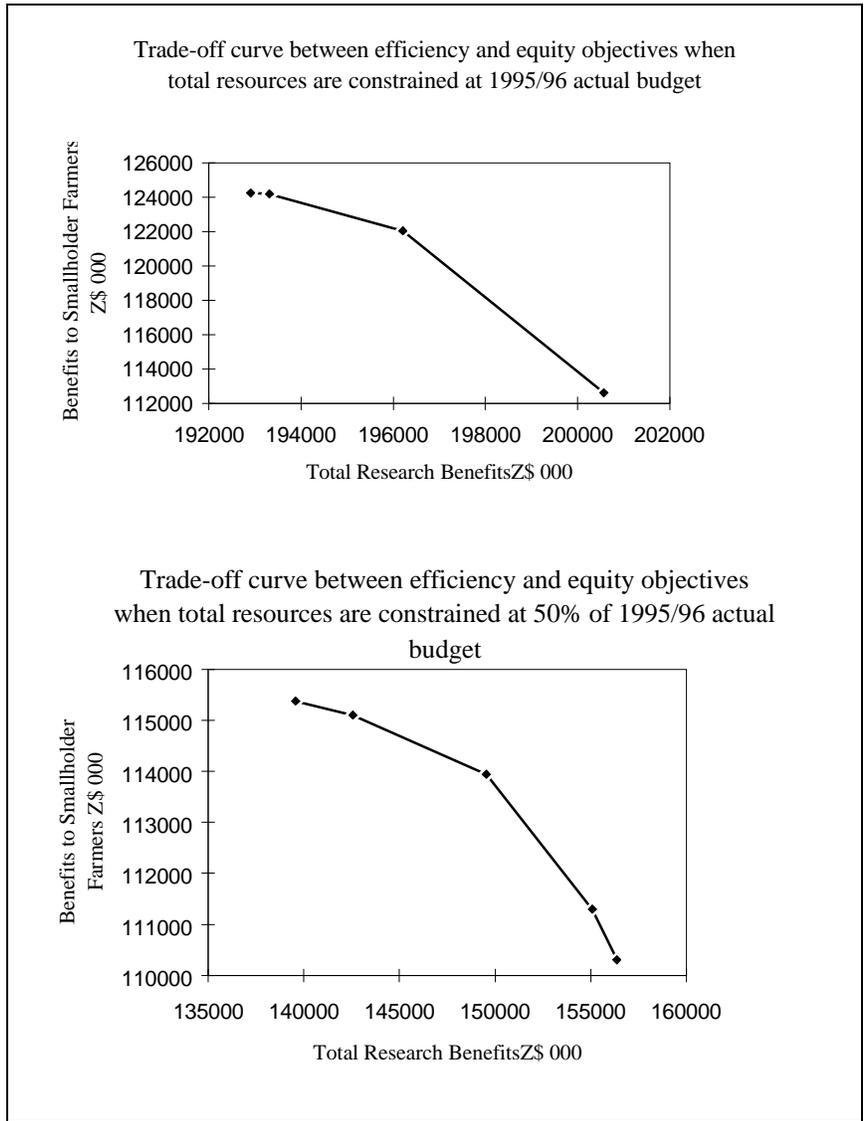


Figure 5.1 Trade-off between efficiency and equity as more weight is placed on smallholder farmers at different levels of total resources.

- If the research system wants to target agricultural research programs to low potential areas, this study suggests that research on traditional commodities (maize, cotton, groundnuts, sunflower, millets, and pulses) and cattle draught power will yield the highest benefits to smallholder farmers, in part because the increases in productivity will be spread over a large number of households.
- Agronomy, plant breeding, plant protection and chemistry and soils research receive high ranking for many of the high ranking commodities (such as maize, cotton, groundnuts, wheat, vegetables), while nutrition, management and pasture and forages tend to be the most important research areas for livestock.
- A trade off of the efficiency and equity objectives did not reveal huge costs as more weight is placed on the equity objective unless the overall research budget is reduced. This implies that DR&SS can invest more resources to smallholder research without incurring a significant loss in efficiency.

### **5.5. Use of the Results in Decision Making**

The above policy implications and results presented in the preceding sections can be used by research administrators as a guide to select a research portfolio. In trying to select a research portfolio it is important to answer the questions: How far from the optimal solution is DR&SS's current resource mix? Where are the departures from optimality? Which research programs can be included in the research portfolio? This section will try to answer these questions, focusing on comparing existing resource allocation to optimal solutions where efficiency is the sole objective and where the weight on the distribution

objective is increased. A comparison of the projected benefits for the actual DR&SS resource allocation for 1995/96 and the optimal funding and research benefits for different weights on smallholder farmers is presented in table 5.19. A summary of the percent changes in funding and benefits when no weight and an additional weight of 1.0 is placed on smallholder farmers is presented in tables 5.20 and 5.21 respectively.

Using the efficiency criterion alone, research programs that have negative net present values (NPVs) are not economically viable and should be avoided. Commodity research programs yielding negative returns include smallholder castor beans, soybeans, coffee, and fish, and large-scale castor beans, bambara nuts, sunflower, cow peas and beans. Resources intended for these activities can be reallocated to selected research programs based on the priorities reached by ranking the NPVs and the mathematical programming analysis.

When both farmer types are weighted equally the optimal portfolio allocates more funds to communal maize, cotton, all vegetables except indigenous and export vegetables, millets, bambara nuts, groundnuts, sunflower, donkey draft, draft cattle, poultry, and sheep, and large-scale maize, wheat, cotton, groundnuts, all vegetables except sweet potato indigenous fruits and vegetables, coffee, macadamia nuts, dairy, and poultry.

Thus, on the basis of the above it may be concluded that there is need for some reallocation of research resources if all farmers are weighted equally.

## **5.6. What are the benefits of allocating research resources based on the identified agricultural research priorities?**

Prioritization of agricultural research activities results in the selection of the optimal research portfolio given the resource constraints. Thus, resource allocations based on identified research priorities will be more efficient and responsive to the research system objectives than when resource allocation is not based on research priorities. The percentage increase in research benefits from the optimal research portfolio with different weights on the equity objective were calculated and compared with research benefits from the unprioritized actual DR&SS research portfolio presented in table 5.19. The benefits from the prioritized research portfolio were 31 percent greater than the unprioritized research portfolio. Therefore given the current budget (100%), there are potential gains of up to 31 percent from a prioritized research resource allocation.

When the weight on smallholder farmers was increased to 1.0 and 2.0, the total benefits were 29 and 27 percent greater than the existing unprioritized resource allocation respectively.

Table 5.19 Projected benefits from actual DR&SS 1995/96 resource allocation and from optimal funding for different weights placed on the smallholder farmers.

Commodity	Farmer Type	Funding Level	Actual Allocation		Optimal portfolio weight = 0 <sup>2</sup>		Optimal Portfolio weight = 1		Optimal Portfolio weight = 2	
			Net Benefits	Actual <sup>1</sup> Funding	Net Benefits	Optimal <sup>2</sup> Funding	Net Benefits	Optimal <sup>2</sup> Funding	Net Benefits	Optimal <sup>2</sup> Funding
Maize	Communal	current	329059	3009	329059	3009	329059	3009	329059	3009
Maize	Communal	incr.	0	0	137978	1505	137978	1505	137978	1505
Maize	Large Scale	current	274644	1504	274644	1504	274644	1504	274644	1504
Maize	Large Scale	incr.	0	0	81314	752	81314	752	81314	752
Sorghum	Communal	current	14858	915	14858	915	14858	915	14858	915
Sorghum	Communal	incr.	0	0	0	0	6948	458	6948	458
Sorghum	Large Scale	current	1581	458	0	0	0	0	0	0
Sorghum	Large Scale	incr.	0	0	0	0	0	0	0	0
Pearl Millet	Communal	current	25005	605	25005	605	25005	605	25005	605
Pearl Millet	Communal	incr.	0	0	12294	303	12294	303	12294	303
Finger Millet	Communal	current	24212	466	24212	466	24212	466	24212	466
Finger Millet	Communal	incr.	0	0	12100	233	12100	233	12100	233
Wheat	Large Scale	current	61461	1256	61461	1256	61461	1256	61461	1256
Wheat	Large Scale	incr.	0	0	23441	628	23441	628	23441	628
Beans	Communal	current	9910	977	0	0	9910	977	9910	977
Beans	Communal	incr.	0	0	0	0	0	0	4336	489
Beans	Large Scale	current	248	488	0	0	0	0	0	0
Beans	Large Scale	incr.	0	0	0	0	0	0	0	0
Bambara nuts	Communal	current	50709	548	50709	548	50709	548	50709	548
Bambara nuts	Communal	incr.	0	0	19669	274	19669	274	19669	274
Bambara nuts	Large Scale	current	-1152	136	0	0	0	0	0	0
Bambara nuts	Large Scale	incr.	0	0	0	0	0	0	0	0
Cow peas	Communal	current	25075	403	25075	403	25075	403	25075	403
Cow peas	Communal	incr.	0	0	7231	202	7231	202	7231	202
Cow peas	Large Scale	current	-118	202	0	0	0	0	0	0
Cow peas	Large Scale	incr.	0	0	0	0	0	0	0	0
Groundnuts	Communal	current	87569	1152	87569	1152	87569	1152	87569	1152
Groundnuts	Communal	incr.	0	0	39630	576	39630	576	39630	576
Groundnuts	Large Scale	current	7793	288	7793	288	7793	288	7793	288
Groundnuts	Large Scale	incr.	0	0	3409	144	3409	144	3409	144
Soybeans	Communal	current	-516	373	0	0	0	0	0	0
Soybeans	Communal	incr.	0	0	0	0	0	0	0	0
Soybeans	Large Scale	current	19474	1117	19474	1117	0	0	0	0
Soybeans	Large Scale	incr.	0	0	0	0	0	0	0	0
Cotton	Communal	current	92320	1404	92320	1404	92320	1404	92320	1404
Cotton	Communal	incr.	0	0	42702	702	42702	702	42702	702

Cotton	Large Scale	current	53444	2807	53444	2807	19877	1043	0	0
Cotton	Large Scale	incr.	0	0	23562	1404	0	0	0	0
Sunflower	Communal	current	38835	558	38835	558	38835	558	38835	558
Sunflower	Communal	incr.	0	0	18246	279	18246	279	18246	279
Sunflower	Large Scale	current	-969	426	0	0	0	0	0	0
Sunflower	Large Scale	incr.	0	0	0	0	0	0	0	0
Castor bean	Communal	current	-72	156	0	0	0	0	0	0
Castor bean	Communal	incr.	0	0	0	0	0	0	0	0
Castor bean	Large Scale	current	-86	78	0	0	0	0	0	0
Castor bean	Large Scale	incr.	0	0	0	0	0	0	0	0
Cabbage	Communal	current	8213	78	8213	78	8213	78	8213	78
Cabbage	Communal	incr.	0	0	2568	39	2568	39	2568	39
Cabbage	Large Scale	current	6165	155	6165	155	6165	155	6165	155
Cabbage	Large Scale	incr.	0	0	2475	78	2475	78	2475	78
Tomato	Communal	current	14337	294	14337	295	14337	295	14337	295
Tomato	Communal	incr.	0	0	6518	147	6518	147	6518	147
Tomato	Large Scale	current	12152	589	12152	589	12152	589	12152	589
Tomato	Large Scale	incr.	0	0	5183	294	0	0	0	0
Potato	Communal	current	4335	186	4335	186	4335	186	4335	186
Potato	Communal	incr.	0	0	1902	93	1902	93	1902	93
Potato	Large Scale	current	10539	372	10539	372	10539	372	10539	372
Potato	Large Scale	incr.	0	0	4137	186	4137	186	4137	186
Sweet Potato	Communal	current	10987	116	10987	116	10987	116	10987	116
Sweet Potato	Communal	incr.	0	0	5235	58	5235	58	5235	58
Sweet Potato	Large Scale	current	3722	233	0	0	0	0	0	0
Sweet Potato	Large Scale	incr.	0	0	0	0	0	0	0	0
Onions	Communal	current	10253	202	10253	202	10253	202	10253	202
Onions	Communal	incr.	0	0	4525	101	4525	101	4525	101
Onions	Large Scale	current	8219	404	8219	404	8219	404	8219	404
Onions	Large Scale	incr.	0	0	3659	202	0	0	0	0
Indig. veg.	Communal	current	9614	233	9614	233	9614	233	9614	233
Indig. Veg.	Communal	incr.	0	0	4738	117	4738	117	4738	117
Peas	Large Scale	current	3209	93	3209	93	3209	93	3209	93
Peas	Large Scale	incr.	0	0	1213	47	1213	47	1213	47
Roses	Large Scale	current	16133	465	16133	465	16133	465	16133	465
Roses	Large Scale	incr.	0	0	7603	233	7603	233	7603	233
Indig. fruits	Communal	current	3345	233	0	0	3345	233	3345	233
Indig. fruits	Communal	incr.	0	0	0	0	1620	117	1620	117
Macadamia nt	Large Scale	current	1693	47	1693	47	1693	47	1693	47
Macadamia nt	Large Scale	incr.	0	0	780	23	780	23	780	23

Coffee	Large Scale	current	32484	900	32484	900	32484	900	32484	900
Coffee	Large Scale	incr.	0	0	14217	450	14217	450	14217	450
Stone fruit	Large Scale	current	20599	419	20599	419	20599	419	20599	419
Stone fruit	Large Scale	incr.	0	0	9992	210	9992	210	9992	210
Apples	Large Scale	current	13300	454	13300	454	13300	454	13300	454
Apples	Large Scale	incr.	0	0	5802	227	5802	227	5802	227
Strawberry	Large Scale	current	1067	35	1067	35	1067	35	1067	35
Strawberry	Large Scale	incr.	0	0	508	18	508	18	508	18
Beef	Communal	current	-7754	1791	0	0	27540	1791	27540	1791
Beef	Communal	incr.	0	0	0	0	0	0	0	0
Beef	Large Scale	current	70427	3583	70427	3583	70427	3583	40039	2036
Beef	Large Scale	incr.	0	0	0	0	0	0	0	0
Dairy	Communal	current	18590	1541	0	0	18590	1541	18590	1541
Dairy	Communal	incr.	0	0	0	0	0	0	6961	771
Dairy	Large Scale	current	43875	2531	43875	2531	0	0	0	0
Dairy	Large Scale	incr.	0	0	4978	310	0	0	0	0
Broilers	Communal	current	8599	155	8599	155	8599	155	8599	155
Broilers	Communal	incr.	0	0	3170	77	3170	77	3170	77
Broilers	Large Scale	current	12647	310	12647	310	12647	310	12647	310
Broilers	Large Scale	incr.	0	0	5988	155	5988	155	5988	155
Layers	Communal	current	8760	155	8760	155	8760	155	8760	155
Layers	Communal	incr.	0	0	5988	77	5988	77	5988	77
Layers	Large Scale	current	8076	310	8076	310	8076	310	8076	310
Layers	Large Scale	incr.	0	0	2910	155	0	0	0	0
Sheep	Communal	current	4000	202	4000	202	4000	202	4000	202
Sheep	Communal	incr.	0	0	1918	101	1918	101	1918	101
Sheep	Large Scale	current	3864	404	0	0	0	0	0	0
Sheep	Large Scale	incr.	0	0	0	0	0	0	0	0
Goats	Communal	current	26180	2660	0	0	26180	2660	26180	2660
Goats	Communal	incr.	0	0	0	0	0	0	10248	1330
Ostriches	Large Scale	current	819	465	0	0	0	0	0	0
Ostriches	Large Scale	incr.	0	0	0	0	0	0	0	0
Cattle draft	Communal	current	17711	624	17711	624	17711	624	17711	624
Cattle draft	Communal	incr.	0	0	8025	312	8025	312	8025	312
Donkey draft	Communal	current	6718	283	6718	283	6718	283	6718	283
Donkey draft	Communal	incr.	0	0	2853	141	2853	141	2853	141
Fish	Communal	current	-1081	233	0	0	0	0	0	0
Fish	Communal	incr.	0	0	0	0	0	0	0	0
TOTAL			1525081	40081	2007031	40081	1963956	40081	1935236	40081
% of gain in benefits					31.4		28.7		26.9	

<sup>1</sup> This is the actual DR&SS unprioritized funding for 1995/96.

<sup>2</sup> This is the funding recommended by the optimal solution.

