RETURNS ON AGRICULTURAL RESEARCH AND DEVELOPMENT IN THE SOUTH AFRICAN SUGAR INDUSTRY

by

PHILIP ANTHONY DONOVAN

Submitted in partial fulfilment of the
requirements for the degree

DOCTOR OF PHILOSOPHY

in the

Department of Agricultural Economics
Faculty of Agriculture
University of Natal
Pietermaritzburg

December 1989

PREFACE

Unless specifically indicated to the contrary in the text, this thesis is the result of my own original work.

P A DONOVAN

ABSTRACT

The lack of information on returns to R&D is considered a handicap to effective decision-making by policy-makers and managers in agricultural commodity organisations. Results of studies reported in the literature, mostly using economic analysis of aggregated and multi-product data, are usually insufficiently detailed to assist decision-making at institute level. The objective of this study is to find an empirical and practical method of estimating returns for that purpose.

Returns on sugarcane production R&D in the South African Sugar Industry are estimated as the factor share of technology in a production function analysis of productivity, as yield per unit area per annum, in which the other significant variables were found to be rainfall, costs of production and area under crop. Eight other variables were excluded from the analysis for lack of significance or collinearity. Under a *user pays* policy, advisory services are considered self-financing, leaving the estimated returns to be divided between the other two primary functions of an R&D institute, research and extension.

It is suggested that the increase in yields obtained by technologists in field trials can represent technology (the output of research) while the increase in the Industry's yield over the same period represents technology plus the transfer of technology (the function of extension). In percentage terms the ratios of research to extension, for three successive decades to 1986, were found to be 65%:35%, 37%:63% and 17%:83%, indicating decline in the contribution of research and increase in the contribution of extension to the Industry's declining productivity. Research's contribution (17% of the total return on R&D during the last decade) was then apportioned among research programmes in the proportions of the subjective estimates made of their returns, after deducting the return on plant breeding, the only programme whose productivity could be quantified directly from production data. Returns and costs are then compared in terms of percentage net returns [(returns - costs)/costs x 100] and benefit:cost ratios (return/cost). The returns estimated on research, extension and whole Station activities, were similar, in terms of benefit:cost ratios, to those obtained in the few other comparable studies. The advantages of the methods proposed are their empirical simplicity and applicability down to programme (project) level.

ACKNOWLEDGEMENTS

This study was made possible by the award of a bursary from Agriprojects (Pty) Ltd for which I am especially grateful. The personal interest and support of two of that company's Directors, Dr Bill Purves and Hu Metelerkamp, who are also former research colleagues, is acknowledged with particular pleasure.

The study would not have been started without the encouragement of my supervisor, Professor WL Nieuwoudt, and certainly not completed without his interest and advice, of which I am most appreciative.

I am indebted to many people for assistance of different kinds, for providing access to unpublished data and information, acquiring references unavailable through normal channels and for giving freely of their particular knowledge. It would be impractical to name them all and invidious to name a few, except those acknowledged among the references for personal communications. There are, however, two persons to whom I am especially grateful; Dr Gerald Thompson whose guidance and comments were invaluable and Mark Darroch whose econometric advice and assistance with data processing, are greatly appreciated.

It would not have been possible to undertake this study without the interest and assistance of the Director and staff of the South African Sugar Association's Experiment Station and of the General Manager and staff of the South African Cane Growers' Association. I am grateful to a number of them individually and to the two organisations, together with the Sugar Association, for the excellent example they provide of agricultural commodity R&D.

To those who had the foresight to found, and to those who continue to support, the South African Sugar Industry Agronomists' Association, I am particularly indebted. Without them the invaluable records of field trial data, which I was privileged to use for this study, would not exist.

Finally, my special thanks go to Miss Joyce Kingham for her excellent word processing and patience in the production of this thesis.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

> Perhaps the most important objective in estimating the returns on R&D is to provide information that can improve decision-making by those responsible for policy or management of R&D (Schuh & Tollini, 1979).

The productivity of agricultural research and development has become a matter of greater concern in recent years. Competition for scarce human and financial resources has increased and policy-makers, when they have to make decisions on the allocation of resources without information on costs and returns, are more easily influenced by emotive social and environmental issues than by the technological problems of increasing agricultural productivity.
The motivation for this study is, therefore, the present lack of economic information of the kind that could improve decision-making at policy and management levels in an agricultural commodity R&D organisation. The primary goal of the study is to find an appropriate empirical method of estimating the returns on agricultural research and development in the South African Sugar Industry that can be of practical value to policy-makers and managers who increasingly need to take into account the economic consequences of investing in R&D.

Policy decisions are required on what functions should be included in an R&D portfolio and on the size of the investment to be made in these functions. Typically in an agricultural commodity R&D organisation, the portfolio comprises three functions, Research, Extension and Technical or Advisory Services.
Management decisions need to be taken on the number and scope of programmes within each function of the portfolio; decisions on the number of programmes become recommendations to the policy-makers while those on their scope and content are required in considering recommendations from lower management levels. The structure of management decision-making remains the same at all levels, recommending on broad issues to a higher level and considering recommendations on detail from a lower level. It is suggested that decisions of both kinds and at all levels can be improved by having information on the costs and returns of R&D functions and programmes.

At higher decision-making levels *ex-post* information on costs and returns is of greater value and is more accurate than *ex-ante* information which only becomes important at lower levels of decision-making. In this study, with its objective of improving decision-making at policy and upper management levels, that is on R&D functions and programmes, the focus is, therefore, on ex-post methods of estimating returns on R&D.

Examination of previous estimates of the returns on investment in agricultural R&D indicates that methods of economic analysis using, as they do, aggregated multi-product data, are insufficiently detailed and accurate to be of value for management purposes in an agricultural commodity R&D institute. The decision was taken, therefore, to devise a suitable empirical method of R&D evaluation for which a minimum of data disaggregation and of economic analysis were necessary.

The case study is sugarcane production R&D conducted at the South African Sugar Association (SASA) Experiment Station. A previous study of R&D management at the Experiment Station (Donovan, 1986) provides an analysis of costs down to programme level leaving the estimation of returns and the implications for management as the essence of this study.

A review of the literature on the development of methods for evaluating R&D generally is undertaken in Chapter 1, and previous estimates of the returns, particularly on sugarcane R&D, are considered in Chapter 2. The sources of technology available to the South African Sugar Industry, from its beginnings 140 years ago, are discussed in Chapter 3 and a production function analysis of the most important factors affecting the Industry's productivity, since the establishment of the SASA Experiment Station in 1925, is proposed. From that date, sufficient data are available to allow an estimate to be made of productivity attributable specifically to production technology in terms of its marginal product in the production function equation.

To facilitate and rationalise the allocation of costs and the apportioning of estimated returns, the R&D functions and the different kinds of research in an agricultural commodity R&D organisation are defined in Chapter 4. The difficulty of estimating the returns on advisory and technical services is overcome by considering them to be self-financing which became possible with the recently adopted 'user pays' policy at the SASA Experiment Station. The separate evaluation of the extension function in R&D has not been successful previously, yet without it returns on research down to programme level cannot be evaluated quantitatively. In Chapter 5 previous work on the evaluation of extension is considered and a method of extension evaluation is proposed in which the change in the relationship between the average commercial yield and the yield obtained by technologists in field trials, can be used as a measure of the transfer of technology or extension.

With quantitative assessments of the value of production technology, obtained from production function analysis, and with the proposed method of apportioning this value between research and extension, estimates are made of the returns on individual research programmes in Chapter 6. In Chapter 7 these returns on research programmes, converted from tons of sucrose to rands, are compared with their costs to obtain an estimate of their profitability.

Finally, in Chapter 8 the value and implications of having estimates of costs and returns on the different functions and programmes of an agricultural commodity R&D organisation, are considered in terms of both policy and management decision-making. The future management challenges that become evident from the particular case study are also considered in this final chapter.

CHAPTER 1

METHODS OF R&D EVALUATION

HISTORICAL DEVELOPMENT OF EVALUATION METHODS

The purpose of research and development is the innovation of new technologies and techniques that can improve productivity and profitability. Schultz described research and development as primarily an economic activity subject to economic analyses and a new technology as '... a valuable (scarce) resource that has a "price" and that this resource is not given to the community or to the producer as a free good; on the contrary it entails costs some of which are borne by the community and some by the producer ... Therefore a new technique is simply a particular kind of input and the economics underlying the supply and use are in principle the same as that of any other type of input' (Schultz, 1953 p.110).

These hypotheses of Schultz stimulated interest in the economic theory of the returns on agricultural R&D which was discussed by economists at the first symposium on the subject, held in Minnesota in 1969. The proceedings of the Minnesota symposium (Fishel, 1971a) generated interest in the returns on agricultural R&D among policy-makers and administrators who attended and contributed to the second meeting on the subject, the Airlie House Conference, held in 1975 (Arndt *et al*, 1977).
At this second meeting attention was given to the economic effects of agricultural production in different countries, including the costs and returns on research, and the construction of theoretical economic models.

By this time, the mid-1970's, agricultural research *and extension*, particularly in the United States, were being subjected increasingly to critical examination, with special interest focussed on '... the orientation, return to investment and income distribution consequences of investment in research and extension' (Araji, 1980 p.iii). These were the main issues discussed at the third meeting entitled 'Research and Extension Productivity in Agriculture' held in Moscow, Idaho in May 1978. Only two years later the fourth major conference in eleven years was held, back in Minnesota on research evaluation and methodology (Norton *et al*, 1981).