Table 5.20. Optimal funding levels and research benefits by commodity with all farm types given equal weight

Commodity Group	Commodity	COMMUNAL				COMMERCIAL			
		Optimal Funding <sup>1</sup>	Percent change <sup>2</sup>	Net Benefits <sup>3</sup>	Percent increase <sup>4</sup>	Optimal Funding <sup>1</sup>	Percent change <sup>2</sup>	Net Benefits <sup>3</sup>	Percent increase <sup>4</sup>
Cereals									
	Maize	4514	50	467037	42	2256	50	355958	30
	Wheat	0	0	0	0	1884	50	84902	38
	Pearl Millet	908	50	37299	49	0	0	0	0
	Finger Millet	699	50	36312	50	0	0	0	0
	Sorghum	915	0	14858	0	0	-100	0	-100
Cotton and Oilseeds									
	Cotton	2106	50	135022	46	4211	50	77006	44
	Groundnuts	1728	50	127199	45	432	50	11202	44
	Sunflower	837	50	57081	47	0	-100	0	-100
	Soybeans	0	-100	0	-100	1117	0	19474	0
	Castor bean	0	-100	0	-100	0	-100	0	0
Pulses									
	Bambara nuts	822	50	70378	39	0	-100	0	0
	Cow peas	605	50	32306	29	0	-100	0	0
	Beans	0	-100	0	-100	0	-100	0	0
Vegetables, Fruits and Flowers									
	Tomato	442	50	20855	45	883	50	17335	43
	Sweet Potato	174	50	16222	48	0	-100	0	-100
	Potato	279	50	6237	44	558	50	14676	39
	Onions	303	50	14778	44	606	50	11878	45
	Indigenous vegetables	350	50	14352	49	0	0	0	0
	Indigenous fruits	0	-100	0	-100	0	0	0	0
	Cabbage	117	50	10781	31	233	50	8640	40
	Strawberry	0	0	0	0	53	51	1575	48
	Stone fruit	0	0	0	0	629	50	30591	49
	Roses	0	0	0	0	698	50	23736	47
	Peas	0	0	0	0	140	51	4422	38
	Apples	0	0	0	0	681	50	19102	44
Coffee and Macadamia									
	Coffee	0	0	0	0	1350	50	46701	44
	Macadamia nuts	0	0	0	0	70	50	2473	46
Livestock									
	Beef	0	-100	0	-100	3583	0	70427	0
	Dairy	0	-100	0	-100	2841	12	48853	11
	Goats	0	-100	0	-100	0	0	0	0
	Broilers	232	50	11769	37	465	50	18635	47
	Layers	232	50	14748	68	465	50	10986	36
	Sheep	303	50	5918	48	0	-100	0	-100
	Fish	0	-100	0	-100	0	0	0	0
	Donkey draft	424	50	9571	42	0	0	0	0

Cattle draft	936	50	25736	45	0	0	0	0
Ostriches	0	0		0	0	-100	0	-100
TOTAL	16926		1128459		23155		878572	

<sup>1</sup> 50% additional funding allowed per commodity, but with overall budget at the existing level.

<sup>2</sup> Percent change from current spending.

<sup>3</sup> Benefits net of costs 1997-2011.

<sup>4</sup> Percent increase from current benefits (listed as 0 if current benefits are 0 or negative).

Note Communal includes small scale commercial for cereals except wheat, for pulses, groundnuts, sunflower and goats and Commercial includes large scale and small scale commercial for all commodities except those noted as included in communal.

Table 5.21. Optimal funding levels and research benefits by commodity with a weight of 1.0 placed on smallholder farmers.

Commodity Group	Commodity	COMMUNAL				COMMERCIAL			
		Optimal Funding <sup>1</sup>	Percent change <sup>2</sup>	Net Benefits <sup>3</sup>	Percent increase <sup>4</sup>	Optimal Funding <sup>1</sup>	Percent change <sup>2</sup>	Net Benefits <sup>3</sup>	Percent increase <sup>4</sup>
Cereals									
	Maize	4514	50	467037	42	2256	50	355958	30
	Wheat	0	0	0	0	1884	50	84902	38
	Pearl Millet	908	50	37299	49	0	0	0	0
	Finger Millet	699	50	36312	50	0	0	0	0
	Sorghum	1373	50	21806	47	0	-100	0	-100
Cotton and Oilseeds									
	Cotton	2106	50	135022	46	1043	-63	19877	-63
	Groundnuts	1728	50	127199	45	432	50	11202	44
	Sunflower	837	50	57081	47	0	-100	0	-100
	Soybeans	0	-100	0	-100	0	-100	0	-100
	Castor bean	0	-100	0	-100	0	-100	0	0
Pulses									
	Bambara nuts	822	50	70378	39	0	-100	0	0
	Cow peas	605	50	32306	29	0	-100	0	0
	Beans	977	0	9910	0	0	-100	0	0
Vegetables, Fruits and Flowers									
	Tomato	442	50	20855	45	589	0	12152	0
	Sweet Potato	174	50	16222	48	0	-100	0	-100
	Potato	279	50	6237	44	558	50	14676	39
	Onions	303	50	14778	44	404	0	8219	0
	Indigenous vegetables	350	50	14352	49	0	0	0	0
	Indigenous fruits	350	50	4965	48	0	0	0	0
	Cabbage	117	50	10781	31	233	50	8640	40
	Strawberry	0	0	0	0	53	51	1575	48
	Stone fruit	0	0	0	0	629	50	30591	49
	Roses	0	0	0	0	698	50	23736	47
	Peas	0	0	0	0	140	51	4422	38
	Apples	0	0	0	0	681	50	19102	44
Coffee and Macadamia									
	Coffee	0	0	0	0	1350	50	46701	44
	Macadamia nuts		0	0		70	49	2473	46
Livestock									
	Beef	1791	0	27540	0	3583	0	70427	0
	Dairy	1541	0	18590	0	0	-100	0	-100
	Goats	2660	0	26180	0	0	0	0	0
	Broilers	232	50	11769	37	465	50	18635	47
	Layers	232	50	14748	68	310	0	8076	0
	Sheep	303	50	5918	48	0	-100	0	-100
	Fish	0	-100	0	-100	0	0	0	0
	Donkey draft	424	50	9571	42	0	0	0	0

Cattle draft	936	50	25736	45	0	0	0	0
Ostriches	0	0		0	0	-100	0	-100
<b>TOTAL</b>	<b>24703</b>		<b>1222592</b>		<b>15378</b>		<b>741364</b>	

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<sup>1</sup> 50% additional funding allowed per commodity, but with overall budget at the existing level.

<sup>2</sup> Percent change from current spending.

<sup>3</sup> Benefits net of costs 1997-2011.

<sup>4</sup> Percent increase from current benefits (listed as 0 if current benefits are 0 or negative).

Note Communal includes small scale commercial for cereals except wheat, for pulses, groundnuts, sunflower and goats and Commercial includes large scale and small scale commercial for all commodities except those noted as included in communal.

### **5.7. What is the role of public versus private research in the light of the identified agricultural research priorities?**

As indicated in chapter 2, Zimbabwe's private sector research is rapidly growing for maize, soybeans, wheat, groundnuts, and for some horticultural commodities. User satisfaction with such private sector research is high, and the prospects for continued producer financing of research at least within the commercial sector, are good (Beynon and Mudimu, 1996). However the needs of the communal farmers might be neglected by private sector, which may only invest in technology in which it can appropriate the benefits. It is possible that although commodities like large-scale maize, wheat, soybeans and vegetables came out high in priority, this is an area where the private sector can be more active, allowing DR&SS to focus research on smallholder commodities in resource poor areas. For some commodities like cotton, macadamia nuts, roses and coffee where research benefits can be appropriated in the form of a levy, DR&SS can readily commercialize or privatize.

## **5.8. Summary of Chapter**

This chapter presented results of economic surplus analysis and mathematical programming. Details of the identified commodity and research program priorities were presented. The chapter presented changes that occur in the optimal research portfolio as the distributional objective is incorporated. Opportunity costs associated with loss in efficiency as the weight on the equity objective increases were estimated and presented. The resulting research portfolio when all resources are devoted to research on smallholder farming was also presented. The last section of the chapter examined the policy implications, how the results can be utilized by DR&SS and the benefits of allocating research resources basing on the identified priorities. The next chapter summarizes the dissertation, highlighting important issues emerging from the study.

## **CHAPTER SIX**

### **SUMMARY AND CONCLUSIONS**

#### **6.1. Introduction**

This chapter summarizes the main elements of the dissertation and presents conclusions based on the results of economic surplus and mathematical programming analyses. Limitations and suggestions for further research are discussed.

#### **6.2. Summary of the Dissertation**

The aim of this study was to develop and apply a methodology for analyzing agricultural research priorities for Zimbabwe. Specific objectives included: (1) designing methods that can assist the government of Zimbabwe in setting agricultural research priorities and making decisions on research resource allocations, and (2) evaluating opportunity costs associated with the use of agricultural research to achieve non-efficiency objectives.

An examination of Zimbabwe's agricultural sector in chapter 2, revealed the existence of different farmer types and agro-ecological regions. This chapter emphasized that the

agricultural priority setting study had to analyze research priorities by farmer type and agro-ecological region so as to fully capture the distribution of research benefits. Most commodity markets were modeled to be small open markets with exception of indigenous vegetables and fruits and donkey draught power which were modeled to be closed.

Chapter 3 presented the theoretical framework for the study. The use of economic surplus analysis in estimating benefits of agricultural research was discussed. A basic economic surplus model used for estimating research benefits was presented. Modifications to the basic model to suit Zimbabwe's conditions and a characterization of the markets for the agricultural commodities were discussed. Finally, a mathematical programming model for calculating the optimal allocation of agricultural research funds across different research programs to meet multiple objectives was presented and discussed.

Chapter 4 gave details of the empirical application of the priority setting process. First, the research system objectives, the target farmers, the list of commodity and non-commodity programs to be prioritized and agro-ecological zones were defined. Second, the requirements of technology-related data (which include anticipated cost reductions or yield increases, probabilities of research success, time required to complete the research, extent of adoption, research depreciation and the effect of research on product quality), and published information such as market-related data (quantities produced by farmer type, prices) and research costs per research program were discussed. Third economic analysis using a spreadsheet computer program was used to incorporate the market data, technical data, and economic formulas to calculate research benefits. Net present values of

economic surplus gains by research program were used to summarize the total economic efficiency gains. Mathematical programming was used to project the optimal allocation of research resources among the various commodities under alternative weights on objectives. Various models with different weights on objectives were run.

Results of economic surplus analysis and mathematical programming were reported in chapter 5. This section indicated that agricultural research priorities were different between smallholder farmers and large-scale commercial farmers, with maize cotton, groundnuts, sunflower, goats, pulses and millets being of high priority for smallholder farmers, while maize, beef, cotton, coffee, wheat, dairy, stone fruit, soybeans and roses were top priority for large-scale commercial farmers.

Under an allocation where all farm types are given equal weight, the resulting optimal portfolio from the mathematical programming model represents efficiency objective only. Under this efficiency criterion alone, research on communal maize, millets, cotton, groundnuts, sunflower, bambara nuts, cowpeas, tomato, onions, cabbage, sweet potato, potato, indigenous vegetables, poultry, draft cattle and donkeys, and sheep, receive increased funding. Research on communal soyabeans, castor beans, beans, indigenous fruit, coffee, beef, dairy, and goats receive decreased funding. For the large scale sector, research on maize, wheat, cotton, groundnuts, all vegetables except sweet potatoes, coffee, macadamia nuts, beef, dairy, and poultry receive increased funding. Research on large scale soybeans, castor beans, sorghum, sunflower, all pulses, goats, sheep and ostriches receive decreased funding. By selecting a research portfolio based on efficiency,

total benefits are 31 percent higher than total benefits when resource allocation not prioritized.

Under an allocation in which double weight was given to communal farmers, communal beef, dairy, beans, and goats receive funding at current levels of funding, while indigenous fruits receive an increase in funding. Research on communal fish and castor beans experience a decrease in funding. On the commercial sector research on soybeans and dairy receive a decrease. When a double weight is placed on communal farmers, total benefits are increased by up to 29 percent when compared the unprioritized scenario, but decrease by 2 percent higher than when both farmer types are weighted equally.

The opportunity costs associated with putting an extra weight of different sizes on the equity objective were calculated and presented. These costs indicated that when agricultural research is used to meet non-efficiency objectives, there is a cost associated with that action. However the this cost associated with loss of efficiency as the weight on the equity objective was increased were relatively modest (estimated to be a maximum of about 4 percent), implying that DR&SS can allocate resources to research on smallholder farming without great loss in efficiency, as long as the current budget is maintained. However, if the DR&SS budget is reduced, these tradeoffs can be significant.

### **6.3. Conclusions**

The study has shown that economic surplus analysis and mathematical programming in combination is a practical approach that can be used to provide information for allocating

agricultural research resources given multiple objectives. The framework is ex-ante in nature and has the advantage that the outputs can be evaluated ex-post. Assumptions about yield increases, research lags, probabilities of success and adoption ceilings can be tested against actual delivery of new research-induced technology, thus facilitating revision and evaluation of research priorities.

Results discussed in chapter 5 indicated that research on traditional crops, maize, cotton, groundnuts, sunflower, millets, pulses and draft cattle can yield high benefits to smallholder farmers in low potential areas, while research on coffee, beef, wheat and soybeans is of high priority for the large-scale commercial sector. This study has estimated that relatively modest opportunity costs are associated with placing more weight on equity, implying that DR&SS can invest more resources into research on smallholder farming, producing benefits for more than one million farmers, without huge losses in efficiency.

#### **6.4. Limitations of the Study and Suggestions for Future Study**

The Marshallian concepts of producer surplus and consumer surplus presented in chapter 3 were constructed under partial equilibrium analysis. This means that this study was based on market equilibrium in a single market ignoring any effects of changes in other relevant markets

The estimates of research benefits are very sensitive to underlying assumptions. The accuracy of the parameters used to a large extent determine the reliability of the results.

There was little information on price elasticities of demand and supply on some of the agricultural commodities. A-priori estimates and elasticity estimates from other regions were used in many cases. However, it has been shown that even though estimates from other countries were used, the rate of return estimates are less sensitive to the elasticity values than to other critical parameters such as adoption rates, and expected yield gains (Anandajayasekeram, 1995).

Data associated with research overhead and extension costs were limited. It would be an improvement to have a formal monitoring and evaluation system in DR&SS to generate better information on such costs.

Investment in research is risky, thus any given portfolio will have an expected return and variance associated with it. This study used the triangular probability distribution to calculate the expected value of yield used to estimate benefits from research. An important extension to this study is incorporating the effect of risk in the determination of the optimal portfolio by calculating the variances associated with the expected yield and net benefits of different research programs at the two levels of funding. This would provide DR&SS an opportunity to choose an efficient portfolio, one which gives the highest expected return for a given standard deviation.

This study is based on an ex-ante analysis of research priorities, hence much of the information used is based on scientist's experience and judgment. Individual scientists may have subjectively overestimated expected yield increases from research leading to

overestimation of research benefits. Interviewing the most knowledgeable people was meant to reduce this inherent bias. However, although there is still likely to be scientist subjectivity in the estimates, the method is still valuable for checking the consistency between researchers' expectations and what eventually results from the research. This study managed to capture and make transparent the dialogue between scientists and policymakers.

The agricultural research priorities analyzed in this study are strategic priorities by commodity and research program area. There is need to identify priorities at the project level (this can be at the institute or researcher level in DR&SS) as a follow-up activity.

Setting agricultural research priorities must not be treated as a once-off exercise. The DR&SS has to treat priority setting as an on-going process of planning and evaluation because each new year brings in new opportunities for research and changes in the agricultural environment.

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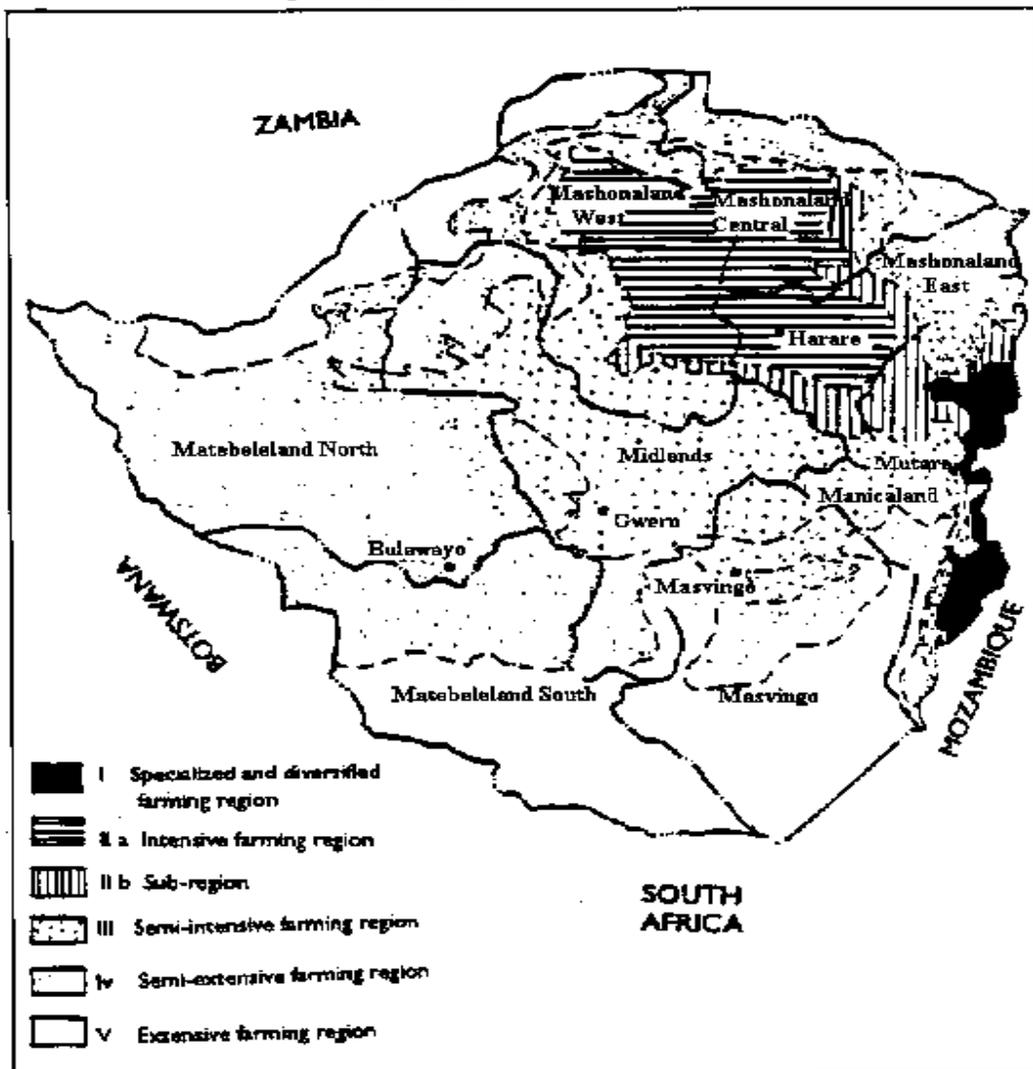
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APPENDIX 1. Zimbabwe Agroecological regions



Source: ENDA-Zimbabwe, Environment Unit, 1991.

## **APPENDIX 2. Organization of the Department of Research and Services Department**

### **The Crop Research Division**

The Crop Research Division conducts research primarily on crop improvement and farming systems. It comprises of; 1) Cotton Research institute - Located in Kadoma the institute is responsible for all aspects of cotton research in the country.

2) Horticulture and Coffee Research institute which has three research stations: the coffee research station at Chipinge; the Horticultural research center at Grasslands research station and the Rhodes Inyanga experiment station in the Eastern Highlands.

3) Crop Breeding Institute - Stationed at the Harare head office, this institute is involved in the breeding of maize, sorghum, pearl millet, wheat, barley, soybeans, groundnuts and sunflowers. The institute is responsible for the development of new plant material as well as the multiplication of seed. The institute also has work undertaken at Gwebi variety testing center, the Rattray-Arnold research farm, the lowveld research station and other small testing sites scattered throughout the country.

4) Agronomy Institute which works on research on field crops in the high and midvelds. Crop ecology and crop production research is done at the Grasslands, Matopos and Makoholi research stations and at the Panmure experiment station. The institute is also responsible for research on weed control and the use of herbicides at the Weed research center at Henderson research station.

5) Lowveld Research stations which include Chiredzi and Chisumbanje research stations. These focus on research on crops grown in the lowveld mainly under irrigation.

6) Farming Systems Research Unit; was initiated in 1980 and since 1984 it has been working in Chivi and Mangwende communal areas. The work has consisted of a combination of diagnostic and detailed survey work on which the on-farm trial and livestock monitoring programs have been based. The unit plays an important catalytic, inter-institute role in focusing technology development, adaptation and testing of technology on small-scale and communal farmers.

#### **2.5.2.2. Livestock and Pasture Division**

The division conducts research on all aspects of livestock (mainly adaptive and applied) and also provides several no-research services. It comprises of:

- 1) Matopos Research station - which works on research on cattle breeding and ranching in medium rainfall areas.
- 2) Grasslands Research station which is engaged in research on improved pasture legumes as well as research on sheep and beef production systems.
- 3) Henderson Research Station which is involved on research on reproductive physiology and fertility (including embryo transplants), nutrition for ruminant animals and detailed research on dairy cattle. In addition, work is carried out on the introduction and screening of pasture grasses.
- 4) Makoholi Research station - responsible for research on indigenous cattle breeds.
- 5) Dairy services section - administers various government dairy acts and regulations. These include the enforcement of hygienic and product quality standards, the regulation of dairy farms and dairies and the grading of dairy products such as cheese and butter.

6) Meat Grading Services section - responsible for the grading of cattle, sheep and pig carcasses at all slaughter houses in the country and the grading of live cattle at all communal area sales.

### **2.5.2.3. Research Services Division**

The research services division comprises of; 1) Chemistry and soil institute - responsible for the chemical analysis of soils, plants, irrigation water, agricultural effluent and fertilizers. It provides full soil analysis and fertilizer recommendation service for farmers and undertakes detailed soil survey work in the country.

2) Plant protection Research institute - responsible for research into entomology, nematology and plant pathology. It also provides regulatory services in phytosanitation and pesticide testing and registration.

3) Biometrics Branch - responsible for the analysis of all data produced in the research department. It runs and operates a computer service for the department as well as supplying statistical and biometric advice in experiment testing and evaluation.

4) Seed Services Section - responsible for the implementation of the seed certification scheme including the necessary seed crop inspection and testing. It is also responsible for administering the Seeds Act, issuing international seed certificates and protecting the rights of plant breeders under the Plant breeders Rights act.

6) National Herbarium and Botanic garden

6) Information Services

7) Legume Inoculant factory

### APPENDIX 3 List of people met

List of People Met	Organization	Subject
Dr. Mushonga	DR&SS	Crops
Mrs Hikwa	DR&SS	Crops
Mr Nyathi	DR&SS	Livestock
Professor Keswani	DR&SS	Crops
DR. Mugwira	DR&SS	Crops
Dr Murwira	DR&SS	Crops
Dr. Tawonezwi	Former DR&SS	Livestock
Dr. Shumba	Former DR&SS	Crops
Dr Tattersfield	Ratray Arnold Res. Station	Crops
Dr. Whingwiri	ARC	Crops
Mr. Tsododo	Agritex	Adoption
Mr Chinembiri	Agritex	Livestock
Mr. Chaonwa	Agritex	Budgets/ Quantity
Mr. De Jong	Agritex	Initial arrangements
Mr. Mawonera	Zimbabwe Farmers Union	Adoption
Mr. Chikaza	Zimbabwe Farmers Union	Adoption
Dr. P. Hatendi	Commercial Farmers Union	Livestock
Dr. J. Grant	Commercial Farmers Union	Crops & livestock
Mr Heri	Horticultural Promotion Council	Crops
Dr. K. Muir Leresche	University of Zimbabwe	Whole study
Dr. Sukume	University of Zimbabwe	Elasticities
Mr. Mudimu	University of Zimbabwe	Whole study
Mr. Makaudze	University of Zimbabwe	Elasticities
Dr. Rusike	University of Zimbabwe	Whole study
Mr. Mubvindi	CSO	Sec. data
Mr. Masiyamhuru	CSO	Sec. data
Mrs Zitsanza	Ministry of Agriculture	Market changes
Mr. Sibanda	Ministry of Agriculture	Area increase
Miss Chawaguta	Ministry of Agriculture	Sec. data
Dr. Attwood	Ministry of Agriculture	Whole study
Dr. Rhorbach	ICRISAT	Whole study
Dr. Anandajayasekeram	SACCAR	Whole study
Dr. Blackie	Rockefeller	Whole study

**APPENDIX 4**

**Scientist Questionnaire for DR&SS (Crop)**

**Commodity:** \_\_\_\_\_

**Respondents**

Name: \_\_\_\_\_

Position: \_\_\_\_\_

Specialty: \_\_\_\_\_

Name: \_\_\_\_\_

Position: \_\_\_\_\_

Specialty: \_\_\_\_\_

**Elicitor**

Name: \_\_\_\_\_

Date: \_\_\_\_\_

Name: \_\_\_\_\_

Position: \_\_\_\_\_

Specialty: \_\_\_\_\_

1. Which disciplines or research program areas contribute to research on this commodity?

Disciplines or Research Program Areas	
1.	5.
2.	6.
3.	7.
4.	8.

2. How many scientists (full-time equivalents) currently conduct research at DR&SS on this commodity?

Disciplines or Research Program Areas			
Plant Breeding		Chemistry & Soils	
Plant Protection		Agroforestry	
Agronomy		Botanical Gardens	
FSR & Others		Total Scientists	

Historical Yield Data (Fill in points on graph before interview)

<b>Region:</b>		<b>Farm Type:</b>	

1975      1980      1985      1990      current      2000      2005

3. What will be the most likely (lowest, highest) expected yield per hectare in 5 - 10 years with continuation of current research funding for the next 5 years? With no funding? With 50 percent more funding? With 100% more funding?

<b>Region:</b>		<b>Location:</b>		
Research Funding Level		Yield (kg/ha)		
Scenario	I.D. No.	Lowest	Most Likely	Highest
Current	1			
No Research	2			
Current + 50%	3			
Current + 100%	4			
		Yield Gain (%)		
Comparison		Lowest	Most Likely	Highest
1 versus 2				
3 versus 1				
4 versus 1				

4. What percent of total variable costs is currently represented by each variable input (hired labor, fertilizer, etc.); likewise for each allocatable fixed input (land, operator labor) for each agroecological region and farm type? What is your estimate of the **percent change** in cost (per hectare or per animal) (if any) for **each** of the major inputs needed to achieve the above yield increase?

<b>Region:</b>		<b>Farm Type:</b>			
		Most Likely Cost Change			
Input	Current Cost Share	Decrease	No Change	Increase	Rate Of Change
Variable (\$/ha)	(%)	(Check One)			(%)
Hired labor					
Tractor operating					
Fertilizer					
Crop chemicals					
Irrigation					
Seed					
Marketing					
Other					
Total Variable	100%				$E(C)^1 =$ %
Allocatable/Fixed (\$/ton of Output)					
Land					
Operator labor					
Total Fixed	100%				$(F)^1 =$ %

<sup>1</sup> Calculate this total rate of change by multiplying the current shares by the rates of change and summing

5. What is the expected percentage contribution of each research program area to the percentage yield change listed above for this commodity in question 3?

Percent contribution to change in yield									
Region	Farm Type	Plant Breeding	Plant Protection	Agronomy	Chemistry & Soils	Agro-forestry	Botanical Gardens	FSR & Others	Total Percent
									100%
									100%
									100%
									100%
									100%
									100%

6. What is the probability (percent chance) of the research leading to new technology that will result in the yield increase (most likely) in question 3?

7. If the research is successful, will the quality of the raw or processed product increase? If the answer is yes, how much higher will the price of the higher quality product be compared to the price of the lower quality product?

Quality Change? Yes or No?									
Region	Farm Type	Plant Breeding	Plant Protection	Agronomy	Chemistry & Soils	Agro-forestry	Botanical Gardens	FSR & Others	(%) Price Increase

8. When will the key research results (transferable technologies) be available to farmers or to processors of this commodity?

Number of years until the results are available								
Region	Farm Type	Plant Breeding	Plant Protection	Agronomy	Chemistry & Soils	Agro-forestry	Botanical Gardens	FSR & Others

9 (a). What percentage of the farmers are expected to adopt the new technology (variety, practice, etc.) once it is released? (b). How many years after it is released do you expect to see maximum adoption? (c). Do you expect the technology to depreciate (become less effective or obsolete) over time? If yes, how many years after maximum adoption do you expect to see adoption begin to decline? Do you expect the decline to be rapid ( 3 to 7 years to no adoption) or slow (8 or more years to no adoption)?

Region	Farm Type	Adoption Lags	Plant Breeding	Plant Protection	Agronomy	Chemistry & Soils	Agro-forestry	Botanical Gardens	FSR & Others
		% Max Adopt							
		Years to Max Adopt							
		Years to Decline							
		Rapid Or Slow							
		% Max Adopt							
		Years to Max Adopt							
		Years to Decline							
		Rapid or Slow							
		% Max Adopt							
		Years to Max Adopt							
		Years to Decline							
		Rapid or Slow							
		% Max Adopt							
		Years to Max Adopt							
		Years to Decline							
		Rapid or Slow							
		% Max Adopt							
		Years to Max Adopt							
		Years to Decline							
		Rapid or Slow							
		% Max Adopt							
		Years to Max Adopt							
		Years to Decline							
		Rapid or Slow							

**The following question should be asked of those people who are most familiar with the market for the commodity (not necessarily the scientists):**

10. Do you expect an increase (decrease) in area devoted to the commodity over the next 5 to 10 years? If so, by what percent per year?

<b>Region</b>	<b>Farm Type</b>	<b>Increase or Decrease</b>	<b>Percent Change Per Year</b>

## APPENDIX 5

### Summary of Key Responses to Scientific Questionnaire (Broken Down by Type of Research)

Table 1.1. Communal Farmers Agro-ecological zone 3, 4 & 5

Commodity	Percent Yield Increase <sup>1</sup>		Percent Increase in Cost <sup>2</sup>		Percent Contribution by Type of Research						Year When Key Results will be Available					
	1	2	C	F	PB	PP	AG	CS	AF	FSR	PB	PP	AG	CS	AF	FSR
Maize	17	25	5		10	20	30	30	5	5	5	5	3	3	4	3
Sorghum	17	25	7		15	20	30	30		5	7	4	3	3		3
Pearl Millet	15	28	7		25	10	35	15		15	7	5	3			3
Finger Millet	15	25	7		35	15	30	15		5	7	5	3	3		3
Beans	20	30	2.8		30	25	30	15			2	4	3	3		
Bambara nuts	25	36	10.4		40	10	30	15		5	4	3	3	3		3
Cowpeas	20	30	5		30	30	20	10	1	9	4	3	3	3	3	3
Groundnuts	17	25	10		25	15	25	25		10	3	3	3	3		3
Cotton	10	15	3.7		30	25	35	10			6	3	3	3		
Sunflowers	20	30	6.		30	10	30	15		15	4	3	3	3		3
Castor beans	30	45	8.3		35	20	30	10		5	6	3	3	3		3
Cabbage	7	12	11.4		35	20	35	10			3	3	2	2		
Tomato	7	12	12		30	30	28	10		2	5	3	3	3		3
Potato	10	15	15		25	25	40	10			4	3	3	3		
Sweet Potato	10	15	5		40	15	20	25			5	4	3	3		
Onions	11	15	15		30	20	25	10		15	4	3	4	3		4
Indigenous vogs	15	25	8		70		30				7		5			
Indigenous fruits	25	35	15		75		25				7		5			

<sup>1</sup> 1 = with current research resources, 2 = with 50% more research resources.

<sup>2</sup> C = change in variable cost to obtain 1, F = change in fixed costs to obtain 1.

<sup>3</sup> PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry and FSR = farming systems research

## APPENDIX 5

Table 1.2. Communal Farmers Natural Regions 3, 4, & 5.