Three comprehensive reviews of the work done on research evaluation between 1953 amd 1980, provide useful guides to the literature. The first of them was by Schuh & Tollini (1979) who were particularly concerned with those aspects of agricultural research evaluation which could improve the allocation of funds between kinds of agricultural research, between research institutions and between agricultural research and other activities. The second review, by Norton & Davis (1981a) gave more attention to a comparison of methods, providing insights into differences in assumptions made and into the different purposes of evaluation. These two reviews were carried out with different objectives but they are sufficiently similar to be summarised together as shown in Figure 1.

ESTIMATING RETURNS ON AGRICULTURAL R&D

Ex-Post Methods	Ex-Ante Methods
Economic or Consumer/ Producer Surplus	Scoring models
Input-saved	Benefit: Cost ratio
Production function	Simulation
Impact on national income	Mathematical models
Impact on human nutrition	Special purposes models ◦ Minnesota ◦ Iowa ◦ Pinstrup-Andersen ◦ Easter & Norton, etc.

Figure 1: Summary of methods for estimating benefits of agricultural R&D for management purposes (Schuh & Tollini, *op. cit.*) and for comparison of methods purposes (Norton & Davis, 1981a)

The third review by Evenson (1981) was primarily a taxonomy of the development of research evaluation methods emphasising those that contribute to the basic understanding of evaluation methods and speculating on future developments in methodology. Evenson's classification (*op. cit.* p.197) which identifies three main categories of work, is summarised in Figure 2.

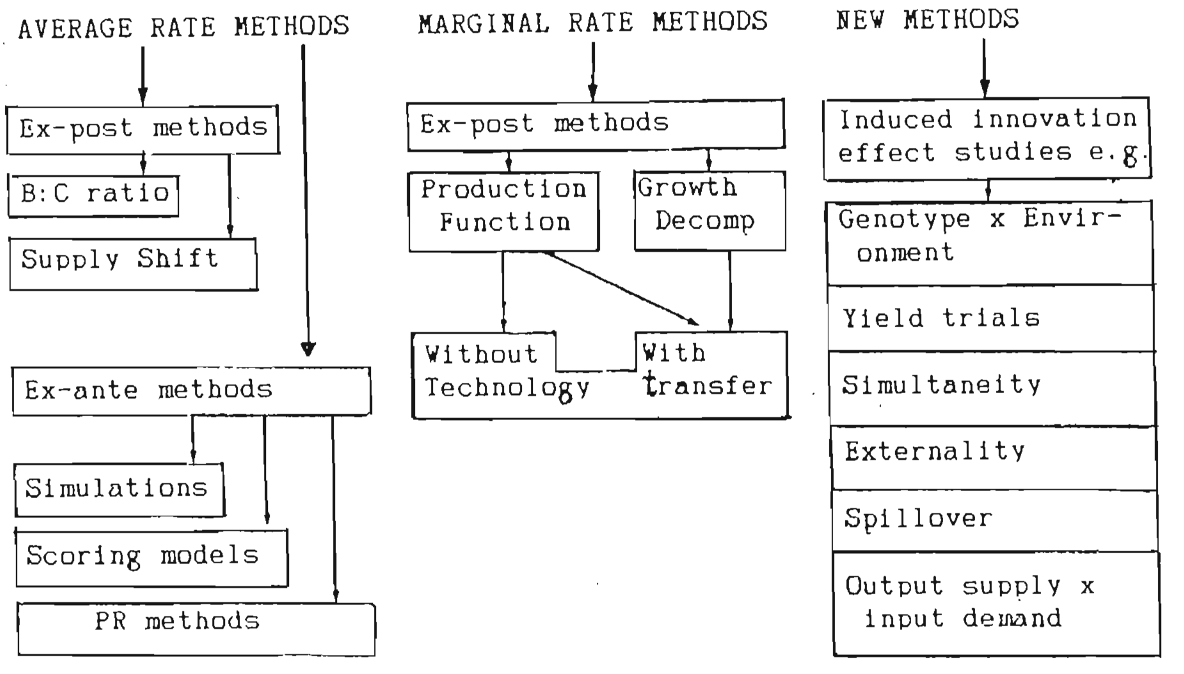

Figure 2: **Development of research evaluation methodology (Evenson, 1981)**

Although these three reviews differ in purpose and approach, there is sufficient commonality among them, and many other references, to permit a general summary of research evaluation methods.

Research evaluation has most commonly been divided into *ex-post* and *ex-ante* categories, that is, the evaluation of research that has been done and research still to be done (or in progress) respectively. As shown in Figure 2, Evenson (1981) prefers to make the first sub-division according to methods of evaluation. For example, he first divides research evaluation methods into those using *average rate of return* and those using *marginal rate of return*, notwithstanding the fact that this puts both ex-post and ex-ante evaluations into the same category, namely the average rate of return category.
This is probably more appropriate from a theoretical point of view, and is no less convenient for the practical purposes of assessing research returns as an aid to research managers and policy-makers, however the more usual convention of division into ex-post and ex-ante, is followed in this review.

EX-POST METHOD OF EVALUATION

Most ex-post evaluations of research use the resultant increase in production, or the economic consequences of increased production, as the measure of the return on research input. Ex-post methods have most commonly been applied to macro-economic data and are only appropriate for micro-economic studies when adequate and reliable data are available. There are three approaches to the ex-post method of evaluation:

The Economic Surplus Approach. This approach is also called the Consumer/Producer Surplus or Index Number Approach. It is based on the fact that the results of research, that is, the adoption of innovations in agricultural production, shift the supply curve making more of the product available and so, theoretically, lowering its price or reducing its cost of production.
This is illustrated by the basic model in Figure 3.

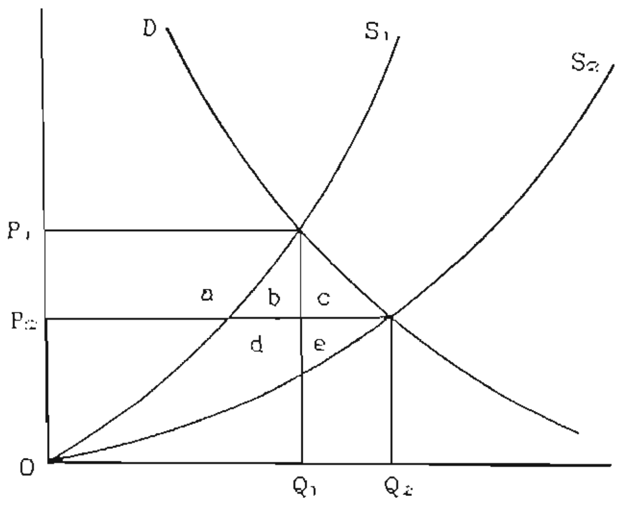

Figure 3 : Economic Surplus model

An increase in the supply of a commodity, from S_1 to S_2, following the use of new technology, results in a surplus which lowers the price of the commodity from P_1 to P_2. The change in the consumers surplus is measured by the area *a+b+c*. The same shift in supply also results in a change in the producers surplus, measured by the area *d+e-a* and the total change in the economic surplus (consumers + producers surplus) is measured by *b+c+d+e*.

Some research innovations are by nature input (cost) saving rather than production increasing and for these a cost-saving approach, originally advocated by Schultz (1953) is more suitable and can be used in either ex-post or ex-ante estimates. In Schultz's (1953 p.117-122) cost-saving approach, the value of R&D saved through the adoption of a new innovation can be measured by the area *a+b+c* in Figure 3. The new innovation results in a saving equivalent to moving the supply curve from S_1 to S_2 and, in this case, this is equal to the consumer surplus.
With information on how much the supply curve has shifted and on the parameters that caused the shift, together with costs of the R&D responsible for these parameters, a benefit:cost analysis can be made.

In a seminal paper, Griliches (1958) used the economic surplus method on a single commodity (hybrid corn) and examined the effect of supply elasticity in such a context.

The distribution of benefits between producers and consumers was estimated, for agricultural research evaluation purposes, by Ayr & Schuh (1972) who also applied a sensitivity test to their results by varying the elasticity of supply. In general producers benefit from technical change (research results) only when the demand for their product is elastic. Akino & Hayami (1975), in considering the social returns to research on rice in Japan, point out that although producers benefit directly from the research done on crops that are mostly exported, consumers benefit appreciably from the indirect effect of such exports, especially the exchange earnings.

The distribution of benefits between consumers and '... producers is extremely sensitive to the assumptions made in the analysis; caution is therefore necessary in developing models to discuss distributional issues' (Wise, 1984 p.30). Scobie (1976) has warned that different assumptions made about shifts in supply and demand, as well as elasticities, can lead to different results and interpretations of the research benefits, even when the same data and formulae are used. Lindner & Jarret (1978 p.48) also advise caution in their conclusion that '... the uncritical application of previously developed formulas without regard to the type of supply shift can result in substantial bias in estimates of research benefits. The implication is that calculation of rates of return on agricultural investment may also be severely biased'.

Estimates made of research returns, using the economic surplus method tend to be low because, as Schultz (1953) himself noted, not all beneficial research aims to increase production levels. Petersen (1971) pointed out that estimates are also biased downward because production levels would almost certainly have declined if research had not been done while the method itself is based on a uniform level of production without research.