Commodity	Maximum Adoption of the Technologies <sup>1</sup>												Technology Degeneration <sup>2</sup>										Percent change in area <sup>3</sup>		
	PB		PP		AG		CS		AF		FSR		PB		PP		AG		CS		AF			FSR	
	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	Yr	S	Yr	S	Yr	S	Yr	S	Yr	S		Yr	S
Maize	70	4	50	5	40	4	40	5	20	5	50	3	20	S	20	S	10	R	10	S	4	S	5	S	1
Sorghum	35	3	30	5	20	5	30	5			20	3	8	S	30	S	10	S	10	S			8	S	0
Pearl Millet	50	3	20	5	30	5	30	5			40	4	8	S	40	S	10	S					8	S	0
Finger Millet	50	5	20	5	10	5	30	5			30	5	30	S	10	S	10	S					8	S	0
Beans	60	4	10	5	30	3	20	5					10	S	15	S	10	S	30	S					0
Bambara nuts	50	5	10	3	20	3	30	5			30	3	15	S	10	S	10	S	10	S			10	S	0
Cowpeas	40	3	40	3	20	3	30	5	20	5	30	3	10	S	10	S	10	S	10	S	5	S	10	S	0
Groundnuts	65	4	50	3	50	4	20	3			30	5	20	S	10	S	4	S	4	S	30	S	10	S	0
Cotton	70	3	60	3	60	4	20	3					5	S	5	R	4	R	10	S					1
Sunflowers	60	4	40	3	60	3	20	3			30	3	5	S	15	S	15	S	10	S			10	S	1
Castor beans	60	4	40	3	30	3	20	3			30	3	20	S	10	S	10	S	10	S			10	S	1
Cabbage	80	2	60	3	80	2	60	3					8	S	10	S	5	S	10	S					0
Tomato	60	3	50	3	50	3	60	3			30	3	8	S	10	S	5	S	5	S			10	S	0
Potato	60	3	50	3	70	5	60	3					8	S	10	S	5	S	8	S					0
Sweet Potato	50	5	70	5	70	5	60	3					15	S	10	S	10	S	10	S					0
Onions	80	2	50	3	80	2	60	3			30	3	5	S	10	S	5	S	5	S			10	S	0
Indigenous vogs	70	2			70	2							ND				ND								5
Indigenous fruits	80	5			70	3							20	S			20	S							0

<sup>1</sup> % = Percentage of farmers expected to adopt the new technology once it is released, Yr. = the number of years after it is released to get maximum adoption.

<sup>2</sup> Yr = Number of years after maximum adoption when technology begins to depreciate, S = the speed of depreciation R = rapid (3-7 years) or S = slow (8 or more years).

<sup>3</sup> The expected percent annual increase (decrease) in area devoted to the commodity over the next 5 - 10 years.

PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry and FSR = farming systems research

## APPENDIX 5

Table 2.1. Communal Farmers Natural Region 1 & 2

Commodity	Percent Yield Increase <sup>1</sup>		Percent Increase in Cost <sup>2</sup>		Percent Contribution by Type of Research						Year When Key Results will be Available					
	1	2	C	F	PB	PP	AG	CS	AF	FSR	PB	PP	AG	CS	AF	FSR
Maize	15	25	5		20	20	25	25	5	5	5	5	3	3	3	3
Beans	20	30	2.8		40	20	18	22			3	4	3	3		
Bambara nuts	25	35	15.4		35	5	40	15		5	4	3	3	3		3
Cowpeas	18	26	6		30	30	25	5	1	9	4	3	3	3	3	3
Groundnuts	20	30	10		25	15	35	15		10	3	3	3	3		3
Soybeans	15	20	8		20	25	35	15		5	4	3	3	4		3
Cotton	9	15	3.7		35	25	30	10			6	3	3	3		
Sunflowers	15	25	6		30	5	35	15		15	4	3	3	3		3
Coffee	10	15	8			50	50					3	6			
Stone fruit	25	35	25		35	15	40			10	5		3			

<sup>1</sup> 1 = with current research resources, 2 = with 50% more research resources.

<sup>2</sup> C = change in variable cost to obtain 1, F = change in fixed costs to obtain 1.

<sup>3</sup> PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry and FSR = farming systems research

## APPENDIX 5

Table 2.2 Communal Farmers Natural Region 1 & 2

Commodity	Maximum Adoption of the Technologies <sup>1</sup>												Technology Degeneration <sup>2</sup>										Percent change in area <sup>3</sup>		
	PB		PP		AG		CS		AF		FSR		PB		PP		AG		CS		AF			FSR	
	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	Yr	S	Yr	S	Yr	S	Yr	S	Yr	S		Yr	S
Maize	90	2	70	4	70	4	60	4	40	3	70	3	20	S	20	S	10	R	10	S	4	S	5	S	1
Beans	70	5	10	5	30	3	30	5					10	S	15	S	10	S	10	S					0
Bambara nuts	60	5	10	3	40	5	30	5			80	3	15	S	10	S	10	S	10	S			10	S	0
Cowpeas	50	3	50	3	40	5	30	5	20	5	30	3	10	S	10	S	10	S	10	S	5	S	10	S	0
Groundnuts	70	3	50	3	65	3	30	4			35	5	20	S	10	S	4	S	30	S			5	S	1
Soybeans	60	4	50	3	50	3	30	5			40	3	8	S	10	S	4	S	30	S			50	S	1
Cotton	70	3	60	3	60	4	30	3					5	R	5	R	4	R	10	S					1
Sunflowers	60	4	40	3	60	3	20	3			45	5	5	S	10	S	15	S	10	S			10	S	0
Coffee	10	3	50	2	30	3							15	R			10	S							0

<sup>1</sup> % = Percentage of farmers expected to adopt the new technology once it is released, Yr. = the number of years after it is released to get maximum adoption.

<sup>2</sup> Yr = Number of years after maximum adoption when technology begins to depreciate, S = the speed of depreciation R = rapid (3-7 years) or S = slow (8 or more years).

<sup>3</sup> The expected percent annual increase (decrease) in area devoted to the commodity over the next 5 - 10 years.

PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry and FSR = farming systems research

**APPENDIX 5** Table 3.1. Small Scale Commercial Farmers Natural Region 3, 4, & 5.

Commodity	Percent Yield Increase <sup>1</sup>		Percent Increase in Cost <sup>2</sup>		Percent Contribution by Type of Research						Year When Key Results will be Available					
	1	2	C	F	PB	PP	AG	CS	AF	FSR	PB	PP	AG	CS	AF	FSR
Maize	10	16	5		10	20	30	30	5	5	5	5	3	3	4	
Sorghum	17	25	7		10	20	30	30		10	7	4	3	3		3
Finger Millet	15	25	9.3		35	15	30	15		5	7	5	3	3		3
Beans	18	25	2.8		20	25	40	15			3	4	3	3		
Bambara nuts	20	30	4.8		40	10	30	15		5	4	3	3	3		3
Cowpeas	17	28	4		30	30	20	10	1	9	4	3	3	3	3	3
Groundnuts	15	25	5		25	15	30	15		10	3	3	3	3		3
Cotton	15	25	3.12		30	25	35	10			6	3	3	3		
Sunflowers	20	30	2.3		30	5	45	5		15	4	3	3	3		
Castor beans	30	45	3.7		35	20	30	10		5	6	3	3	3		
Sweet Potato	10	15	5		25	15	35	25			5	3	4	3		

<sup>1</sup> 1 = with current research resources, 2 = with 50% more research resources.

<sup>2</sup> C = change in variable cost to obtain 1, F = change in fixed costs to obtain 1.

<sup>3</sup> PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry and FSR = farming systems research

**APPENDIX 5 TABLE 3.2** Small Scale Commercial Farmers Natural Region 3, 4 & 5

Commodity	Maximum Adoption of the Technologies <sup>1</sup>												Technology Degeneration <sup>2</sup>										Percent change in area <sup>3</sup>		
	PB		PP		AG		CS		AF		FSR		PB		PP		AG		CS		AF			FSR	
	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	Yr	S	Yr	S	Yr	S	Yr	S	Yr	S		Yr	S
Maize	90	3	60	7	60	5	60	5	20	3	70	3	20	S	20	S	10	R	10	S	4	S	5	S	1
Sorghum	25	3	25	5	25	5	30	5			20	3	8	S	30	S	10	S	10	S			8	S	1
Finger Millet	50	5	20	5	10	5	30	5			30	5	30	S	10	S	10	S	10	S			8	S	0
Wheat	80	4	80	5			30	3					7	R	10	S	10	S	10	S					0
Beans	80	4	10	5	30	3	30	3					10	S	15	S	10	S	30	S					0
Bambara nuts	50	5	10	5	50	5	30	3					15	S	10	S	6	S	10	S			10	S	0
Cowpeas	50	3	50	3	50	5	30	3	20	5	30	3	10	S	10	S	10	S	10	S	5	S	10	S	0
Groundnuts	90	3	50	3	65	3	30	5			30	5	20	S	10	S	4	S	30	S			10	S	0
Cotton	70	3	60	3	60	3	30	3					5	R	5	R	4	R	10	S					1
Sunflowers	60	3	40	3	60	3	20	3			45	5	5	S	10	S	15	S	10	S			10	S	0
Castor beans	60	3	40	3	65	5	20	3			30	3	20	S	10	S	5	S	10	S					0
Sweet Potato	50	5	99	5	70	5	60	3					15	S	10	S	10	S	10	S					0

<sup>1</sup> % = Percentage of farmers expected to adopt the new technology once it is released, Yr. = the number of years after it is released to get maximum adoption.

<sup>2</sup> Yr = Number of years after maximum adoption when technology begins to depreciate, S = the speed of depreciation R = rapid (3-7 years) or S = slow (8 or more years).

<sup>3</sup> The expected percent annual increase (decrease) in area devoted to the commodity over the next 5 - 10 years.

PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry and FSR = farming systems research

**APPENDIX 5** Table 4.1. Small Scale Commercial Farmers Natural Region 1 & 2.

Commodity	Percent Yield Increase <sup>1</sup>		Percent Increase in Cost <sup>2</sup>		Percent Contribution by Type of Research						Year When Key Results will be Available					
	1	2	C	F	PB	PP	AG	CS	AF	FSR	PB	PP	AG	CS	AF	FSR
Maize	8	13	3		20	20	25	25	5	5	5	5	3	3	4	3
Wheat	17	30	5		65	5	30				3	4	3			
Beans	15	25	2.8		40	20	18	22			3	4	3	3		
Bambara nuts	25	35	4.8		35	5	40	15		5	4	3	3	3		3
Cowpeas	15	26	5		30	30	25	5	1	9	4	3	3	3	3	3
Groundnuts	27	35	10		25	15	35	15		10	3	3	3	3		3
Soybeans	15	22	8		20	25	35	15		5	4	3	3	4		3
Cotton	10	17	3.1		30	25	35	10			6	3	3	3		
Macadamia nuts	20	33	10			80	20					5	5			
Coffee	15	20	8			50	50					3	6			

<sup>1</sup> 1 = with current research resources, 2 = with 50% more research resources.

<sup>2</sup> C = change in variable cost to obtain 1, F = change in fixed costs to obtain 1.

<sup>3</sup> PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry and FSR = farming systems research

**APPENDIX 5** Table 4.2 Small Scale Commercial Farmers Natural Regions 1 & 2

Commodity	Maximum Adoption of the Technologies <sup>1</sup>												Technology Degeneration <sup>2</sup>										Percent change in area <sup>3</sup>		
	PB		PP		AG		CS		AF		FSR		PB		PP		AG		CS		AF			FSR	
	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	Yr	S	Yr	S	Yr	S	Yr	S	Yr	S		Yr	S
Maize	90	3	60	7	60	5	60	5	20	3	70	3	20	S	20	S	10	R	10	S	4	S	5	S	1
Wheat	80	5	80	5	70	5							10	S	10	S	10	S							1
Beans	80	4	10	5	30	3	30	5					10	S	15	S	10	S	30	S					0
Bambara nuts	50	5	10	5	50	5	30	3					15	S	10	S	6	S	10	S			10	S	0
Cowpeas	50	3	50	3	50	5	30	3			30	3	10	S	10	S	10	S	10	S	5	S	10	S	0
Groundnuts	90	5	50	3	65	3	30	4			35	4	20	S	10	S	4	S	30	S			5	S	0
Soybeans	80	3	50	3	70	3	30	5			40	3	6	S	10	S	4	S	30	S			10	S	0
Cotton	70	3	60	3	60	3	30	3					5	R	5	R	4	R	10	S					0
Macadamia nuts			60	3	60	5									10	S	10	S							0
Coffee			10	1	30	5									10	S	10	S							1

<sup>1</sup> % = Percentage of farmers expected to adopt the new technology once it is released, Yr. = the number of years after it is released to get maximum adoption.

<sup>2</sup> Yr = Number of years after maximum adoption when technology begins to depreciate, S = the speed of depreciation R = rapid (3-7 years) or S = slow (8 or more years).

<sup>3</sup> The expected percent annual increase (decrease) in area devoted to the commodity over the next 5 - 10 years.

PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry and FSR = farming systems research

**APPENDIX 5** Table 5.1. Large Scale Commercial Farmers Natural Region 3, 4, & 5.

Commodity	Percent Yield Increase <sup>1</sup>		Percent Increase in Cost <sup>2</sup>		Percent Contribution by Type of Research						Year When Key Results will be Available					
	1	2	C	F	PB	PP	AG	CS	AF	FSR	PB	PP	AG	CS	AF	FSR
Maize	8	12	2		60	10	25	5			5	5	3	3	4	
Sorghum	8	15	4.4		40	20	35	5			5	4	3	3		
Wheat	12	18	8		60	5	35				3	4	3			
Beans	12	20	3		40	20	18	22			3	4	3	3		
Bambara nuts	15	25	5		40	15	30	15			4	3	3	3		
Cowpeas	10	15	5		40	15	30	15			4	3	3	3		
Soybeans	10	15	7.5		30	20	25	25			4	3	3	4		
Cotton	15	20	8		40	30	20	10			6	3	3	3		
Sunflowers	8	15	2.1		60		20	20			4	3	3	3		
Castor beans	30	50	3.7		40	10	30	20			6	3	3	3		
Cabbage	8	12	9		40	10	40	10			3	3	2	2		
Tomato	8	13	6.9		40	20	30	10			5	3	3	3		
Potato	10	15	10		55	10	25	10			3	3	3	3		
Sweet Potato	15	25	5		60	10	10	20			5	4	3	3		
Onions	10	15	7.3		40	10	40	10			4	3	4	3		

<sup>1</sup> 1 = with current research resources, 2 = with 50% more research resources.

<sup>2</sup> C = change in variable cost to obtain 1, F = change in fixed costs to obtain 1.

<sup>3</sup> PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry and FSR = farming systems research

**APPENDIX 5** Table 5.2. Large Scale Commercial Farmers Natural Region 3, 4 & 5

Commodity	Maximum Adoption of the Technologies <sup>1</sup>												Technology Degeneration <sup>2</sup>								Percent change in area <sup>3</sup>				
	PB		PP		AG		CS		AF		FSR		PB		PP		AG		CS			AF		FSR	
	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	Yr	S	Yr	S	Yr	S	Yr	S		Yr	S	Yr	S
Maize	100	2	80	2	70	3	100	2					20	S	20	S	3	R	10	R					0
Sorghum	40	3	40	5	40	3	40	3					8	S	30	S	5	S	10	S					0
Wheat	80	3	80	3	70	3							7	R	10	S	10	S							0
Beans	85	3	40	3	70	3	30	3					10	S	15	S	10	S	30	S					0
Bambara nuts	50	3	40	3	40	3	30	3					15	S	10	S	10	S	10	S					0
Cowpeas	20	2	99	2	40	3	30	3					10	S	10	S	10	S	10	S					0
Soybeans	90	2	80	2	90	2	40	2					8	S	10	S	3	S	30	S					1
Cotton	80	2	90	2	60	3	40	2					5	R	5	R	5	R	10	S					0
Sunflowers	20	2			40	3	30	3					5	S			10	S	10	S					0
Castor beans	80	3	40	3	65	5	30	3					10	S	10	S	5	S	10	S					1
Cabbage	90	2	70	3	70	2	80	3					5	S	5	S	5	S	10	S					0
Tomato	75	2	70	3	75	2	80	3					2	R	5	S	2	R	5	S					1
Potato	90	3	70	3	75	2	80	3					5	S	5	S	5	S	5	S					1
Sweet Potato	70	3	70	3	70	3	80	3					5	R	10	S	5	S	5	S					1
Onions	80	3	70	3	100	3	80	3					3	S	3	S	3	S	5	S					1

<sup>1</sup> % = Percentage of farmers expected to adopt the new technology once it is released, Yr. = the number of years after it is released to get maximum adoption.

<sup>2</sup> Yr = Number of years after maximum adoption when technology begins to depreciate, S = the speed of depreciation R = rapid (3-7 years) or S = slow (8 or more years).

<sup>3</sup> The expected percent annual increase (decrease) in area devoted to the commodity over the next 5 - 10 years.

PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry and FSR = farming systems research

**APPENDIX 5** Table 6.1. Large Scale Commercial Farmers Natural Region 1 & 2.

Commodity	Percent Yield Increase <sup>1</sup>		Percent Increase in Cost <sup>2</sup>		Percent Contribution by Type of Research						Year When Key Results will be Available					
	1	2	C	F	PB	PP	AG	CS	AF	FSR	PB	PP	AG	CS	AF	FSR
Maize	10	15	4		60	10	25	5			5	5	3	3		
Wheat	7	10	6		60	5	35				3	4	3			
Beans	18	30	3		40	20	18	22			3	4	3	3		
Bambara nuts	20	30	5		40	15	30	15			4	3	3	3		
Cowpeas	15	20	3		40	15	30	15			4	3	3	3		
Groundnuts	10	15	4		30	20	30	10			3	3	3	3		
Soybeans	8	12	7		30	20	25	25			4	3	3	4		
Cotton	12	20	5		40	35	15	10			3	3	3	3		
Strawberry	10	15	15		40	10	50				3		3			
Apples	15	25	15		60	20	20				5	3	3			
Cabbage	7	12	9		40	10	40	10			3	3	2	2		
Tomato	10	15	6.9		40	20	30	10			5	3	3	3		
Potato	8	12	10		40	25	25	10			3	3	3	3		
Sweet Potato	10	15	8		60	10	10	20			5	4	3	3		
Onions	10	15	7.3		30	20	25	25			4	3	4	4		
Peas	10	18	10		40	10	40	10			3	2	2	2		
Flowers	0	0	-.02		60	10	25	5			2	2	2	2		
Macademia nuts	8	12	14			80	20						5			
Coffee	10	15	15			70	30					3	6			
Stone fruit	15	25	15		30	20	50				5	3	3			

<sup>1</sup> 1 = with current research resources, 2 = with 50% more research resources.

<sup>2</sup> C = change in variable cost to obtain 1, F = change in fixed costs to obtain 1.

<sup>3</sup> PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry and FSR = farming systems research

**APPENDIX 5** Table 6.2 Large scale Commercial Farmers Natural region 1 & 2.

Commodity	Maximum Adoption of the Technologies <sup>1</sup>												Technology Degeneration <sup>2</sup>										Percent change in area <sup>3</sup>		
	PB		PP		AG		CS		AF		PH		PB		PP		AG		CS		AF			PH	
	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	Yr	S	Yr	S	Yr	S	Yr	S	Yr	S		Yr	S
Maize	100	2	80	2	70	3	100	2					20	S	20	S	3	R	10	S					0
Wheat	80	5	80	3	80	3							7	R	10	S	10	S							0
Beans	85	3	40	3	70	3	30	3					10	S	15	S	10	S	30	S					0
Bambara nuts	99	4	25	5	80	5	30	3					15	S	10	S	10	S	10	S					1
Cowpeas	99	2	99	2	80	5	30	3					10	S	10	S	10	S	10	S					0
Groundnuts	90	3	80	3	80	2	30	3					20	S	10	S	5	S	30	S					0
Soybeans	90	2	80	2	90	2	40	2					6	S	10	S	3	S	30	S					0
Cotton	80	2	90	2	60	5	40	2					5	R	5	R	5	R	20	S					0
Cabbage	90	2	70	3	100	2	80	3					5	S			5	S							0
Tomato	75	2	70	3	75	2	80	3					2	R	5	S	2	R	5	S					0
Potato	100	3	70	3	75	2	80	3					5	S	5	S	5	S	5	S					0
Sweet Potato	100	5	70	3	75	3	80	3					5	R	10	S	5	S	5	S					0
Onions	100	3	70	3	100	3	80	3					3	S	5	S	3	S	5	S					0
Peas	100	2	70	3	100	2	80	3					2	R	5	S	3	S	5	S					0
Flowers	80	1	70	2	60	1	80	1			80	1	1	R	2	R	1	R	2	R					0
Strawberry	100	5	80	3	50	3							15	S											0
Apples	100	2	80	3	50	3							15	R	10	S	15	R	10	S					0
Macademia nuts			60	3	60	3									10	S	10	S							0
Coffee			100	1	30	5									10	S	10	S							0
Stone fruit	100	5	80	3	50	3							15	S	10	R	10	S							0

<sup>1</sup> % = Percentage of farmers expected to adopt the new technology once it is released, Yr. = the number of years after it is released to get maximum adoption.

<sup>2</sup> Yr = Number of years after maximum adoption when technology begins to depreciate, S = the speed of depreciation R = rapid (3-7 years) or S = slow (8 or more years).

<sup>3</sup> The expected percent annual increase (decrease) in area devoted to the commodity over the next 5 - 10 years.

PB = plant breeding, PP = plant protection, AG = agronomy, CS = chemistry and soils, AF = agroforestry.

**APPENDIX 5** Table 7.1. Communal Farmers All Natural Regions.

Commodity	Percent Yield Increase <sup>1</sup>		Percent Increase in Cost <sup>2</sup>		Percent Contribution by Type of Research						Year When Key Results will be Available					
	1	2	C	F	LB	LM	LN	PF	VR	FSR	LB	LM	LN	PF	VR	FSR
Beef	0	9	19		5	5	20	35	30	5	15	3	3	4	5	3
Broilers	9	13	19		5	40	55				5	1	1			
Layers	9	13	19			60	40									
Sheep	8	13	5		10	20	40	30			5	3	3			
Goats	11	18	10		25	15	25	13	12	10	5	3	3	3	3	3
Fish	0	13	5.5			50	50					3	3			
Multipurpose	9	13	19		40	20	20	20			6	3	3	3		
Donkeys	8	12	25			50	50						2	2		
Cattle Draft	9	20	26		5	30	30	15	15	5	10	3	2	2	5	3

<sup>1</sup> 1 = with current research resources, 2 = with 50% more research resources.

<sup>2</sup> C = change in variable cost to obtain 1, F = change in fixed costs to obtain 1.

<sup>3</sup> LB = Livestock breeding, LM = Livestock Management, LN=Livestock Nutrition, PF = Pastures and Forages, VR = Veld and Rangeland and MKT = research on beef carcass grading.

**APPENDIX 5** Table 7.2 Communal Farmers All Natural regions

Commodity	Maximum Adoption of the Technologies <sup>1</sup>												Technology Degeneration <sup>2</sup>										Percent change in herd <sup>3</sup>		
	LB		LM		LN		PF		VR		FSR		LB		LM		LN		PF		VR			FSR	
	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	Yr	S	Yr	S	Yr	S	Yr	S	Yr	S		Yr	S
Beef	10	5	30	5	30	5	30	4	10	4	50	3	60	S	20	S	10	R	20	S	15	S	10	R	0
Broilers	60	3	60	3	60	3							15	S	5	R	5	R							1
Layers			60	3	60	3									5	R	5	R							1
Sheep	20	3	50	3	30	3	20	3									30	S							0
Goats	35	3	50	20	30	3	50	3	30	50	50	3	5	S	30	S	30	S	40	S	10	S	5	S	1
Fish			60	3	60	3									5	S	5	S							0
Multi-purpose	30	5	30	5	30	5	30	5					8	S	3	S	3	S							0
Donkey Draft			40	3	50	2									60	S	60	S							0
Cattle Draft	10	5	40	3	40	5	30	4	10	4	50	5	60	S	60	S	60	S	10	S	10	S	20	S	0

<sup>1</sup> % = Percentage of farmers expected to adopt the new technology once it is released, Yr. = the number of years after it is released to get maximum adoption.

<sup>2</sup> Yr = Number of years after maximum adoption when technology begins to depreciate, S = the speed of depreciation R = rapid (3-7 years) or S = slow (8 or more years).

<sup>3</sup> The expected percent annual increase (decrease) in the herd of this commodity over the next 5 - 10 years.

LB = Livestock Breeding, LM=Livestock Management, LN = Livestock Nutrition, PF = Pastures and Forages, VR = Veld and Rangeland, FSR = Farming systems research.

**APPENDIX 5** Table 8.1. Small Scale Commercial Farmers All Natural Regions.

Commodity	Percent Yield Increase <sup>1</sup>		Percent Increase in Cost <sup>2</sup>		Percent Contribution by Type of Research						Year When Key Results will be Available					
	1	2	C	F	LB	LM	LN	PF	VR	FSR	LB	LM	LN	PF	VR	FSR
Beef	0	9	20		5	5	30	30	25	5	15	3	3	43	3	3
Dairy	8	12	19		20	20	40	20			7	3	3	4		
Broilers	9	13	19.7			40	60					1	1			
Layers	9	13	19.7			60	40					1	1			
Sheep	14	25	5		20	10	40					5	5	3		
Goats	11	14	10		25	15	25	13	12	10	5	3	3	3	3	3

**APPENDIX 5** Table 8.2 Small Scale Commercial Farmers All Natural regions

Commodity	Maximum Adoption of the Technologies <sup>1</sup>												Technology Degeneration <sup>2</sup>										Percent change in herd <sup>3</sup>		
	LB		LM		LN		PF		VR		FSR		LB		LM		LN		PF		VR			FSR	
	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	Yr	S	Yr	S	Yr	S	Yr	S	Yr	S		Yr	S
Beef	10	10	30	5	30	5	30	4	10	5	99	1	60	S	20	S	10	R	20	S	15	S	10	R	0
Dairy	60	5	80	5	80	5	90	5							5	S	5	S	20	S					1
Broilers			60	3	60	3									5	R	5	R							1
Layers			60	3	60	3									5	R	5	R							1
Sheep	40	3	60	3	60	3	50	3							5	S	5	S	10	S					0
Goats	20	3	50	3	50	5	20	5	70	5	5	1	5	S	30	S	30	S	40	S	10	S	5	S	0

**APPENDIX 5** Table 9.1. Large Scale Commercial Farmers All Natural Regions.

Commodity	Percent Yield Increase <sup>1</sup>		Percent Increase in Cost <sup>2</sup>		Percent Contribution by Type of Research						Year When Key Results will be Available					
	1	2	C	F	LB	LM	LN	PF	VR	FSR	LB	LM	LN	PF	VR	FSR
Beef	5	8	10		10	10	30	30	20	10	15	3	3	3	3	3
Dairy	5	8	8			25	50	25				2	2	4		
Broilers	9	15	10			60	40					1	1			
Layers	6	9	10			40	60					2	2			
Sheep	11	15	3		20	20	30	30				5	5	3		
Ostriches	5	8	8		20	20	60					1	1			

<sup>1</sup> 1 = with current research resources, 2 = with 50% more research resources.

<sup>2</sup> C = change in variable cost to obtain 1, F = change in fixed costs to obtain 1.

<sup>3</sup> LB = Livestock breeding, LM = Livestock Management, LN=Livestock Nutrition, PF = Pastures and Forages, VR = Veld and Rangeland and FSR Farming Systems research.

**APPENDIX 5** Table9.2 Large Scale Commercial Farmers All Natural regions

Commodity	Maximum Adoption of the Technologies <sup>1</sup>											Technology Degeneration <sup>2</sup>										Percent change in herd <sup>3</sup>			
	LB		LM		LN		PF		VR		FSR		LB		LM		LN		PF		VR		FSR		
	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	%	Yr	Yr	S	Yr	S	Yr	S	Yr	S	Yr		S	Yr	S
Beef	20	5	80	2	80	2	30	5	50	10			60	S	30	S	10	R	10	S	10	S	10	R	0
Dairy			70	5	70	5	70	5							2	R	2	R	10	S					0
Broilers			80	1	80	1									5	R	5	R							1
Layers			80	1	80	1									5	R	5	R							1
Sheep	40	3	60	3	60	3	50	3							5	S	5	S	10	S					0
Ostriches	60	3	60	3	80	1											30	S							1

<sup>1</sup> % = Percentage of farmers expected to adopt the new technology once it is released, Yr. = the number of years after it is released to get maximum adoption.

<sup>2</sup> Yr = Number of years after maximum adoption when technology begins to depreciate, S = the speed of depreciation R = rapid (3-7 years) or S = slow (8 or more years).

<sup>3</sup> The expected percent annual increase (decrease) in the herd of this commodity over the next 5 - 10 years.

LB = Livestock breeding, LM = Livestock Management, LN=Livestock Nutrition, PF = Pastures and Forages, VR = Veld and Rangeland and FSR Farming Systems research.

## APPENDIX 6

### Percentage yield increase data for each triangular distribution

Table 1. Communal Farmers Low Potential areas

	Percent Yield Gain								Probability of success	
	Current Funding vs no funding				Current + 50% vs No funding				Funding level	
Commodity	Lowest	Most Likely	Highest	Average	Lowest	Most Likely	Highest	Average	Current	Current +50%
Maize	0	17	33	17	17	33	67	39	0.50	0.46
Sorghum	0	20	60	27	20	100	200	107	0.46	0.48
Pearl Millet	0	25	100	42	50	100	275	142	0.45	0.45
Finger Millet	0	50	100	50	50	150	250	150	0.50	0.50
Beans	0	30	50	27	40	100	140	93	0.53	0.53
Bambara nuts	0	20	60	27	20	40	60	40	0.46	0.50
Cowpeas	67	133	233	144	100	200	333	211	0.47	0.48
Groundnuts	50	100	150	100	125	200	275	200	0.50	0.50
Soybeans	0	0	17	6	0	33	67	33	0.44	0.50
Cotton	0	20	60	27	20	60	140	73	0.46	0.46
Sunflowers	0	100	200	100	0	200	200	133	0.50	0.50
Castor Beans	0	200	300	167	20	300	500	273	0.59	0.54
Indigenous Fruits	0	20	100	40	60	100	300	153	0.45	0.45
Cabbage	0	100	200	100	20	200	300	173	0.50	0.53
Tomato	0	50	100	50	50	150	200	133	0.50	0.54
Potatoes	0	25	88	38	88	125	150	121	0.46	0.53
Sweet Potatoes	0	5	17	7	0	67	150	72	0.46	0.48
Onions	0	25	50	25	50	100	150	100	0.50	0.50

Indigenous vegetables	0	150	300	150	150	400	500	350	0.50	0.54
High Potential Areas										
Maize	0	11	44	19	44	122	167	111	0.45	0.53
Beans	25	50	88	54	50	88	125	88	0.47	0.50
Bambara nuts	0	20	33	18	13	47	100	53	0.54	0.47
Cowpeas	40	100	200	113	60	140	300	167	0.47	0.46
Groundnuts	15	25	40	27	45	60	75	60	0.47	0.50
Soybeans	0	33	67	33	33	87	133	84	0.50	0.51
Cotton	0	6	11	6	6	11	33	17	0.50	0.45
Sunflowers	0	0	25	8	0	25	50	25	0.44	0.50
Coffee	0	30	60	30	10	60	100	57	0.50	0.52
Apples	100	200	300	200	200	400	600	400	0.50	0.50

## APPENDIX 6

### Percentage yield increase data for each triangular distribution

Table 2. Small Scale Commercial Farmers Low Potential areas

Commodity	Percent Yield Gain								Probability of success	
	Current Funding vs no funding				Current + 50% vs No funding				Funding level	
	Lowest	Most Likely	Highest	Average	Lowest	Most Likely	Highest	Average	Current	Current +50%
Maize	3	6	19	9	13	25	88	42	0.45	0.45
Sorghum	0	20	60	27	20	100	200	107	0.46	0.48
Finger Millet	0	0	38	13	38	50	100	63	0.44	0.45
Wheat	12	48	68	43	20	60	84	55	0.53	0.53
Beans	0	30	50	27	40	100	140	93	0.54	0.53
Bambara nuts	0	25	88	38	13	88	175	92	0.46	0.49
Cowpeas	67	133	233	144	100	200	333	211	0.47	0.48
Groundnuts	50	100	150	100	125	200	275	200	0.50	0.50
Soybeans	0	67	100	56	0	150	233	128	0.54	0.53
Cotton	0	20	60	27	20	60	140	73	0.46	0.46
Sunflowers	0	100	200	100	0	200	400	200	0.50	0.50
Castor Beans	0	200	300	167	20	300	500	273	0.54	0.52
Sweet Potatoes	0	0	0	0	0	67	150	72	0.50	0.48
High Potential Areas										
Maize	3	5	10	6	5	15	20	13	0.46	0.54
Wheat	12	48	68	43	20	60	84	55	0.53	0.53
Beans	0	30	50	27	10	50	80	47	0.53	0.52
Bambara nuts	50	100	150	100	60	110	150	107	0.50	0.52