An interesting study of the returns from research on a single crop was made by Duncan (1972). He estimated the returns from research on pastures, using the supply of meat and milk as the products and assuming perfect elasticity of demand for them. Other economic surplus studies on single commodities include those of Kislev & Hoffman (1978) on wheat, Evenson (1969) on sugarcane, Hertford *et al* (1977) on rice, soybeans, wheat and cotton, Nagy & Furtan (1978) on rape seed.

The economic surplus method of evaluating research is particularly useful in economic policy formulation in spite of its major limitations which are not being able to quantify the gain due solely to research and not being able to separate research and technical transfer effects (Schuh & Tollini, 1979).

The Production Function Approach. This is based on the premise that the production function for a commodity can be used to estimate the pay-off, or contribution, of any production factor, such as R&D, which is well defined and included in the function. The usual production function for a crop commodity commonly includes only the on-farm inputs but there is no reason why others, such as research, should not be included. Griliches (1964) used this approach to estimate the contribution of agricultural research and extension to the level of output and their rate of social (that is, consumer + producer) return. The functional form for an estimate of the total return has been conceptualized by Dalrymple (1977) as follows:

$$B = PQK(1 + K/2E_d)[1 - (1 - E_d)^2 E_s/(E_d - E_s)]$$

Where: B = total return. K = shift in supply due to research.

P = product price. E_d = elasticity of product demand.

Q = product quantity. E_s = elasticity of product supply.

The most difficult factor to measure is K because of its congruity with other factors that influence productivity. Griliches (1964) simply assumed a particular yield increase (5%) in corn production from planting hybrid instead of open-pollinated varieties. Field trial results from experiment stations and from farms have been used in other studies (Dalrymple, 1977). The estimation of the elasticity factors, E_d and E_s, are also often difficult to make. Griliches (1958 p.421) found that '... these elasticities have only a second-order effect, and hence different reasonable assumptions about them will affect the results very little'.

Ayr & Schuh (1972) found that results were changed very little by using different price and supply elasticities. Other studies also suggest '... that it is possible to be flexible and pragmatic in obtaining estimates of K, and that introductory analyses might leave out estimates of E_s and E_d' (Dalrymple, 1977 p.197). An important advantage of the production function approach is that it can provide an estimate of the *marginal* product of research as Peterson (1967) demonstrated for poultry research in the United States. The input-saved and economic surplus approaches estimate the *average* rate of return which is not as useful for research administrators and policy-makers. Because '... decisions to invest or not to invest in agricultural research must be made continually, the relevant criterion is a marginal rather than an average rate of return' (Peterson & Hayami, 1977).

In early studies little or no time lag between research and adoption was allowed but more recently workers (for example Fishel, 1971b) have improved estimates of research value by using a lag of six to seven years to the high point of a V- or U-shaped research adoption curve.

Evenson *et al*, quoted by Schuh & Tollini (1979), used the basic production function approach to isolate the effects of technology transfer which, in many circumstances, can be a major contributor to the total returns from research.

The output used in the production function has usually been the national aggregate for agriculture as a whole (Griliches, 1958) or for different commodities or groups of commodities (Peterson, 1967 and Bredahl & Peterson, 1976). In the latter study the purpose was to obtain a relative order of returns on research applied to groups of commodities so that the allocation of resources to R&D could be improved.

The quality and relevance of data representing all factors in the production function equation is critically important. Expenditure is commonly used to represent the research factor in spite of the considerable variation in what is included in expenditure. The number of published papers has also been used as a measure of research output (Evenson, 1974 and Evenson & Kislev, 1973) but as Donovan (1986) points out, this may not be a good measure, especially in an applied research organisation.

Davis (1979) in applying eight procedural variations in a basic production function, using the same empirical data, found that the estimates of the marginal rates of return were extremely sensitive to the estimation procedure, varying from 23,9 to 49,7 percent. It is therefore important to ensure compatibility of estimation procedures when comparing the marginal rates of return from different studies. In contrast to this, Dalrymple (1977), in comparing his results using the economic surplus method, with results obtained by Evenson using the production function method, believes there is sufficient agreement to justify using either method.

Dalrymple regards the economic surplus method as suitable for measuring the effects of the newer, high yielding varieties but considers the production function method more useful for separating the factors responsible for increased productivity. Griliches (1979 p.113) concludes a paper on the contribution of research and development to productivity growth in *intensive industries* by making a '... plea for realism as to what the production function approach can and cannot accomplish. Given good data, it can tell us something about average returns to R&D investments in the past and whether they appear to be changing over time. It may be able to indicate industries where returns have been especially high or low, but it will not be able to tell us whether a particular proposed R&D project is a good bet or not'.

The Impact Approach. Tweeten & Hines (1965) calculated how much lower the national income would be if the percentage of people on the farm was still the same as in 1910 and the resulting additional farmers had the income of today's farmers instead of today's non-farmers. This, they suggested, provides an estimate of the benefits of research but it can only be a rough approximation of the value of research on single commodities; however, it is a method that is easily understood in the national context and for which only commonly available data are required.

A second type of impact method was proposed by Pinstrup-Andersen *et al*, (1976) in which the impact of increased agricultural output on the level of nutrition, in different income groups, is used as a measure of research value. This very indirect method may be relevant under those conditions in which research is focussed primarily on improving standards of nutrition but it needs detailed knowledge of, and data on, food demand parameters and consumption levels.

Conclusions to be drawn from a review of ex-post methods of research evaluation are that:

- no one method is suitable for all purposes;
- most methods examine the interaction of aggregated agricultural R&D data and some aspect of the national economy and some are suitable for decision-making at national level;
- both the economic surplus and production function methods are very susceptible to error and misinterpretation if the formulae, assumptions and factors used are inappropriate or inaccurate.

EX-ANTE METHODS OF EVALUATION

These methods of research evaluation attempt to estimate the value of research still to be conducted or of research in progress. There are three main kinds of ex-ante analysis: Scoring models, Benefit:Cost analysis and Simulation or Mathematical models. Ex-ante methods are more commonly used for estimating the returns on research projects and programmes, that is, on a micro-economic scale and all depend on predicting or projecting yield or rank.

Scoring models. These are relatively simple procedures used to formalize and improve decision-making on choice. Evaluators, usually scientists, score alternative research projects numerically in terms of their likely contribution or chances of success in achieving pre-specified goals (Schuh & Tollini, 1979). Scoring models cannot, however, be used to assess returns on research in quantitative terms (Williamson, 1971). The usefulness of scoring models depends very largely on the correct definition of objectives, on the use of an appropriate weighting structure and on the choice of expert evaluators. Scoring can be either continuous or discrete in nature but must be quantitative.

A scoring model known as the Iowa Model described by Mahlstede (1971), had as its goal, ensuring the best return on research expenditure at the Iowa Experiment Station. Sub-goals and their weights (relative importance) were first agreed then further sub-divided into areas and sub-areas, each of which had its own panel of evaluators. The evaluations of future research projects was done by consensus on priorities and in terms of estimated project costs. The Iowa Model is described as a *static deterministic* model because time and uncertainty are not quantified; the model is probably only somewhat better than making no attempt at rating potential returns on research. The North Carolina Model, described by Shumway (1977), differs from the Iowa Model in using the Delphi technique (Beattie & Reader, 1971), in having external or extramural evaluators, and in using standard deviations to improve the choice between categories with equal scores (Shumway & McCracken, 1975). Its main fault is poor definition of goals.

All scoring models are conceptually simple and can incorporate multiple goals but they are very labour intensive (Norton & Davis, 1981b).

Benefit: Cost Analysis. This type of analysis has most often been used for ex-post purposes (Schuh & Tollini, 1979) but Norton & Davis (1981b) have put it in their ex-ante category, probably because the best known example of its use in agriculture, the Minnesota Model, was used primarily for ex-ante purposes. The Minnesota model, with the acronym MARRAIS (Minnesota Agricultural Research Resources Allocation Information System) is '... a computer based generalized structure for collecting and processing information relative to resource allocation decisions under situations characterized by a high degree of uncertainty' (Fishel, 1971b p.344). Marrais requires estimates by extramural scientists of expenditure, time, technical feasibility and other parameters, followed by generation of their distribution and deterministic levels using the Monte Carlo method (Norton & Davis, 1981a). This is one of the most sophisticated models, requiring high operational quality in terms of staff and computer facilities and is therefore costly; it could equally well be classified as a simulation model.

Easter & Norton (1977) used scientists' estimates of yield and actual costs to calculate the sensitivity of the benefit: cost ratios to variations in yield, prices and lag-lengths. They also emphasised the importance of using social scientists on the panel of evaluators. A scoring model by Castro & Schuh (1984) uses secondary data, instead of scientists opinion, to estimate the impact of research and technical change, including growth and distributional effects. Araji *et al* (1978) evaluated research and extension programmes on commodities using scientists' estimates and opinions on yield, probability of success, time, costs and rate of adoption.

Simulation and Mathematical Models. One of the more sophisticated models in this category is that of Pinstrup-Andersen & Franklin (1977) which they proposed for the ex-ante prediction of the relative contributions and the costs of alternative research programmes in order to establish research priorities. Their procedure was to define overall goals, followed by the identification of changes in product supply, input demand and farm consumption needed to achieve those goals. This is followed by the identification of research problems and alternative technologies needed to solve the problems, together with estimates of the time, costs and probabilities of success of research and adoption on the farm. The effects of these various alternatives on farm consumption, product demand and output supply are then estimated. This model was suggested for use by international research centres where the relationship between production and research is not well established and because production levels in different areas are not necessarily determined by the same facotrs. However, models of this kind require the availability of much detailed data and involve complex mathematics.