Cowpeas	40	100	200	113	60	140	300	167	0.47	0.46
Groundnuts	15	25	40	27	45	60	75	60	0.47	0.50
Soybeans	0	33	47	27	20	67	87	58	0.54	0.54
Cotton	0	6	11	6	6	11	33	17	0.50	0.45
Macademia nuts	10	20	30	20	20	30	50	33	0.50	0.46
Coffee	0	30	60	30	10	60	100	57	0.50	0.52

## APPENDIX 6

### Percentage yield increase data for each triangular distribution

Table 3. Large Scale Commercial Farmers Low Potential areas

Commodity	Percent Yield Gain								Probability of success	
	Current Funding vs no funding				Current + 50% vs No funding				Funding level	
	Lowest	Most Likely	Highest	Average	Lowest	Most Likely	Highest	Average	Current	Current +50%
Maize	20	27	33	27	20	30	40	30	0.50	0.50
Sorghum	0	4	20	8	0	12	52	21	0.45	0.45
Finger Millet	0	50	100	50	50	100	150	100	0.50	0.50
Wheat	14	51	77	48	23	63	94	60	0.52	0.52
Beans	0	20	27	16	30	80	109	73	0.54	0.53
Bambara nuts	13	33	67	38	20	47	73	47	0.47	0.50
Cowpeas	50	100	150	100	60	110	160	110	0.50	0.50
Soybeans	0	50	100	50	50	150	250	150	0.50	0.50
Cotton	0	25	75	33	25	75	100	67	0.46	0.54
Sunflowers	0	0	25	8	0	25	50	25	0.44	0.50
Castor Beans	0	300	500	267	100	400	600	367	0.53	0.53
Cabbage	0	33	67	33	67	100	167	111	0.50	0.46
Tomato	0	100	200	100	100	200	300	200	0.50	0.50
Potatoes	0	25	50	25	50	75	125	83	0.50	0.46
Sweet Potatoes	33	100	100	78	67	153	167	129	0.56	0.55
Onions	0	25	50	25	50	75	88	71	0.50	0.54
High Potential Areas										
Maize	13	16	20	16	18	22	33	24	0.46	0.46

Wheat	0	7	14	7	7	10	14	10	0.50	0.47
Beans	0	20	33	18	7	33	67	36	0.53	0.48
Bambara nuts	25	75	100	67	30	85	110	75	0.54	0.54
Cowpeas	33	67	100	67	33	73	113	73	0.50	0.50
Groundnuts	13	25	38	25	25	38	50	38	0.50	0.50
Soybeans	0	7	17	8	17	33	50	33	0.47	0.50
Cotton	0	7	25	11	7	25	43	25	0.46	0.50
Macademia nuts	10	20	30	20	20	30	50	33	0.50	0.46
Coffee	0	10	20	10	7	20	33	20	0.50	0.50
Strawberry	0	17	33	17	17	43	67	42	0.50	0.51
Apples	300	400	500	400	400	500	600	500	0.50	0.50
Cabbage	0	33	67	33	67	100	167	111	0.50	0.46
Tomato	0	100	200	100	100	200	300	200	0.50	0.50
Potatoes	0	25	50	25	50	75	125	83	0.50	0.46
Sweet Potatoes	33	100	100	78	67	153	167	129	0.56	0.55
Onions	0	50	100	50	50	100	150	100	0.50	0.50
Peas	0	20	40	20	40	60	80	60	0.50	0.50
Roses stems/ha	0	10	20	10	0	20	30	17	0.50	0.59

**APPENDIX 6**

**Percentage yield increase data for each triangular distribution**

Table 4. Livestock Communal Farmers

Commodity	Percent Yield Gain								Probability of success	
	Current Funding vs no funding				Current + 50% vs No funding				Funding level	
	Lowest	Most Likely	Highest	Average	Lowest	Most Likely	Highest	Average	Current	Current +50%
Beef calving rate	0	0	0	0	0	0	25	8	0.00	0.44
Poultry Broilers mort.%	0	17	33	17	17	33	50	33	0.50	0.50
Poultry Layers eggs/b/yr	0	50	80	43	50	80	100	77	0.53	0.53
Sheep months to slaughter	0	17	25	14	25	33	58	39	0.54	0.45
Goats sl. wt. kg	0	20	40	20	20	40	60	40	0.50	0.50
Fish kg/yr/100sq m	0	17	33	17	17	33	50	33	0.50	0.50
Dairy calv. %	0	13	25	13	13	25	50	29	0.50	0.46
Draught Power										
Donkeys ha/hr	0	0	25	8	0	25	50	25	0.44	0.50
Cattle ha/hr	0	20	40	20	20	40	50	37	0.50	0.54
<b>Small Scale Commercial</b>										
Beef calving rate %	0	0	0	0	0	0	25	8	0.00	0.44
Dairy litres/lactation	0	50	100	50	50	100	120	90	0.50	0.54
Poultry Broilers mort. %	0	17	33	17	17	33	50	33	0.50	0.50
Poultry Layers eggs/b/yr	0	50	80	43	50	80	100	77	0.53	0.53
Sheep months to slaughter	0	17	25	14	25	33	58	39	0.59	0.45
Goats sl. wt. kg	0	20	40	20	20	40	60	40	0.50	0.50

Large Scale Commercial										
Beef calving rate %	0	0	0	0	0	8	17	8	0.00	0.50
Dairy litres/lactatn	0	0	0	0	0	6	13	6	0.00	0.50
Poultry Broilers mort. %	0	10	20	10	10	20	30	20	0.50	0.50
Poultry Layers eggs/b/yr	0	8	20	9	8	20	30	19	0.47	0.51
Sheep months to slaughter	0	8	17	8	8	17	25	17	0.50	0.50
Ostriches sl. wt. kg	0	0	1	0	0	4	6	3	0.44	0.53

**APPENDIX 7 Table 1. Large Scale Commercial Farms Quantity of Production ('000 tons)**

Commodity	1989	1990	1991	1992	1993	Average	High Potential	Low Potential
Maize	745.73	688.14	606.95	161.00	825.99	605.56	508.67	96.89
Sorghum	14.70	20.02	11.25	7.55	23.70	15.44	3.24	12.20
Wheat	247.01	273.98	243.66	77.75	221.81	212.84	166.02	46.83
Beans	2.76	1.80	1.73	1.12	3.54	1.64	0.44	0.88
Bambara n	0.02	0.03	0.03	0.02	0.04	0.03	0.01	0.01
Cowpeas	0.69	0.45	0.43	0.28	0.89	0.55	0.22	0.33
Groundnuts	15.12	11.59	9.46	2.23	2.37	8.15	7.18	0.98
Soyabeans	118.88	111.16	110.83	48.09	75.72	92.94	83.64	9.29
Cotton	115.54	80.29	83.24	31.27	56.36	73.34	54.27	19.07
Sunflower	2.68	1.70	1.65	0.77	2.61	1.88		1.88
Castor beans	0.04	0.08	0.02	0.03	0.06	0.05		0.05
Cabbage	41.39	18.00	30.66	31.78	31.76	30.72	15.36	15.36
Tomatoes	10.69	8.69	12.75	17.56	18.15	13.57	10.86	2.71
Potatoes	40.06	35.87	36.60	26.26	34.80	34.72	27.77	6.94
Sweet Potato	0.49	0.43	0.85	1.18	1.23	0.83	0.42	0.42
Onions	5.95	9.13	7.18	8.49	8.27	7.80	6.24	1.56
Peas	1.50	1.60	2.04	2.56	4.38	2.42	1.93	0.48
Coffee	11.48	10.81	10.04	5.76	6.73	8.97	8.97	0.00
Strawberry	0.29	0.32	0.38	0.54	0.62	0.43	0.43	
Apples *		5.38	4.88	2.50	5.28	4.51	4.51	
Macademia nuts	3.06	3.94	4.08	4.35	6.28	4.34	4.34	
Stone Fruit		2.41	1.16	2.11	1.44	1.78	1.78	
Roses					9.84	9.84	9.84	
Beef	74	64	69	68	80	71.16		
Dairy	261980	259173	220758	204824	195000	228347		
Layers 000 doz. eggs	18576.4	19340	19498	17325	19009.5	18749.5		
Broilers	23.77	25.17	24.18	20.87	21.86	23.17		
Sheep tot. herd 000	106.00	117	110	112	103.80	109.60		
Sheep 000t	0.42	0.47	0.44	0.45	0.42	0.44		
Ostriches					0.72	0.72		

\* From 1991 to 1995. Broilers and layers refers to formal marketing only broilers assumed a 2.1kg avg weight / bird.

Source: CSO, Ministry of Agriculture and farmer's unions, AMA annual reports, National Livestock Policy.

**APPENDIX 7 Table 2. Small Scale Commercial Farms Quantity of Production ('000 tons)**

Commodity	1990	1991	1992	1993	1994	Average	High Potential	Low Potential
Maize	67.59	62.21	9.77	66.14	60.46	53.23	27.68	25.55
Sorghum	0.45	0.52	0.12	1.40	1.34	0.76	0.09	0.67
P Millet	0.22	0.16	0.05	0.38	0.26	0.22		0.22
F millet	1.37	0.81	0.14	2.60	1.30	1.24		1.24
Wheat	0.04	0.00	0.01	0.01	0.00	0.01	0.01	0.01
Beans	0.27	0.17	0.07	0.17	0.24	0.18	0.09	0.09
Bambara n	1.08	0.77	0.12	0.57	0.79	0.67	0.33	0.33
Cowpeas	0.27	0.17	0.07	0.17	0.24	0.18	0.09	0.09
Groundnuts U	5.07	4.51	0.81	4.50	6.07	4.19	1.59	2.60
Soyabeans	0.12	0.08	0.02	0.05	0.02	0.06	0.03	0.03
Cotton	4.15	7.13	1.97	7.22	6.17	5.33	2.40	2.93
Sunflower	3.29	3.31	1.20	4.13	2.83	2.95		2.95
Castor beans	0.03	0.03	0.00	0.00	0.01	0.01		0.01
Cabbage						20.21	7.28	12.93
Tomatoes						13.47	4.85	8.62
Potatoes						4.30	1.55	2.75
Sweet Potato						6.74	2.43	4.31
Onions						6.50	2.34	4.16
Coffee	0.01	0.00	0.00	0.00	0.00	0.00	0.00	
Macademia nuts		0.04	0.04	0.00	0.04	0.03	0.03	
Beef			1.23	1.31	1.14	1.23		
Dairy			1046.00	1757.00	2400	1734.33		
Layers	78.1	92.17	156.4	171.2	141.7	127.91		
Broilers								
Sheep 000 head					31.35	31.35		
Sheep offtake 10%					3.14	3.14		
Sheep 000t 20kg/head					0.06	0.06		
Goats tot. herd 000		46.00	74.00	72.00	78.00	67.50		
Goat offtake 15%		6.90	11.10	10.80	11.70	10.13		
Goat '000 t	0.14	0.22	0.22	0.23	0.20			

Source: CSO, Ministry of Agriculture and farmer's unions.

Vegetable production calculated from total area under small scale irrigation.

**APPENDIX 7. Table 3. Communal Area Farms and Resettlement Quantity of Production ('000 tons)**

Commodity	1989	1990	1991	1992	1993	National Avg	High Potential	Low Potential
Maize	264.71	1262.30	1019.26	118.57	1195.82	772.13	262.53	509.61
Sorghum	63.85	72.50	51.28	6.58	70.71	52.98		52.98
P Millet		90.00	73.07	13.82	57.13	58.50		58.50
F millet	84.00	44.00	49.17	13.70	37.88	45.75		45.75
Beans	7.26	9.35	5.57	3.41	5.65	6.25	3.12	3.12
Bambara n	32.00	34.65	23.95	62.27	16.31	33.84	16.92	16.92
Cowpeas	21.79	28.04	16.70	10.22	16.94	18.74	9.37	9.37
Groundnuts	78.20	102.44	87.78	28.77	49.35	69.31	22.18	47.13
Soyabeans	4.67	2.16	2.18	0.65	1.49	2.23	2.23	
Cotton	137.54	113.64	155.67	36.17	135.60	115.73	40.50	75.22
Sunflower	54.05	59.00	59.00	17.54	61.65	50.25	10.05	40.20
Castor beans	0.112	0.041	0.084	0.068	0.124	0.09		0.0858
Cabbage						67.23	24.20	43.03
Tomatoes	132.07	129.54	120.83	127.38	108.29	123.62	44.50	79.12
Potatoes						14.34	5.16	9.18
Sweet Potato						22.41	8.07	14.34
Onions						21.50	7.74	13.76
Indigenous veg*						12.00		
Indigenous fruit*						6.25		
Coffee			0.032			0.03	0.032	
Beef herd	3815	3856	4576	3509	4259	4003.00		
Beef offtake 4%	153	154	183	140	170	160.12		
Beef 000kg @220kg/head	33572	33933	40269	30879	37479	35226.40		
Beef 000t	34	34	40	31	37	35.23		
Beef Manure 000t	3434	3470	4118	3158	3833	3602.70		
Dairy 000 t					370	370.00		
Layers 000 doz. eggs					6667	6667.00		
Broilers 000 birds	1691.12	1791.06	1720.71	1484.78	1555.32	1648.60		
Sheep tot. herd 000	410.00	483.00	381.00	381.00	361.00	403.20		
Sheep offtake 10%	41.00	48.30	38.10	38.10	36.10	40.32		
Sheep 000t 20kg/head	0.82	0.97	0.76	0.76	0.72	0.81		
Goats tot. herd 000	2200	2289	2466	2433	2434	2364.40		
Broilers 000t #	3.55	3.76	3.61	3.12	3.27	3.46		
Multipurpose bird					4.50	4.50		
Goat offtake 15%	330.00	343.35	369.90	364.95	365.10	354.66		
Goat 000t @ 20kg/head	6.60	6.87	7.40	7.30	7.30	7.09		
Draft power cattle						1434915.00		
Draft power donkeys						486486		
Fish						0.132		

\* Estimated with consultations with Agritex and CSO.

Source: CSO, Ministry of Agriculture and farmer's unions.

#### **APPENDIX 7 cont'd Assumptions made for estimating quantities in table 4**

Broiler figures refer to formal marketing, and are for 1990-1994.

Vegetable figures total production was estimated from total communal area under vegetables given in the World Bank sector study multiplied by average yields of vegetables estimated from the Ministry of Agriculture Farm Management survey and yields given in MOA Horticulture Export Marketing Study.

Beef figures from AMA, National Livestock Policy, and are for 1988-1992

Average carcass weight =220kg

Dairy production calculated assuming 30% of cattle herd are cows which lactate every year at 300litres / lactation/ year.

# figures include small scale commercial

Draft power area tilled is based on available data, 73-90% total communal area is tilled (Zimbabwe government, 1996)

Donkey draft constitute 22% whilst cattle draft account for 55% (DRSS, 1994).

Multipurpose bird figures calculated assuming each of the 1 million communal households consume 3 indigenous birds every year with average weight 1.5kg / bird.

Number of eggs produced calculated assuming each of the 1 million communal households have 1 hen giving 80 eggs/year.

APPENDIX 8 Research Costs For Communal Farmers ( Z\$ 000 )

Commodity	PB	PP	AG	CS	AF	FSR	TOTAL
Natural Region 3,4,5							
Maize	75	150	226	226	38	38	752
Sorghum	69	92	137	137	0	23	458
Pearl Millet	151	60	212	91	0	91	605
Finger Millet	81	35	70	35	0	12	233
Beans	49	61	98	37	0	0	244
Bambara nuts	55	14	41	21	0	7	137
Cowpeas	30	30	25	5	1	9	101
Groundnuts	72	43	72	72	0	29	288
Soybeans	0	0	0	0	0	0	0
Cotton	211	175	246	70	0	0	702
Sunflowers	84	28	84	42	0	42	279
Castor Beans	27	16	23	8	0	4	78
Cabbage	14	8	14	4	0	0	39
Tomato	44	44	41	15	0	3	147
Potatoes	23	23	37	9	0	0	93
Sweet Potatoes	23	9	12	15	0	0	58
Onions	30	20	25	10	0	15	101
Indigenous Fruits	195	0	84	0	0	0	279
Indigenous Vegetables	163	0	70	0	0	0	233
Natural Region 1 and 2							
Maize	150	150	188	188	38	38	752
Beans	98	49	44	54	0	0	244
Bambara nuts	48	7	55	21	0	7	137
Cowpeas	30	30	25	5	1	9	101
Groundnuts	72	43	101	43	0	29	288
Soybeans	74	93	130	56	0	19	372
Cotton	246	175	211	70	0	0	702
Sunflowers	84	14	98	42	0	42	279
Cabbage	16	8	12	4	0	0	39
Tomato	44	44	41	15	0	3	147
Potatoes	23	23	37	9	0	0	93
Sweet Potatoes	23	9	12	15	0	0	58
Onions	30	20	25	10	0	15	101
Coffee	22	225	202	0	0	0	450
Apples	53	23	60	0	0	15	151
Stone fruit	53	23		60	0	15	151

**APPENDIX 8** cont'd

**Research Costs For Small Scale Commercial Sector (Z\$ 000)**

Commodity	PB	PP	AG	CS	AF	FSR	TOTAL
Natural Region 3,4,5							
Maize	75	150	263	226	38	0	752
Sorghum	46	92	137	137	0	46	458
Finger Millet	58	23	81	35	0	35	233
Beans	0	0	0	0	0	0	0
Bambara nuts	0	0	0	0	0	0	0
Cowpeas	30	30	25	5	1	9	101
Groundnuts	72	43	101	43	0	29	288
Soybeans	0	0	0	0	0	0	0
Cotton	211	175	246	70	0	0	702
Sunflowers	84	14	126	14	0	42	279
Castor Beans	27	16	23	8	0	4	78
Cabbage	16	8	12	4	0	0	39
Tomato	44	44	41	15	0	3	147
Potatoes	23	23	37	9	0	0	93
Sweet Potatoes	15	9	20	15	0	0	58
Onions	30	20	25	10	0	15	101
Natural Region 1 and 2							
Commodity	PB	PP	AG	CS	AF	FSR	TOTAL
Maize	150	150	188	188	38	38	752
Wheat	272	21	126	0	0	0	419
Beans	0	0	0	0	0	0	0
Bambara nuts	0	0	0	0	0	0	0
Cowpeas	30	30	25	5	1	9	101
Groundnuts	72	43	101	43	0	29	288
Soybeans	74	93	130	56	0	19	372
Cotton	211	175	246	70	0	0	702
Cabbage	16	8	12	4	0	0	39
Tomato	44	44	41	15	0	3	147
Potatoes	23	23	37	9	0	0	93
Sweet Potatoes	15	9	20	15	0	0	58
Onions	30	20	25	10	0	15	101
Macademia nuts	0	19	5	0	0	0	23
Coffee	0	225	225	0	0	0	450
Apples	53	23	60	0	0	15	151
Stone fruit	53	23	60	0	0	15	151

**APPENDIX 8** cont'd

**Research Costs For Large Scale Commercial Sector (Z\$ 000)**

Commodity	PB	PP	AG	CS	AF	FSR	TOTAL
Natural Region 3,4,5							
Maize	451	75	188	38	0	0	752
Sorghum	183	92	160	23	0	0	458
Finger Millet	0	0	0	0	0	0	0
Wheat	251	21	147	0	0	0	419
Beans	98	49	44	54	0	0	244
Bambara nuts	55	21	55	7	0	0	137
Cowpeas	40	15	40	5	0	0	101
Soybeans	112	74	93	93	0	0	372
Cotton	281	211	140	70	0	0	702
Sunflowers	168	0	56	56	0	0	279
Castor Beans	27	31	16	4	0	0	78
Cabbage	16	4	16	4	0	0	39
Tomato	59	29	44	15	0	0	147
Potatoes	51	9	23	9	0	0	93
Sweet Potatoes	35	6	6	12	0	0	58
Onions	40	10	40	10	0	0	101
Natural Region 1 and 2							
Maize	451	75	188	38	0	0	752
Wheat	251	21	147	0	0	0	419
Beans	98	49	44	54	0	0	244
Bambara nuts	55	21	55	7	0	0	137
Cowpeas	40	15	40	5	0	0	101
Groundnuts	115	58	87	29	0	0	288
Soybeans	112	74	93	93	0	0	372
Cotton	281	246	105	70	0	0	702
Strawberry	30	8	38	0	0	0	76
Apples	38	8	30	0	0	0	76
Cabbage	16	4	16	4	0	0	39
Tomato	59	29	44	15	0	0	147
Potatoes	37	23	23	9	0	0	93
Sweet Potatoes	35	6	6	12	0	0	58
Onions	30	20	25	25	0	0	101
Peas	37	9	37	9	0	0	93
Flowers	279	47	116	23	0	0	465
Macademia nuts	0	19	5	0	0	0	23
Coffee	0	225	225	0	0	0	450
Stone fruit	45	30	76	0	0	0	151

**Research Costs For Livestock Section (Z\$ 000)**

Commodity	LB	LM	LN	PF	VR	FSR	TOTAL
<b>COMMUNAL FARMERS</b>							
Beef	179	179	537	537	269	90	1791
Broilers	8	62	85	0	0	0	155
Layers	0	93	62	0	0	0	155
Sheep	20	40	81	60	0	0	202
Goats	332	199	332	173	160	133	1330
Fish	0	116	116	0	0	0	233
Multi-purpose	279	140	140	140	0	0	698
Draught Power	45	271	496	0	90	0	903
<b>SMALL SCALE COMMERCIAL FARMERS</b>							
Beef	90	90	537	537	448	90	1791
Dairy	337	337	675	337	0	0	1687
Broilers	0	62	93	0	0	0	155
Layers	0	93	62	0	0	0	155
Sheep	40	40	60	60	0	0	202
Goats	332	199	332	173	160	133	1330
<b>LARGE SCALE COMMERCIAL FARMERS</b>							
Beef	179	179	537	537	358	0	1791
Dairy	0	422	1265	0	0	0	1687
Broilers	0	93	62	0	0	0	155
Layers	0	62	93	0	0	0	155
Sheep	40	40	60	60	0	0	202
Ostriches	93	93	279	0	0	0	465

## APPENDIX 9. LINDO results of mathematical programming model when both farmer types are weighted equally

Note: The codes MZ is maize, GN groundnuts, SG sorghum, PM pearl millet, FM finger millet, BB bambara nuts, BN beans, CP cow peas, CO cotton, SF sunflower, SB soyabeans, CB cabbage, TO tomatoes, PO potatoes, SP sweet Potatoes, AP apples, ON Onions, IV indigenous vegetables, IF indigenous fruits, RO roses, PE peas, MA macadamia, CF Coffee, ST stonefruit, SW strawberry, BF beef, DR dairy, BR broiler, SH sheep, GO goats, LY layers, CD cattle draft, DD donkey draft, FS fish.

The numbers 11 and 12 refers to communal farmers at current level and additional 50% more funding (e.g. MZ11 and MZ12 are communal maize at current level of funding and 50% additional funding respectively). While 31 and 32 refers to large-scale commercial current and additional 50% more funding (e.g. MZ31 and MZ32 are large-scale commercial maize at current level of funding and 50% additional funding respectively). X1 is the efficiency objective, while X2 is the equity objective.

MAX X1

SUBJECT TO

$$\begin{aligned}
 & 2) - X1 + 1.094 MZ11 + 0.917 MZ12 + 1.826 MZ31 + 1.081 MZ32 \\
 & + 0.162 SG11 + 0.152 SG12 + 0.413 PM11 + 0.406 PM12 + 0.52 FM11 \\
 & + 0.51 FM12 + 0.489 WH31 + 0.373 WH32 + 0.101 BN11 + 0.089 BN12 \\
 & + 0.924 BB11 + 0.72 BB12 + 0.622 CP11 + 0.359 CP12 + 0.76 GN11 \\
 & + 0.688 GN12 + 0.271 GN31 + 0.237 GN32 + 0.658 CO11 + 0.608 CO12 \\
 & + 0.192 CO31 + 0.17 CO32 + 0.174 SB31 + 0.158 SB32 + 0.696 SF11 \\
 & + 0.654 SF12 + 1.053 CB11 + 0.658 CB12 + 0.39 CB31 + 0.32 CB32 \\
 & + 0.488 TO11 + 0.443 TO12 + 0.206 TO31 + 0.176 TO32 + 0.233 PO11 \\
 & + 0.205 PO12 + 0.283 PO31 + 0.222 PO32 + 0.947 SP11 + 0.903 SP12 \\
 & + 0.16 SP31 + 0.145 SP32 + 0.293 AP31 + 0.256 AP32 + 0.508 ON11 \\
 & + 0.448 ON12 + 0.204 ON31 + 0.181 ON32 + 0.413 IV11 + 0.405 IV12 \\
 & + 0.347 RO31 + 0.327 RO32 + 0.144 IF11 + 0.139 IF12 + 0.345 PE31 \\
 & + 0.258 PE32 + 0.36 MA31 + 0.34 MA32 + 0.361 CF31 + 0.316 CF32 \\
 & + 0.492 ST31 + 0.477 ST32 + 0.35 SW31 + 0.28 SW32 + 0.154 BF12 \\
 & + 0.197 BF31 + 0.039 BF32 + 0.121 DR11 + 0.09 DR12 + 0.173 DR31 \\
 & + 0.161 DR32 + 0.555 BR11 + 0.406 BR12 + 0.408 BR31 + 0.38 BR32 \\
 & + 0.198 SH11 + 0.19 SH12 + 0.096 SH31 + 0.075 SH32 + 0.09799999 GO11 \\
 & + 0.077 GO12 + 0.565 LY11 + 0.482 LY12 + 0.266 LY31 + 0.188 LY32 \\
 & + 0.284 CD11 + 0.257 CD12 + 0.24 DD11 + 0.204 DD12 + 0.022 FS12 \\
 & = 0
 \end{aligned}$$

$$\begin{aligned}
 & 3) 1.094 MZ11 + 0.917 MZ12 + 0.162 SG11 + 0.152 SG12 + 0.413 PM11 \\
 & + 0.406 PM12 + 0.52 FM11 + 0.51 FM12 + 0.101 BN11 + 0.089 BN12 \\
 & + 0.924 BB11 + 0.719 BB12 + 0.622 CP11 + 0.359 CP12 + 0.76 GN11 \\
 & + 0.688 GN12 + 0.658 CO11 + 0.608 CO12 + 0.696 SF11 + 0.654 SF12 \\
 & + 1.053 CB11 + 0.658 CB12 + 0.488 TO11 + 0.443 TO12 + 0.233 PO11 \\
 & + 0.205 PO12 + 0.947 SP11 + 0.903 SP12 + 0.508 ON11 + 0.448 ON12 \\
 & + 0.413 IV11 + 0.405 IV12 + 0.144 IF11 + 0.139 IF12 + 0.154 BF12 \\
 & + 0.121 DR11 + 0.09 DR12 + 0.555 BR11 + 0.406 BR12 + 0.198 SH11 \\
 & + 0.19 SH12 + 0.09799999 GO11 + 0.077 GO12 + 0.565 LY11 + 0.482 LY12 \\
 & + 0.284 CD11 + 0.257 CD12 + 0.24 DD11 + 0.204 DD12 + 0.022 FS12 - X2 \\
 & = 0
 \end{aligned}$$

$$\begin{aligned}
 & 4) MZ11 + MZ12 + MZ31 + MZ32 + SG11 + SG12 + PM11 + PM12 + FM11 \\
 & + FM12 + WH31 + WH32 + BN11 + BN12 + BB11 + BB12 + CP11 + CP12 + GN11 \\
 & + GN12 + GN31 + GN32 + CO11 + CO12 + CO31 + CO32 + SB31 + SB32 + SF11
 \end{aligned}$$

+ SF12 + CB11 + CB12 + CB31 + CB32 + TO11 + TO12 + TO31 + TO32 + PO11  
+ PO12 + PO31 + PO32 + SP11 + SP12 + 2 SP31 + SP32 + AP31 + AP32  
+ ON11 + ON12 + ON31 + ON32 + IV11 + IV12 + RO31 + RO32 + IF11 + IF12  
+ PE31 + PE32 + MA31 + MA32 + CF31 + CF32 + ST31 + ST32 + SW31 + SW32  
+ BF12 + BF31 + BF32 + DR11 + DR12 + DR31 + DR32 + BR11 + BR12 + BR31  
+ BR32 + SH11 + SH12 + SH31 + SH32 + GO11 + GO12 + LY11 + LY12 + LY31  
+ LY32 + CD11 + CD12 + DD11 + DD12 + FS12 = 400810

- 5) MZ31 <= 15040
- 6) MZ31 + MZ32 <= 22560
- 7) MZ11 <= 30090
- 8) MZ11 + MZ12 <= 45140
- 9) SG11 <= 9150
- 10) SG11 + SG12 <= 13730
- 11) PM11 <= 6050
- 12) PM11 + PM12 <= 9080
- 13) FM11 <= 4660
- 14) FM11 + FM12 <= 6990
- 15) WH31 <= 12560
- 16) WH31 + WH32 <= 18840
- 17) BN11 <= 9770
- 18) BN11 + BN12 <= 14660
- 19) BB11 <= 5480
- 20) BB11 + BB12 <= 8220
- 21) CP11 <= 4030
- 22) CP11 + CP12 <= 6050
- 23) GN11 <= 11520
- 24) GN11 + GN12 <= 17280
- 25) GN31 <= 2880
- 26) GN31 + GN32 <= 4320
- 27) SB31 <= 11170
- 28) SB31 + SB32 <= 16760
- 29) CO11 <= 14040
- 30) CO11 + CO12 <= 21060
- 31) CO31 <= 28070
- 32) CO31 + CO32 <= 42110
- 33) SF11 <= 5580
- 34) SF11 + SF12 <= 8370
- 35) CB11 <= 780
- 36) CB11 + CB12 <= 1170
- 37) CB31 <= 1550
- 38) CB31 + CB32 <= 2330
- 39) TO11 <= 2940
- 40) TO11 + TO12 <= 4410
- 41) TO31 <= 5890
- 42) TO31 + TO32 <= 8840
- 43) PO11 <= 1860
- 44) PO11 + PO12 <= 2790
- 45) PO31 <= 3720
- 46) PO31 + PO32 <= 5580
- 47) SP11 <= 1160
- 48) SP11 + SP12 <= 1740
- 49) SP31 <= 2350
- 50) SP31 + SP32 <= 3520
- 51) ON11 <= 2020

- 52)  $ON11 + ON12 \leq 3030$
- 53)  $ON31 \leq 4040$
- 54)  $ON31 + ON32 \leq 6060$
- 55)  $IV11 \leq 2330$
- 56)  $IV11 + IV12 \leq 3500$
- 57)  $PE31 \leq 930$
- 58)  $PE31 + PE32 \leq 1400$
- 59)  $MA31 \leq 470$
- 60)  $MA31 + MA32 \leq 700$
- 61)  $RO31 \leq 4650$
- 62)  $RO31 + RO32 \leq 6980$
- 63)  $IF11 \leq 2330$
- 64)  $IF11 + IF12 \leq 3500$
- 65)  $ST31 \leq 4190$
- 66)  $ST31 + ST32 \leq 6290$
- 67)  $CF31 \leq 9000$
- 68)  $CF31 + CF32 \leq 13500$
- 69)  $AP31 \leq 4540$
- 70)  $AP31 + AP32 \leq 6810$
- 71)  $SW31 \leq 350$
- 72)  $SW31 + SW32 \leq 530$
- 73)  $BF12 \leq 17910$
- 74)  $BF31 \leq 35830$
- 75)  $BF31 + BF32 \leq 53750$
- 76)  $DR11 \leq 15410$
- 77)  $DR11 + DR12 \leq 23120$
- 78)  $DR31 \leq 25310$
- 79)  $DR31 + DR32 \leq 37960$
- 80)  $BR11 \leq 1550$
- 81)  $BR11 + BR12 \leq 2320$
- 82)  $BR31 \leq 3100$
- 83)  $BR31 + BR32 \leq 4650$
- 84)  $LY11 \leq 1550$
- 85)  $LY11 + LY12 \leq 2320$
- 86)  $LY31 \leq 3100$
- 87)  $LY31 + LY32 \leq 4650$
- 88)  $SH11 \leq 2020$
- 89)  $SH11 + SH12 \leq 3030$
- 90)  $SH31 \leq 4030$
- 91)  $SH31 + SH32 \leq 6050$
- 92)  $GO11 \leq 26600$
- 93)  $GO11 + GO12 \leq 39900$
- 94)  $SP31 \leq 2350$
- 95)  $SP31 + SP32 \leq 3520$
- 96)  $CD11 \leq 6240$
- 97)  $CD11 + CD12 \leq 9360$
- 98)  $DD11 \leq 2830$
- 99)  $DD11 + DD12 \leq 4240$
- 100)  $FS12 \leq 2330$