Lu *et al* (1978) proposed a simulation model to examine the relationship between research and extension and the growth of agricultural productivity; they used expenditure on research and extension as the main decision variable. Changes in agricultural productivity were related to lagged values of investment in research and extension, changes in the level of farmers' education and weather parameters. The model was used to project agricultural growth at three rates of investment in research and extension. From this the authors predicted agricultural production growth resulting from specific new technologies and also estimated benefit:cost ratios and internal rates of return on investment in research and extension. Knutson & Tweeten (1979) used a similar model to project farm output and prices resulting from a predicted change in agricultural productivity. White *et al* (1978) used simulation techniques to determine an optimum level and time path of research spending to obtain a certain rate of farm price increase; they also examined the effect on consumer costs of reduced spending on research.

Simulation models rely on past yield increases or scientists' estimates of future increases to predict the effect on yield of a research innovation. Kislev & Rabiner (1979) applied what they called the 'black box' treatment, that is, they built a simulation model of a breeding programme to increase milk production in a dairy herd. They then tried to explain the production gap between actual and predicted (model) yields in terms of quantitative genetics and the decision variables and natural constraints limiting the selection process. Simulation models are flexible, being capable of estimating optimum inputs for research at national or portfolio* level, of determining the effects of research on prices, income and employment. Russell (1975) developed a model to assist in selecting agricultural research programmes (portfolios) in the United Kingdom. He first established an overall goal for the production of outputs '... needed to permit the attainment of an ideal state for social welfare ...' (p.34) then identified three dimensions of the goal, nine aspects of the dimensions and a rating system. Russell then used the model to maximise the utility of the research programme (portfolio) to achieve those goals. According to Norton & Davis (1981b) Cartwright's proposed model for allocating research projects in a university department of agricultural economics was not sufficiently developed for practical use; the main difficulty was in specifying the personal preference factor.

Simulation models have been more widely used in industry than in agriculture, probably because the industrial research processes are more easily controlled and are subject to less uncertainty in terms of pay-off (Norton & Davis, *op. cit.*). The main disadvantage of siumulation models is that they need a great deal of information, are time consuming to build and operate, and depend on sophisticated computer facilities.

The conclusions to be drawn from a review of ex-ante methods of research evaluation, of which more than one hundred have been proposed (Schuh & Tollini, 1979), varying from simple scoring to complex mathematical programmes, are as follows:

- they can provide information to improve decision-making in research evaluation;

*In the R&D literature the meanings of the terms portfolio, programme and project appear to vary. For the purposes of this study a *portfolio* embraces all activities needed to carry out a discrete organisational goal: for example 'To develop, propagate and distribute new varieties'. A portfolio usually involves multi-disciplinary and inter-departmental action. a *programme* consists of a number of projects or activities usually within a single discipline or to tackle a single problem. A *project* is taken to mean a single experiment, field or laboratory trial, or activity, conducted usually by a 'research module', i.e.: a single researcher and his associated and supporting technical staff and resources (Oram, 1985).

- extramural opinion, when it is used, can provide constructive criticism and stimulus for research but the danger of 'pooled opinion' equating with 'pooled ignorance' is real;
- research goals are better defined when ex-ante estimates are to be made;
- the resource requirements of most ex-ante methods are excessive in relation to the objectives sought;
- few of the methods proposed have been applied in practice more widely than in the situations for which they were developed, except in the case of scoring models which are used to some extent in industry.

THE PUBLIC RELATIONS APPROACH

This approach to the evaluation of agricultural R&D is described by Peterson (1971). The method is one of simple accounting in which costs and returns are compared. The approach is so named because its simple, descriptive method is probably more effective than methods using economic theory, with its associated jargon, for persuading the public to provide resources for agricultural R&D. With any method of R&D evaluation, costs (expenditure) are recorded or can be determined empirically, with acceptable accuracy, but returns on research expenditure, or investment, usually have to be estimated. The accuracy of estimates of returns depends on the reliability and relevance of the data used and on the estimates obtained from logical deduction by informed experts. These are likely to be as reliable and relevant as those obtained by indirect, association or surrogate methods, provided the experts are estimating within their own fields of expertise.

Most of the ex-ante methods of research evaluation reviewed depend on expert opinion for their estimates of returns but, in view of the highly aggregated and diverse kinds of data involved, the number of experts required to cover the range of disciplines would have to be considerable.

Most ex-post methods use data derived from economic theorems or surrogate data such as the number of papers published as proxy for research output. In view of the reservations noted in the literature on the reliability of such data, the alternative of using experts to provide the data might well result in estimates no less reliable, again with the proviso that the experts are estimating within their field of expertise. Wise's (1975 p.260) comment on this matter is apt: 'The issue, however, is not between a completely quantitative system and a completely haphazard, intuitive system, but between a completely quantitative (but very imperfect) system and an intuitive system using systematic aids as appropriate. On what basis, other than intuition, can it be said that the advantage must lie with the completely quantitative system?'

An early, partial and elementary use of this method was reported two years before the publication of Schultz' 'The economic organisation of Agriculture' in 1953 which is taken to be the original motivation for formal economic studies of the return on research. Mangelsdorf, a pioneer and eminent geneticist, estimated the return on research that had made hybrid corn available to farmers in the early 1930's, when he said corn yields had been increased by 50% through the use of hybrid seed (Mangelsdorf 1951). It is unfortunate that he did not convert yield into dollars and complete the procedure by accounting for the cost of the research done. This would have given, in 1951, a 'public relations' estimate to compare with Griliches' 1958 'economic surplus' estimate of the value of hybrid corn research.

Of, perhaps, more significance than Mangelsdorf's estimate of yield increase was his comment 'Since increases of this magnitude are seldom met in controlled experiments, it follows that the use of hybrid corn has brought in its wake other improved agricultural practices including crop rotation, the use of fertilizers, and the growing of soil-improving crops. The successful utilization of hybrid corn has made the American farmer receptive to an entire complex of new and improved methods' (Mangelsdorf *op. cit.* p.566-7). It is that beneficial synergistic effect of a successful innovation that has confounded all attempts and methods of research evaluation so far and is a matter that will be considered later.

A more recent and local use of the 'public relations' approach for estimating the return on R&D was in the SASA Experiment Station's (1983) cost effectiveness exercise, the results of which are included in Appendix 1 and which is discussed in detail later.

The advantages of the Public Relations approach would, therefore, appear to be:

- It is a method of evaluation easily understood by those allocating resources to R&D.
- The results can be expressed in terms of a benefit:cost ratio or as a marginal or average rate of return.
- The method can be used for both ex-post and ex-ante estimates of return on R&D.

Peterson (1971) points out the main disadvantages of the public relations approach as follows:

- Because the method is usually applied only to successful projects, a distorted estimate of the return on a research portfolio could be obtained.
- The method cannot estimate quantitatively the postive returns on negative research results.
- It is not possible, using this method, to apportion benefits between producers and consumers.
- Finally, and perhaps the '... most serious drawback of this approach is that it does not yield any information that is useful in achieving allocation of resources' (Peterson *op. cit.* p.144).

GENERAL COMMENTS ON EVALUATION METHODS

Many studies of the returns on research were motivated by Schultz' (1953) statement that an innovation emanating from agricultural research and development should be considered a valuable resource and merely as another input governed by established economic principles. While these studies may have been productive of economic theory, it is a pity that so few of them could be of an applied nature. In the absence of real or adequate output data, most studies had to use indirect measures of R&D output such as assumed shifts in the supply and demand for agricultural products. Even for the studies of the effect of R&D on individual agricultural commodities, indirect or surrogate indicators of change in output have had to be used. More than twenty years ago Rubenstein (1966 p.169) said: 'In the field of economic evaluation of research and development activities, there is a wide gap between actual practice and the theories in the literature. The former is characterised by heavy reliance on subjective judgements and little use of quantitative methods. The theoretical literature, on the other hand, leans heavily towards mathematical models whose underlying assumptions and data requirements present difficulties in attempted application'. Referring to various theoretical micro-economic methods of research evaluation, Foster (1971 p.27) said '... it is difficult to relate any of these methods to the daily problems of research management'.

There have been two main reasons for the interest in agricultural R&D evaluation; first, the need to justify the increasing public expenditure on R&D in recent times and, secondly, to improve the allocation of the scarce resources made available for R&D. Most studies and empirical assessments of the returns on agricultural R&D have, therefore, been concerned with the *social* benefit derived from the expenditure of public monies. This is generally appropriate because in most countries agricultural R&D is wholely or largely funded by the State. However, it is surprising that very few studies are reported in the literature on the returns to agricultural commodity R&D which is funded by producers themselves with private profit motives. Some studies have sought suitable techniques for estimating the division of returns between social and private gains (or losses) but invariably starting from a theoretical estimate of social benefits.

Peterson, who defined private returns as the additional net earnings a firm is able to capture by investing in R&D, argues that '... in spite of the lack of empirical evidence on the social returns to private R&D, we can be assured that, as long as R&D is privately profitable, it is also socially profitable' (Peterson, 1976 p.324). Rausser *et al* (1981), in considering different kinds of research activity, believe they are distinguished in terms of their potential pecuniary effects and whether these can be captured by the private sector. They say (p.264) that to '... the extent that such benefits can be captured, the public sector should not be involved in such research and development activities'.

Attention also needs to be given to the important question of returns on agricultural *research services.* As the potential for increasing output or decreasing costs through R&D, declines, so the demand for (research) services which can improve profitability indirectly, increases. Commodity R&D institutes especially, serving the producers of a single product, are likely to devote as much or more resources to services than to research *per se* (Donovan, 1986). There are many agricultural research services that are not public goods and consequently, should be provided by the private sector which includes associations of producers. The advantage of private production and provision of services is that they are then subject to the '... incorruptible judgement of that unbribable tribunal, the account of profit and loss. Thus the question of *who* should perform agricultural research - the private or the public sector - warrants more study' (Pasour & Johnson, 1982 p.313).

When the main interest is in the viability of producers, it should be a relatively easy task to estimate the private gain from agricultural R&D, leaving the associated social benefit (of secondary concern in this situation) to be estimated by remainder, difference or assumption.
However, Wise (1981 p.151-152) points out that the '... effect of technological change can be profound, and several groups need to be considered ...

(i) consumers,
(ii) producers who do not adopt new technology and who move to another sector,
(iii) producers who adopt new technology, and
(iv) producers who do not adopt new technology but will continue to produce the commodity in question'.

It is, therefore, necessary for the purposes of this study to define *producers* more specifically as the corporate bodies representing those producing agricultural commodities.

The other reason for R&D evaluation has been to improve the allocation of increasingly scarce resources for R&D. Again, when it is public monies being allocated, it is appropriate that techniques should be developed to compare the returns on investment *between* different R&D portfolios. Because the data available for such studies is invariably aggregated and sometimes even secondary (or derived) data, studies of this type have not given much attention to the allocation of resources *within* R&D portfolios. Some work has been done on project evaluation that has led to estimates of project ranking or priority rating and while this may indicate where the resource threshold is, it does not provide management with quantitative information that is needed to make better decisions on projects and programmes above the threshold boundary.

As described earlier, R&D evaluation is most commonly grouped into three main categories, the ex-post, ex-ante and 'public-relations' approaches. Evenson (1981), however, prefers a classification based on method of evaluation and his first taxonomic distinction is between *average rate of return* and *marginal rate of return* methods. Since it is the kind and amount of data available that usually determined the choice of method of analysis, Evenson's classification seems more practical. However, it is his call for R&D evaluation methods which allow *separate assessment of the returns on commodity, disciplinary and maintenance research*, that is particularly valuable. Unfortunately there appear to have been few papers published on this aspect since then. Link (1982) has examined the question of whether the decline in the average annual rate of productivity growth in the United States during the 1960's and 1970's could have been caused by a decline in the productivity of R&D. He presents evidence that the decline in R&D productivity, though real, is misleading because the R&D resources devoted to non-productive activities, particularly towards compliance with environmental protection regulations, increased significantly during that time. A method, therefore, that could apportion the returns on R&D among the different kinds of research activity, as suggested by Evenson, would be advantageous for both policy-makers and R&D managers.

In their concluding comments on agricultural R&D evaluation, Schuh & Tollini (1979 p.53) say 'Methodological developments have probably outrun the availability of data ... and (mere) ... mechanical implementation of a given procedure or procedures could be more dangerous than productive'. Perhaps the most important objective in estimating the returns on R&D is to provide information that can improve decision-making by those responsible for policy or management of R&D. Therefore, the data and methods used in evaluation need to be derived from, or specifically appropriate to, the R&D concerned, bearing in mind that the method of data collection should not '... stifle activity and destroy research entrepreneurship' (Schuh & Tollini *op. cit.*). This must, however, be balanced by the fact that proper, preferably quantitative, assessment of the achievements or value of R&D should be an integral part of the goals of any R&D portfolio, programme or project.

It is not considered necessary, for the purposes of this study, to detail the advantages and disadvantages of the various theoretical methods proposed for estimating returns on R&D, but consideration needs to be given to one general criticism that has often been made and of all methods. The criticism is that the invariably high rates of return obtained surely indicate faulty or inadequate methodology. The rates of return are typically in the range 30 to 70 percent (Appendix 1). Ruttan (1980) points out that some of the earlier estimates of the returns on research (eg: Griliches, 1958) were expressed in terms of external rate of return. In these, the costs and benefits are accumulated to a particular time, sometimes using an interest rate to reflect the opportunity cost of capital. The accumulated costs are taken to be a capital sum while the benefits, accumulated to the same time, are assumed to continue into the future indefinitely. An external rate of return, expressed as a percentage, is then obtained by dividing the accumulated (but continuing) benefits by the accumulated (past) costs. The assumption that the benefits of R&D continue indefinitely, which is not valid in all cases, can lead to the over-estimation of returns. The benefit:cost method of expressing returns on research uses the same procedure, expressing the result as a ratio rather than as a percentage.

Another major criticism of the external rate of return method has been that it does not take into account complementary inputs such as marketing, extension and education costs that are needed to realize the benefits (Wise 1975). Peterson (1971) has also pointed out that the benefit:cost and external rate of return methods are very sensitive to the rate of interest chosen to reflect the opportunity cost of capital. This is not the case with the internal rate of return method which is the rate at which returns have to be discounted to equal costs, at any one time or accumulated to a particular time. The internal rate of return is therefore a preferable measure of return on R&D. Ruttan (1980) has calculated that Griliches' (1958) 743% external rate of return on hybrid corn research (using a 5% opportunity cost for capital), converts to an internal rate of return of 37%. More recent studies, using the index number and production function methods, are based on more refined model specifications, better measurement of costs of both direct and complementary inputs, more complete accounting for distributional implications (such as labour displacement) and have produced better estimates of the return on R&D. In fact Davis (1979), quoted by Ruttan (1980 p.544), found a modest under-estimation of the rate of return in more recent estimates made by Bredahl & Peterson (1976) and others.

Peterson (1971) seriously questions whether an average (internal or external) rate of return is an appropriate measure of return on an investment such as research which involves regular and *ad hoc* marginal decisions on whether to terminate, continue or increase investment. He believes that in the agricultural R&D context the information required is the marginal rate of return on a regular basis.

In spite of these methodological advances and improvements, estimates of the returns on agricultural research remain high when compared with returns on R&D in other fields. This is shown by a comparison of the rates of return in paragraphs 1.1, 1.2 and 1.3 (agricultural) with those in paragraph 1.4 (non-agricultural) of Appendix 1. Oehmke

(1986) suggests that the under-investment in agricultural research which results in high rates of return is due to funding agencies, usually State departments, responding too slowly to the demands of research which, in turn, results in only a few and usually the most 'profitable' problems being researched. Among a number of reasons given by Pasour & Johnson (1982) for the high rate of return is that agricultural research is conducted under monopolistic conditions, that is by a single, protected and bureaucratic firm, again the State in most cases. Private agricultural research institutions often cannot capture the benefits of their research and this leads to under-investment and high rates of return.

In countries with a large agricultural sector, such as the United States, the demand for agricultural products is generally inelastic and the gains from increases in agricultural productivity accrue almost entirely to consumers. In other countries where agriculture is a price-taker on export markets, producers may be the main beneficiaries from research. Where subsidies or price support for producers are based on cost-plus formulae, which is usually the case, the innovative and efficient producers benefit more than the average and below-average producers. It is these above-average producers who tend to be the opinion leaders or who constitute the strongest lobby on political decision-makers. Even under competitive market conditions the innovative and efficient producers benefit from agricultural research for only a short time (until the market is fully supplied) and usually only at considerable extra cost. Under most circumstances, therefore, the under-investment in agricultural research appears to be in the interests of the influential producers and the political decision-makers In a freer-market economy in which subsidies and price supports are only used for security reasons, the producers of each commodity would, corporately decide what level of investment in R&D they consider optimum for their own profitability.

The difficulties of estimating and allocating the so-called *externality costs* of R&D are regarded as major factors responsible for under-estimating research costs and therefore the over-estimation of research benefits. The two best known examples of externality costs are firstly, those borne by society and by the individuals concerned when labour is displaced by machines and, secondly, from the use of agricultural chemicals. Whether R&D should be debited with these externality costs is debatable; in the long term, displaced farm workers probably increase their earning capacity and make a greater contribution to the national product by moving into non-agricultural occupations, albeit with hardship in the short-term. A case can also be made for not debiting the costs of countering the effects of agricultural chemicals, solely or at all, to agricultural R&D. Chemicals have been a major factor in increasing yields per unit area of land, a policy deliberately encouraged by price supports and subsidies, to feed larger populations, to offset the loss of land to urbanisation and to raise the quality of agricultural produce. Without official encouragement the rapid, and sometimes injudicious, use of agricultural chemicals might well have been much more cautious, especially because their use increases costs of production. When the objective of R&D is to maximize social welfare it is undoubtedly important to include the costs of external effects of the research programmes. However, in any estimate of returns on agricultural commodity R&D where the objective is to improve the profitability of its producers, it is only necessary to include the costs and returns that affect producers' profit margins (O'Riordan, 1980).

Spill-over effects have been noted as a source of considerable error in estimates of R&D returns. A spill-over is the free use, in one area, of research results produced and paid for, in another area. In spite of the location-specific nature of most applied agricultural research results, more so with crop than animal commodities, and in spite of the number and distribution of experiment stations in the United States, Bredahl & Peterson (1976) and Evenson *et al* (1979) have indicated significant spill-over effects.