END

LP OPTIMUM FOUND AT STEP 108

OBJECTIVE FUNCTION VALUE

1) 200570.00

VARIABLE	VALUE	REDUCED COST
X1	200570.000000	.000000
MZ11	30090.000000	.000000
MZ12	15050.000000	.000000
MZ31	15040.000000	.000000
MZ32	7520.000000	.000000
SG11	9150.000000	.000000
SG12	.000000	.009000
PM11	6050.000000	.000000
PM12	3030.000000	.000000
FM11	4660.000000	.000000
FM12	2330.000000	.000000
WH31	12560.000000	.000000
WH32	6280.000000	.000000
BN11	.000000	.060000
BN12	.000000	.072000
BB11	5480.000000	.000000
BB12	2740.000000	.000000
CP11	4030.000000	.000000
CP12	2020.000000	.000000
GN11	11520.000000	.000000
GN12	5760.000000	.000000
GN31	2880.000000	.000000
GN32	1440.000000	.000000
CO11	14040.000000	.000000
CO12	7020.000000	.000000
CO31	28070.000000	.000000
CO32	14040.000000	.000000
SB31	11170.000000	.000000
SB32	.000000	.003000
SF11	5580.000000	.000000
SF12	2790.000000	.000000
CB11	780.000000	.000000
CB12	390.000000	.000000
CB31	1550.000000	.000000
CB32	780.000000	.000000
TO11	2940.000000	.000000
TO12	1470.000000	.000000
TO31	5890.000000	.000000
TO32	2950.000000	.000000
PO11	1860.000000	.000000
PO12	930.000000	.000000
PO31	3720.000000	.000000
PO32	1860.000000	.000000
SP11	1160.000000	.000000
SP12	580.000000	.000000
SP31	.000000	.162000
SP32	.000000	.016000
AP31	4540.000000	.000000
AP32	2270.000000	.000000
ON11	2020.000000	.000000

ON12	1010.000000	.000000
ON31	4040.000000	.000000
ON32	2020.000000	.000000
IV11	2330.000000	.000000
IV12	1170.000000	.000000
RO31	4650.000000	.000000
RO32	2330.000000	.000000
IF11	.000000	.017000
IF12	.000000	.022000
PE31	930.000000	.000000
PE32	470.000000	.000000
MA31	470.000000	.000000
MA32	230.000000	.000000
CF31	9000.000000	.000000
CF32	4500.000000	.000000
ST31	4190.000000	.000000
ST32	2100.000000	.000000
SW31	350.000000	.000000
SW32	180.000000	.000000
BF12	.000000	.007000
BF31	35830.000000	.000000
BF32	.000000	.122000
DR11	.000000	.040000
DR12	.000000	.071000
DR31	25310.000000	.000000
DR32	3100.000000	.000000
BR11	1550.000000	.000000
BR12	770.000000	.000000
BR31	3100.000000	.000000
BR32	1550.000000	.000000
SH11	2020.000000	.000000
SH12	1010.000000	.000000
SH31	.000000	.065000
SH32	.000000	.086000
GO11	.000000	.063000
GO12	.000000	.084000
LY11	1550.000000	.000000
LY12	770.000000	.000000
LY31	3100.000000	.000000
LY32	1550.000000	.000000
CD11	6240.000000	.000000
CD12	3120.000000	.000000
DD11	2830.000000	.000000
DD12	1410.000000	.000000
FS12	.000000	.139000
X2	112617.700000	.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-1.000000
3)	.000000	.000000
4)	.000000	.161000
5)	.000000	.745000
6)	.000000	.920000

7)	.000000	.177000
8)	.000000	.756000
9)	.000000	.001000
10)	4580.000000	.000000
11)	.000000	.007000
12)	.000000	.245000
13)	.000000	.010000
14)	.000000	.349000
15)	.000000	.116000
16)	.000000	.212000
17)	9770.000000	.000000
18)	14660.000000	.000000
19)	.000000	.204000
20)	.000000	.559000
21)	.000000	.263000
22)	.000000	.198000
23)	.000000	.072000
24)	.000000	.527000
25)	.000000	.034000
26)	.000000	.076000
27)	.000000	.013000
28)	5590.000000	.000000
29)	.000000	.050000
30)	.000000	.447000
31)	.000000	.022000
32)	.000000	.009000
33)	.000000	.042000
34)	.000000	.493000
35)	.000000	.395000
36)	.000000	.497000
37)	.000000	.070000
38)	.000000	.159000
39)	.000000	.045000
40)	.000000	.282000
41)	.000000	.030000
42)	.000000	.015000
43)	.000000	.028000
44)	.000000	.044000
45)	.000000	.061000
46)	.000000	.061000
47)	.000000	.044000
48)	.000000	.742000
49)	2350.000000	.000000
50)	3520.000000	.000000
51)	.000000	.060000
52)	.000000	.287000
53)	.000000	.023000
54)	.000000	.020000
55)	.000000	.008000
56)	.000000	.244000
57)	.000000	.087000
58)	.000000	.097000
59)	.000000	.020000
60)	.000000	.179000

61)	.000000	.020000
62)	.000000	.166000
63)	2330.000000	.000000
64)	3500.000000	.000000
65)	.000000	.015000
66)	.000000	.316000
67)	.000000	.045000
68)	.000000	.155000
69)	.000000	.037000
70)	.000000	.095000
71)	.000000	.070000
72)	.000000	.119000
73)	17910.000000	.000000
74)	.000000	.036000
75)	17920.000000	.000000
76)	15410.000000	.000000
77)	23120.000000	.000000
78)	.000000	.012000
79)	9550.000000	.000000
80)	.000000	.149000
81)	.000000	.245000
82)	.000000	.028000
83)	.000000	.219000
84)	.000000	.083000
85)	.000000	.321000
86)	.000000	.078000
87)	.000000	.027000
88)	.000000	.008000
89)	.000000	.029000
90)	4030.000000	.000000
91)	6050.000000	.000000
92)	26600.000000	.000000
93)	39900.000000	.000000
94)	2350.000000	.000000
95)	3520.000000	.000000
96)	.000000	.027000
97)	.000000	.096000
98)	.000000	.036000
99)	.000000	.043000
100)	2330.000000	.000000

NO. ITERATIONS= 108

RANGES IN WHICH THE BASIS IS UNCHANGED:

VARIABLE	OBJ COEFFICIENT RANGES		
	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
X1	1.000000	INFINITY	1.000000
MZ11	.000000	INFINITY	.177000
MZ12	.000000	.177000	.756000
MZ31	.000000	INFINITY	.745000
MZ32	.000000	.745000	.920000
SG11	.000000	INFINITY	.001000

SG12	.000000	.009000	INFINITY
PM11	.000000	INFINITY	.007000
PM12	.000000	.007000	.245000
FM11	.000000	INFINITY	.010000
FM12	.000000	.010000	.349000
WH31	.000000	INFINITY	.116000
WH32	.000000	.116000	.212000
BN11	.000000	.060000	INFINITY
BN12	.000000	.072000	INFINITY
BB11	.000000	INFINITY	.204000
BB12	.000000	.204000	.559000
CP11	.000000	INFINITY	.263000
CP12	.000000	.263000	.198000
GN11	.000000	INFINITY	.072000
GN12	.000000	.072000	.527000
GN31	.000000	INFINITY	.034000
GN32	.000000	.034000	.076000
CO11	.000000	INFINITY	.050000
CO12	.000000	.050000	.447000
CO31	.000000	INFINITY	.022000
CO32	.000000	.022000	.009000
SB31	.000000	INFINITY	.013000
SB32	.000000	.003000	INFINITY
SF11	.000000	INFINITY	.042000
SF12	.000000	.042000	.493000
CB11	.000000	INFINITY	.395000
CB12	.000000	.395000	.497000
CB31	.000000	INFINITY	.070000
CB32	.000000	.070000	.159000
TO11	.000000	INFINITY	.045000
TO12	.000000	.045000	.282000
TO31	.000000	INFINITY	.030000
TO32	.000000	.030000	.015000
PO11	.000000	INFINITY	.028000
PO12	.000000	.028000	.044000
PO31	.000000	INFINITY	.061000
PO32	.000000	.061000	.061000
SP11	.000000	INFINITY	.044000
SP12	.000000	.044000	.742000
SP31	.000000	.162000	INFINITY
SP32	.000000	.016000	INFINITY
AP31	.000000	INFINITY	.037000
AP32	.000000	.037000	.095000
ON11	.000000	INFINITY	.060000
ON12	.000000	.060000	.287000
ON31	.000000	INFINITY	.023000
ON32	.000000	.023000	.020000
IV11	.000000	INFINITY	.008000
IV12	.000000	.008000	.244000
RO31	.000000	INFINITY	.020000
RO32	.000000	.020000	.166000
IF11	.000000	.017000	INFINITY
IF12	.000000	.022000	INFINITY
PE31	.000000	INFINITY	.087000

PE32	.000000	.087000	.097000
MA31	.000000	INFINITY	.020000
MA32	.000000	.020000	.179000
CF31	.000000	INFINITY	.045000
CF32	.000000	.045000	.155000
ST31	.000000	INFINITY	.015000
ST32	.000000	.015000	.316000
SW31	.000000	INFINITY	.070000
SW32	.000000	.070000	.119000
BF12	.000000	.007000	INFINITY
BF31	.000000	INFINITY	.036000
BF32	.000000	.122000	INFINITY
DR11	.000000	.040000	INFINITY
DR12	.000000	.071000	INFINITY
DR31	.000000	INFINITY	.012000
DR32	.000000	.001000	.003000
BR11	.000000	INFINITY	.149000
BR12	.000000	.149000	.245000
BR31	.000000	INFINITY	.028000
BR32	.000000	.028000	.219000
SH11	.000000	INFINITY	.008000
SH12	.000000	.008000	.029000
SH31	.000000	.065000	INFINITY
SH32	.000000	.086000	INFINITY
GO11	.000000	.063000	INFINITY
GO12	.000000	.084000	INFINITY
LY11	.000000	INFINITY	.083000
LY12	.000000	.083000	.321000
LY31	.000000	INFINITY	.078000
LY32	.000000	.078000	.027000
CD11	.000000	INFINITY	.027000
CD12	.000000	.027000	.096000
DD11	.000000	INFINITY	.036000
DD12	.000000	.036000	.043000
FS12	.000000	.139000	INFINITY
X2	.000000	.045455	.006173

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	.000000	200570.000000	INFINITY
3	.000000	112617.700000	INFINITY
4	400810.000000	9550.000000	3100.000000
5	15040.000000	7520.000000	15040.000000
6	22560.000000	3100.000000	7520.000000
7	30090.000000	15050.000000	30090.000000
8	45140.000000	3100.000000	9550.000000
9	9150.000000	3100.000000	9150.000000
10	13730.000000	INFINITY	4580.000000
11	6050.000000	3030.000000	6050.000000
12	9080.000000	3100.000000	3030.000000
13	4660.000000	2330.000000	4660.000000
14	6990.000000	3100.000000	2330.000000
15	12560.000000	6280.000000	12560.000000

16	18840.000000	3100.000000	6280.000000
17	9770.000000	INFINITY	9770.000000
18	14660.000000	INFINITY	14660.000000
19	5480.000000	2740.000000	5480.000000
20	8220.000000	3100.000000	2740.000000
21	4030.000000	2020.000000	4030.000000
22	6050.000000	3100.000000	2020.000000
23	11520.000000	5760.000000	11520.000000
24	17280.000000	3100.000000	5760.000000
25	2880.000000	1440.000000	2880.000000
26	4320.000000	3100.000000	1440.000000
27	11170.000000	3100.000000	9550.000000
28	16760.000000	INFINITY	5590.000000
29	14040.000000	7020.000000	14040.000000
30	21060.000000	3100.000000	7020.000000
31	28070.000000	14040.000000	28070.000000
32	42110.000000	3100.000000	9550.000000
33	5580.000000	2790.000000	5580.000000
34	8370.000000	3100.000000	2790.000000
35	780.000000	390.000000	780.000000
36	1170.000000	3100.000000	390.000000
37	1550.000000	780.000000	1550.000000
38	2330.000000	3100.000000	780.000000
39	2940.000000	1470.000000	2940.000000
40	4410.000000	3100.000000	1470.000000
41	5890.000000	2950.000000	5890.000000
42	8840.000000	3100.000000	2950.000000
43	1860.000000	930.000000	1860.000000
44	2790.000000	3100.000000	930.000000
45	3720.000000	1860.000000	3720.000000
46	5580.000000	3100.000000	1860.000000
47	1160.000000	580.000000	1160.000000
48	1740.000000	3100.000000	580.000000
49	2350.000000	INFINITY	2350.000000
50	3520.000000	INFINITY	3520.000000
51	2020.000000	1010.000000	2020.000000
52	3030.000000	3100.000000	1010.000000
53	4040.000000	2020.000000	4040.000000
54	6060.000000	3100.000000	2020.000000
55	2330.000000	1170.000000	2330.000000
56	3500.000000	3100.000000	1170.000000
57	930.000000	470.000000	930.000000
58	1400.000000	3100.000000	470.000000
59	470.000000	230.000000	470.000000
60	700.000000	3100.000000	230.000000
61	4650.000000	2330.000000	4650.000000
62	6980.000000	3100.000000	2330.000000
63	2330.000000	INFINITY	2330.000000
64	3500.000000	INFINITY	3500.000000
65	4190.000000	2100.000000	4190.000000
66	6290.000000	3100.000000	2100.000000
67	9000.000000	4500.000000	9000.000000
68	13500.000000	3100.000000	4500.000000
69	4540.000000	2270.000000	4540.000000

70	6810.000000	3100.000000	2270.000000
71	350.000000	180.000000	350.000000
72	530.000000	3100.000000	180.000000
73	17910.000000	INFINITY	17910.000000
74	35830.000000	3100.000000	9550.000000
75	53750.000000	INFINITY	17920.000000
76	15410.000000	INFINITY	15410.000000
77	23120.000000	INFINITY	23120.000000
78	25310.000000	3100.000000	25310.000000
79	37960.000000	INFINITY	9550.000000
80	1550.000000	770.000000	1550.000000
81	2320.000000	3100.000000	770.000000
82	3100.000000	1550.000000	3100.000000
83	4650.000000	3100.000000	1550.000000
84	1550.000000	770.000000	1550.000000
85	2320.000000	3100.000000	770.000000
86	3100.000000	1550.000000	3100.000000
87	4650.000000	3100.000000	1550.000000
88	2020.000000	1010.000000	2020.000000
89	3030.000000	3100.000000	1010.000000
90	4030.000000	INFINITY	4030.000000
91	6050.000000	INFINITY	6050.000000
92	26600.000000	INFINITY	26600.000000
93	39900.000000	INFINITY	39900.000000
94	2350.000000	INFINITY	2350.000000
95	3520.000000	INFINITY	3520.000000
96	6240.000000	3120.000000	6240.000000
97	9360.000000	3100.000000	3120.000000
98	2830.000000	1410.000000	2830.000000
99	4240.000000	3100.000000	1410.000000
100	2330.000000	INFINITY	2330.000000

## **Vita**

Gladys Mutangadura was born of school teachers Josephine and Danson Bindura on 12 May, 1965. She attended elementary school at different schools where her parents were teaching. She attended Old Mutare Mission for her secondary education (1978-1983). In December 1986 she graduated with Bachelor of Science degree in Agricultural Economics from the University of Zimbabwe. In January 1987 she joined the Ministry of Agriculture working as a Farm Management Extension Specialist (AGRITEX) in the first year, a Farm Management Lecturer (Chibero Agricultural College) in the second year, and as an Agricultural Economist (Economics and Markets Branch) from January 1989. In 1990-1991 she undertook part-time studies on adult education, graduating in December 1991 with a Diploma in Adult Education from the University of Zimbabwe. In 1991 she was promoted to senior agricultural economist.

In June 1992, Gladys was awarded a Kellogg Foundation Fellowship which supported her one year intensive masters studies in development economics at Williams College (Massachusetts). In June 1993 she graduated with an MA in Development Economics and was awarded a Jack Larned 1942, International Management Prize, for best Masters Research Paper. Gladys was awarded a research assistantship and admitted into Virginia Polytechnic Institute and State University Agricultural and Applied Economics Department in August 1993 and completed her doctorate in Spring 1997.

Gladys is married to Godfrey Mutangadura.