CONCLUSIONS

* It would seem that little in the literature on research evaluation can be of direct use in deriving a practical method for estimating the return on agricultural commodity R&D, particularly when the estimates are required to improve policy and management decision-making at portfolio and programme level.

However, a number of studies reported in the literature will be of considerable indirect value in this quest.

* Within a single R&D portfolio ex-post methods of evaluation would probably be more valuable for higher level decision-making and ex-ante methods more valuable for lower decision-making. This is because at the higher level there is likely to be only a small proportion of *new* project proposals in the total portfolio whereas at the lower levels, new projects could make up a high proportion of the total decision-making required.
* When the total (social) benefits of agricultural R&D in an aggregated form are being estimated by the economic surplus method, it is important to take elasticities of supply and demand into account. When, however, the returns to R&D applied to a single commodity are being estimated, the use of the economic surplus method is probably less suitable than other methods because of the difficulties in quantifying the effects of various controls on production, both domestic and international.
* Production function methods are likely to be preferred for estimating the value of new varieties or specific technological advances.
* Methods of estimating the cost-saving value of R&D will probably prove as important as methods of estimating the value of production-increasing R&D, except perhaps in the case of new varieties.
* The 'Public Relations' approach is so called because R&D funds usually have to be obtained from the public purse in competition with other, and sometimes higher, social priorities. Because commodity R&D, in the context of the present study, is usually funded by producers and not by the public, it would be more appropriate to describe this approach as *expert accounting*, and, it is a method likely to be useful for estimating returns at programme and project levels of decision-making.
* Since this study is concerned primarily with the private returns on agricultural R&D, the inclusion of spill-over and externality factors in the equation is not considered as important as it would be if total social returns were being estimated.
* In estimates of the social returns on public sector expenditure it may be important to account for market distortions such as support programmes, price controls and production quotas.

However, for estimating returns on R&D on private sector investments (as is the case of agricultural commodity R&D), actual or projected market prices should be used because they represent the true costs of resources to the 'firm'. The incidental social benefits such as foreign currency earnings on exports, increased employment opportunities, higher rural productivity as well as the indirect benefits of employee housing, medical aid and pensions, should be noted and acknowledged as the commodities' contribution towards the cost of infra-structural facilities that are important for any viable industry.

* The final conclusion in this review of the literature on estimating returns from agricultural R&D, particularly in the case of a single commodity, can best be expressed in the words of Arnt & Ruttan (1977 p.23) 'Economic analysis at present, yields only gross indications of the consequences from various choices. More data on the appropriation of research benefits and on the research cost function, in addition to further theoretical development and empirical testing of models, are needed to improve decision-making tools'.

The likely suitability of various methods of estimating the returns on R&D and services, provided by an agricultural commodity institute, is considered to be as shown in Figure 4. Three of the five methods are capable of estimating returns down to at least programme level (the minimum requirement for management purposes) but only two of these methods, production function analysis and expert accounting - or a combination of the two - are likely to be suitable for routine use in an agricultural commodity R&D institute.

Appendix 1 brings together from the literature, and other sources, over 240 individual estimates of returns on agricultural R&D and research services. Data on 21 commodities from 19 countries or regions, as well as 95 results on pest, disease and other research projects, and on agriculture in aggregate, are presented. When known, the results have been arranged by method of evaluation, with the effects of lag and extension on research, given. For comparison, 35 estimates of returns on non-agricultural investment in industrial innovation and training, water resource development, urban renewal and transport projects, are also quoted.

<table>
<tr><th rowspan="2">Methods of estimating returns</th><th rowspan="2">*</th><th colspan="3">Commodity R&D and services</th></tr>
<tr><th>Whole portfolio</th><th>Individual programmes</th><th>Separate projects</th></tr>
<tr><td rowspan="2">ECONOMIC SURPLUS</td><td>A</td><td rowspan="2">Yes within limitations of price and production controls</td><td>No</td><td>No</td></tr>
<tr><td>P</td><td>No</td><td>No</td></tr>
<tr><td rowspan="2">PRODUCTION FUNCTION</td><td>A</td><td>Yes with expert forecasting</td><td>No</td><td>No</td></tr>
<tr><td>P</td><td>Yes</td><td>Yes By decomposition of portfolio function</td><td>Possibly By decomposition of program function</td></tr>
<tr><td rowspan="2">EXPERT ACCOUNTING & SCORING MODELS</td><td>A</td><td rowspan="2">Yes By programme simulation</td><td rowspan="2">Yes By project simulation</td><td>Yes</td></tr>
<tr><td>P</td><td>Yes</td></tr>
<tr><td>IMPACT ANALYSIS</td><td>P</td><td>Possibly if social data available</td><td>No</td><td>No</td></tr>
<tr><td rowspan="2">SIMULATION AND MATH. MODELS</td><td rowspan="2">A</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td colspan="3">Only with expert forecasting</td></tr>
</table>

* A = Ex-ante P = Ex-post

Figure 4 : Comparison of methods for estimating returns on R&D in an agricultural commodity research institute.

CHAPTER 2

PREVIOUS ESTIMATES OF RETURNS ON SUGARCANE R&D

The conclusion reached in Chapter 1 that the estimation of returns on agricultural commodity R&D. by economic analysis methods, is impractical for management purposes, poses the question whether the comprehensive and detailed data available on production in the South African Sugar Industry, might be suitable for the derivation of an empirical method of estimating returns on sugarcane R&D.
Before investigating this possibility, the results of only three previous estimates of the returns on sugar cane R&D, are considered in this chapter. The first two of these estimates, by Evenson (1969) and Evenson *et al* (1970), were incidental to Evenson's attempt to identify and quantify technology transfer between countries. The third estimate of the returns on R&D was part of an assessment of the cost effectiveness of the SASA Experiment Station (SASA Experiment Station, 1983).

Evenson's marginal and internal rates of return. Evenson used sugarcane in his study of technology transfer between countries because data were readily available in a number of cane growing countries on increased production resulting from the exchange of varieties between them. Furthermore he believed, correctly at that time, that in the case of sugarcane, improved production technology had, very largely, been embodied in new varieties, particularly their disease resistance or tolerance and therefore higher production potential.
Evenson used, amongst others, data comparing industry yields before, during and after the replacement of older varieties, principally Uba, with the newer varieties imported from India and Indonesia. These data had been published in the SA Sugar Yearbooks for 1935/36, 1948/49 and 1961/62.

For the purposes of estimating returns on R&D Evenson categorised sugarcane varieties into four stages of development which, for South Africa, he gave the following time scale. In Table 1 the column for typical varieties has been added.

Table 1: Development stages and periods of South African sugar-cane varieties (after Evenson) with typical varieties.

Development stages	Period	Typical varieties
Stage 1 'Wild' varieties imported from Java, Mauritius and India.	1849	Green Natal, Bourbon, Gold Dust, Louisier, China Cane, Uba (1883).
Stage 2 Imported 'nobel' cane varieties.	1925	Co 281, Co 290. Co 301, Co 331, POJ 2714, POJ 2725, POJ 2727, POJ 2728.
Stage 3 Inter-specific crosses bred for local general conditions.	1945	NCo 310 (1945), NCo 291, NCo 293, NCo 376 (1955).
Stage 4 Systematic breeding for specific local conditions and characteristics.	1959	N50/211 (1959), N55/805. N52/219, J59/3, N7 (1973), N8, N11, N13, N14, N15, N16, N20 (1987).

Using yield data for the 1935 - 1939 period, when Uba was being replaced by Stage 2 and 3 varieties, Evenson (*op. cit.* p.224) estimated a 40% increase in yield but after correcting for ratoon decline, the advantage of the newer varieties was reduced to 27%.

Using comparable data for the 1954 - 1957 period, Evenson found a 28% advantage for the locally bred Stage 4 varieties which were replacing the imported Stage 3 varieties at that time. The comparisons were made in terms of sucrose yield because much of the advantage of the newer varieties was due to their higher sucrose percent cane. Evenson expressed the varietal change from year to year as the *varietal turnover*, the adoption rate of a new variety as the time taken by a new variety to reach its peak usage and the relationship between plant breeding activity and adoption rate as the number of plant breeders per unit of varietal turnover.
From the yield data and these derived indices Evenson estimated the return on investment in cane breeding at the Experiment Station in two ways: first, the marginal return on additional investment in the programme and second, the internal rate of return on the current investment in the programme.

The marginal return on investing an additional $7 000 (the cost of a plant breeder in 1931) was estimated at $12 000 to $15 000 in South Africa. Evenson based this estimate on a varietal turnover of 0,11% per annum which resulted in a yield increase of 0,02 tons sucrose per acre at that time. He pointed out that this estimate needed downward adjustment for cane age distribution which he could not do with the data available.

Evenson (*op. cit.* p.226) estimated a 40% internal rate of return on investment in cane breeding at the Experiment Station for the period 1954 - 1959. He computed the rate of return from the cost of research per unit of varietal turnover and assumed that costs remained constant during that period and that the research lag was eight years.

Evenson's average rate of return. The second estimate of the returns on sugarcane R&D was made by Evenson *et al* (1970). Using Griliches' (1958) technique and the same data source as before (Evenson, 1969), the Experiment Station's costs were accumulated to 1945 at an interest rate of six percent and a flow of annual benefits was calculated from the supply function shift. The resultant benefit was found to be 2,47 times the accumulated research costs up to 1945. This can be interpreted as an average rate of return of 147% on the investment in research up to that time. The authors point out certain reservations in accepting this return at face value; the first of these is that the Experiment Station was probably not exclusively, or alone, responsible for the production of the new varieties. Secondly the production from new varieties shifts not only the supply and demand function of its own economy but also those of other economies with consequent back-firing effects, particularly in a free-market situation. These reservations have been noted repeatedly in the literature as being responsible, among other factors, for the over-estimate of returns on research.

THE EXPERIMENT STATION'S COST EFFECTIVENESS EXERCISE.

A third, unpublished, estimate of the returns on sugarcane R&D was made by the SASA Experiment Station (1983) when it undertook an assessment of the cost effectiveness of its activities in 1983/84.

An assessment of cost-effectiveness is an administrative procedure carried out to satisfy an organisation's policy-makers that the resources provided are being used to good advantage in the pursuit of the organisation's goals (Schuh & Tollini, 1979). In contra-distinction, estimates of returns on R&D are of particular interest to a research organisation's senior management who have to make frequent decisions on, and choices between, research programmes and projects.

The Experiment Station's cost-effectiveness assessment does, however, provide useful experience in certain aspects of estimating returns on R&D. With the exception of six projects (Republic of South Africa, 1987), conducted at Universities primarily for academic purposes, all sugarcane production R&D in South Africa is carried out by the SASA Experiment Station at Mount Edgecombe. The total and departmental expenditure on sugarcane R&D can, therefore, be obtained directly and accurately from the Experiment Station's accounting records kept for annual audit purposes. The sub-division of departmental costs among portfolios requires subjective assessment by appropriate members of staff and can therefore only be estimates. For the cost-effectiveness exercise conducted in 1983 it was not considered feasible to further sub-divide portfolio costs among programmes and projects (of which there were 300 at that time) because this could also only have been done subjectively and with even less accuracy.

Two years later, in 1985, in a study of management at the Experiment Station for which accurate estimates of costs of departmental services, functions and R&D programmes were required, a survey of technologists' use of time was undertaken (Donovan, 1986). The survey was structured to allow the analysis of time, and therefore costs, of the first stage breakdown of portolios into programmes. A comparison of some of the results obtained in the 1983 cost-effectiveness exercise and the 1985 time-use survey are given in the following tables.

It is not possible to compare actual expenditure in the two years; not only were the departmental totals different but the number and emphases on programmes had changed in the interim. Tables 2, 3 and 4 express the costs of programmes as percentages of total departmental expenditure.

Table 2: Comparison of methods for allocating costs to programmes in the Chemistry & Soils department of the SASA Experiment Station, expressed as percentages of total departmental costs.

1985 Time-use survey	%	%	1983 Cost-effectiveness estimates
Services:	45,9	60,0	
Fertilizer advisory	32,4	60,0	Fertilizer advisory service
Specialist advisory	6,0		
Education	7,5		
Functions:*	24,8	18,0	
Millroom operation	19,6	18,0	Millrooms
Liaison	2,0		
Congresses	3,2		
Research Programmes:	29,3	22,0	
Potassium nutrition	7,2	12,0	Analytical chemistry
Foliar analysis	0,5	10,0	Soil physics
Nutrition bulletin	0,5		
Infra-red analysis	3,4		
Universal soil extractant	1,3		
Sulphur	0,6		
Soil P availability	0,3		
Acid chlorosis	4,0		
Computerization	0,4		
Micro-nutrients	0,1		
Drainage	4,2		
Compaction	1,7		
Mid-Ecca and Dwyka	1,6		
Salinity	2,5		
Laboratory manual	0,3		
Co-ordinated projects	0,7		
	100,0	100,0	

* Most of the activities classified under *functions* in this survey have been described as maintenance research in other studies.

Table 2 shows that for the Department of Chemistry & Soils, a department committed fairly equally to all three categories of activity, namely, services, functions and research, the 1983 estimates of programme costs made by informed staff, were reasonably accurate. The perception of the senior members of staff, who did the estimating, seemed to be that services took up more time than, in fact, was the case (60% v 46%). This could be construed as the natural reaction of scientists to routine activities.

This contrasts strongly with a department, of which Agronomy is the example given in Table 3 , in which traditionally, research has been regarded as the major commitment. The 1983 subjective estimates, made by senior members of staff in the department clearly show the conceptual bias in favour of the department's main activity, research, while the other activities, were (presumably subconsciously) underestimated to the extent of being omitted. It should be noted, however, that *Inter-departmental cooperation* and *Congresses* are concerned more with research than with other categories of activity.

Table 3: Comparison of methods for allocating costs to programmes in the Agronomy department of the SASA Experiment Station, expressed as percentages of total departmental costs.

1985 Time-use survey	%	%	1983 Cost-effectiveness estimates
Services:	3,2	–	
Specialist advice	2,2		
Education	0,8		
Seed nurseries	0,2		
Functions:	15,1	–	
Inter-dept cooperation	8,4		
Liaison	4,2		
Congresses	2,5		
Research Programmes:	81,7	100,0	
Herbicides & Weeds	22,9	24.0	Herbicides & Weeds
Varieties	24,8	20,0	Varieties
Nematicides	9,0	12,0	Nematicides
Growth regulators	4,1	12,0	Growth regulators
Nutrition	12,4		
Trashing	0,9		
Planting systems	1,4		
Trickle irrigation	1,7	24,0	'General' research
Soil amelioration	2,6		
Coordinated projects	1,6		
Lysimeter project	0,3		
		5,0	Moisture stress
		3,0	Swaziland projects
	100,0	100,0	

The third example is given in Table 4 for the Plant Breeding (Crossing) department which provides no services and in which departmental functions and research programmes have a common objective and in which all activities are controlled by a single technologist. Under these circumstances the subjective and survey estimates are shown to be very close.

Table 4: Comparison of methods for allocating costs to programmes in the Plant Breeding (Crossing) department of the SASA Experiment Station, expressed as percentages of total depatmental costs.

1985 Time-use survey	%	%	1983 Cost-effectiveness estimates
Services:	-	-	
Functions:	70,8	72,6	Crossing and Breeding
Crossing/Breeding	70,8		
Research Programmes:	29,2	27,4	Breeding research
Flowering & Fertility	3,3		
Breeding performance	3,8		
Seed set	0,9		
Seed storage	2,6		
Recurrent selection	0,7		
Coordinated projects	17,9		
	100,0	100,0	

These comparisons emphasise the importance of having, or collecting, data specific to the purpose for which they are required. The objective of the cost-effectiveness exercise was to assess for the information of policy-makers, the efficiency of resource utilization in pursuing the organisation's goals (Appendix 2). For this purpose accurate data on costs, available from the organisation's accounts, and some subjective estimates were adequate. In the case of the 1985 time-use survey, the objective was to provide information, in the form of costs of services, functions and research programmes that could improve senior management's decision-making on strategy. For this purpose the breakdown of portfolio costs into services, functions and research programmes was not available from the accounts and could not (as has been shown) be estimated accurately other than by a survey structured for that purpose.

In the 1983 cost-effectiveness exercise, the public relations, or *expert accounting*, method was used to estimate the benefits resulting from the Experiment Station's activities and four different approaches to the method were employed, examples of which follow:

Cost-saving approach. One of the Experiment Station's goals is to provide growers with advice on the use of machines and equipment used in sugarcane production (Appendix 2, item 2c). The estimate of the potential benefit resulting from this advice was made in the following way:

- Costs of mechanisation comprise 30% of total cane production costs which average R16 per ton (SA Cane Growers' Association, 1983).

- On a *normal* crop of 20 million tons growers spend, therefore, Rm96 on mechanisation maintenance each year.

- If the estimate of costs saved by growers who use the Experiment Station's advice is taken to be only 1%, the total saving would be R960 000 per annum.

The return of R960 000 on portfolio 2c (Appendix 2) is therefore estimated to have been obtained on an investment of R289 000 in that section of the Agricultural Engineering department responsible for providing advice on mechanisation and equipment. This is an average return of 232% or a benefit-cost ratio of 3,3.

Yield-increasing approach. The Experiment Station's research programme on nematicides (Appendix 2, item 3a) has led to improvements in crop yield and the benefit of this work was estimated in the following way:

- On about 20% of the soils growing sugarcane, a minimum yield increase of 25% has been obtained from the correct use of nematicides and appropriate associated agronomic practices that have been determined by field experimentation.

- On a normal crop of 20 million tons grown at a cost of R16 per ton the potential annual benefit of the Experiment Station's nematicide research programme can be calculated as: (20 000 000 x R 16 x 20 x 0,25)/(100 x 100) = R160 000.

With a cost of R55 000 per annum, the estimated average rate of return on this reserarch programme is therefore 191% and the benefit-cost ratio is 2,91.

Another example of the *yield-increasing approach* was in the estimate of the benefit of plant breeding. Experimental data were available to indicate the yield increases due to the five most recently released varieties. Using the assumptions that:

- growers achieve only half the increase obtained in field trials, and that

- only one in four growers change to a new variety in any one year,

the return on the plant breeding programme was estimated to be Rm4 for an investment of R851 000 in that particular year, an average rate of return of 370% and a benefit-cost ratio of 4,7.

Insurance approach. An arbitrary division was made of total plant breeding costs, allocating R638 000 to yield-increasing activities (discussed in the previous paragraph) and R213 000 to activities against yield decline. If the latter amount is regarded as the cost of insurance against yield decline, it represents a premium of 0,05% of the value of the crop which was considered a satisfactory investment to the benefit of the whole sugarcane growing industry. If the breeding costs had not been divided between yield-increasing activities and yield decline insurance, the average rate of return and benefit-cost ratios for plant breeding would decline from 494% and 5,9 to 370% and 4,4 respectively.

A second example of the insurance approach to estimate returns on R&D was used in the Experiment Station's cost-effectiveness exercise. The expenditure of R392 000 by the Agricultural Engineering department on the development of labour-saving machines and devices can be regarded as insurance against future labour shortages. This equates to a premium of 0,1% which, compared with other insurance premiums such as 0,09% for cane fire insurance, can also be regarded as satisfactory.

Intuitive approach. That extension is one of the Experiment Station's most important activities was indicated by Donovan's (1986, p.96) finding that expenditure on this portfolio was the highest (17,9%) in 1985/86, followed closely by plant breeding (16,6%), with training (10,5%) third highest. The return on the investment in extension was, for the purposes of the cost-effectiveness exercise, intuitively assumed to be half the return estimated for all R&D yield-increasing programmes on the basis that without adoption, through extension action, research results would have no value at all. The cost of extension and education was R865 000 and the return, estimated in that way, was Rm2,01, an average rate of return of 170,6% or a benefit-cost ratio of 2.4.

The relative importance of the four approaches used in the cost-effectiveness exercise is indicated in Table 5 and the conclusions drawn were as follows (SASA Experiment Station, 1983 p.32):

'Because figures used in this report have necessarily been based on the estimates that could be unacceptably inaccurate, it would be useful to compare some results of the calculations with an entirely independent figure. An analysis of industrial sugar production over the past thirty years has been conducted and the effects of rainfall have been taken into account. The outcome has been a linear relationship between yield and time which indicates that yields per hectare are currently increasing at the rate of 1,4% per annum. (An alternative assessment, which takes into account the change in mapping principles concerning the size of breaks that are included in the area of the field, indicates that the increase to be about 3%)'. The total benefit estimated in the cost-effectiveness exercise, expressed as a percentage of the gross value of the agricultural product, suggests an increase of 2,1%. 'Neither the 1,4%, the 3,0% nor this 2,1% is purported to be a necessarily accurate figure ... The pertinent conclusion may be that, whether the 1,4% is more or less accurate than 3% or 2,1%, all three figures would still indicate that the Station's activities are likely to be creditably cost effective'.

Table 5: Summary of SASA Experiment Station's estimates of returns on expenditure in 1983 classified by approaches used in assessments.

Approach used to assess benefits	Programmes and activities	% of Experiment Station total		Average return %	B - C ratio
		Cost	Benefit		
Cost-saving	Mechanisation & machinery developments, Civil works, Farm planning (50%), Herbicides & Weeds (50%), Growth regulators (40%), General research, Fertilizer advisory service, Training.	28	39	189	2,9
Yield-increasing	Farm planning (50%), Irrigation & Drainage, Herbicides & Weeds (50%), Growth regulators (60%), Nematicides, Variety choice, Plant breeding, Entomology advice, Pathology advice.	27	31	150	2,5
Insurance	Against yield decline, Against labour shortage.	6 3	= premium 0,05% = premium 0,10%		
Intuitive	Extension & Education, Pest & Disease control.	26	29	158	2,6
	Basic research	10	--	--	--
	Experiment Station total:	100	100	133	2,3

Estimates of benefit-cost ratios for individual programmes, functions and services calculated in the Experiment Station's cost-effectiveness exercise are listed in paragraph 1.3 of Appendix 1.

CONCLUSIONS

The previous estimates of the returns on sugarcane R&D, discussed in this chapter, were derived from data of different periods and using different methodologies. Notwithstanding these differences, it is informative to compare the results obtained and shown in Table 6.

Table 6: Comparison of previous estimates of returns on sugarcane R&D.

Methods of expressing returns and subject of R&D	Data reported by Evenson (1969) and Evenson *et al* (1970)	SASA Experiment Station (1983) Cost Effectiveness exercise
Benefit:Cost ratio of plant breeding	-	4,4
Internal rate of return on plant breeding (%)	40 (8 yr lag)	37,5 (no lag)
Percentage increase in yield of new varieties over old	1935-39: 27 1954-57: 28	1983: 16
Marginal rate of return on plant breeding (%)	70 - 115	-
Average rate of return on all R&D (%)	147	133

The importance of using all relevant data, particularly age of cane at harvest and rainfall, is illustrated in Table 7. Evenson (1969) employed the production function approach to estimate returns on the SASA Experiment Station's plant breeding programme but had available data only on cane yields per acre (Table 7, column 1). If all cane had been harvested at the age of 24 months, which was the average harvest age at that time, Evenson's yields would have been, in terms of cane per acre per annum (column 2), a better comparison with the yields estimated with all yield influencing factors taken into account (column 3).

Table 7: **South African sugarcane yields used by Evenson (1969) and those estimated from all relevant data.** (Short tons per acre).

Periods	Evenson's yields		Complete data yields
	as used	as per acre per annum	
1923 - 1924	8,8	4.4	7,9
1928 - 1932	20,5	10.25	11,1
1938 - 1942	26,3	13,15	13,3
1948 - 1952	25,1	12,55	13,1
1958 - 1962	35,3	17,85	15,0

Comparisons of yields and returns on R&D should, therefore, be made in the knowledge that criteria and conditions used in the different estimates, are likely to differ, with results demonstrated in Table 7.

The SASA Experiment Station (1983) cost-effectiveness study estimated the ex-post returns on R&D in terms of benefit:cost ratios for its various programmes and for the Station as a whole. These estimates are undoubtedly more accurate than Evenson's but they still have, for management purposes, the shortcomings of:-

+ representing the situation at only one time,
+ relying on subjective assessments of R&D returns, and probably most important of all, of
+ having no direct and quantitative relationship with the changes in production levels brought about by the R&D generated.

A major objective of the present study is, therefore, to estimate returns on sugarcane R&D that, if possible, overcome the shortcomings of previous exercises and in particular relates the returns on R&D to changes in sucrose production over time. To this end, an attempt is made, in the next chapter, to quantify the contribution of technology (the product of research) to the increase in the industry's total productivity.

CHAPTER 3

ESTIMATING PRODUCTIVITY INCREASES IN THE SOUTH AFRICAN SUGAR INDUSTRY

Increases in the production of sucrose on a per unit area basis, in the South African Sugar Industry, must be attributable to a number of factors of which technology is only one. Acceptable estimates of these increases will depend on the availability and reliability of data on the relevant factors.

DATA AVAILABILITY

Recording of sugar production data appears to have started in 1862 (South African Sugar Journal Annual, 1925 p.29) some twelve years after the first sugarcane crop had been harvested, but until 1920/21 (South African Sugar Journal Annual, 1927/28 p.15) records are not available on age of cane at harvest or the area under cane, one of which is needed to calculate a yield per unit area per annum. 'To obtain the actual area under cane ... the (area harvested) should be doubled, especially for the years after 1899 when (the variety) Uba, requiring an average of 22 months to mature, became the standard variety' (Anon. 1924).

There is also circumstantial evidence that the average age of cane at harvest was usually more than 24 months. In Appendix 3 the area under cane has been obtained by doubling the area harvested except for the two seasons 1921/22 and 1922/23. The actual area under cane in these two seasons was recorded at the time and therefore their per hectare per annum yields can be regarded as acceptably accurate. The generally higher yields obtained for the other years is probably due to the underestimate of the area under cane if age at harvest is taken to be 24 months when it was often older. However, in the absence of more definite and reliable evidence on cane age at harvest, it is considered preferable to overestimate yields from 1862 and until cane age at harvest became available, than to arbitrarily choose another age at harvest.

The earliest rainfall records available were those started by Natal Estates in 1881 and which are, until the early 1920s, the only data available to represent rainfall for the whole industry. However, up to that time most of the cane was grown relatively close to the Natal Estates rainfall recording site. From 1923/24 the Sugar Association published rainfall records in the Sugar Journal and since 1966 the Experiment Station has been responsible for collecting and collating the Industry's climate data. In 1954 there were 54 sites recording rainfall for the Industry and today there are 70, many with more than 60 years of data. The Industry Mean rainfall is calculated as the arithmetic mean for all recording stations (SASA Experiment Station, 1988a).

Since 1925/26, the year the Experiment Station was founded, records of the following potential yield influencing factors are available (South African Cane Growers' Association, 1988 and SASA Experiment Station Annual Reports):

* Rain in millimetres,
* Land, as hectares under cane,
* Price, expressed as rand per metric ton of sucrose paid to growers,
* Technology, represented by the Experiment Station's net expenditure in rand per hectare under cane.

Since 1936/37 records are also available, in terms of rands per hectare, on the following yield influencing factors (South African Cane Growers' Association, 1988):

* Capital invested in cane growing,
* Net farm income,
* Costs of all production inputs (except labour), and
* Labour, as numbers employed in cane production.

Other variables for which data are available, or can be derived, from Experiment Station records are:

* Varieties, in terms of a yield index calculated from comparative yields and area grown.

* Extension, also in terms of an index based on hectares under cane per extension worker.
* Training, in terms of numbers trained for which data are available only since 1976.
* Fertilizers, in terms of kilograms per hectare (of all types and mixtures) used.

In addition, South African Cane Growers' Association have records of tons of cane cut per labour unit but these have not been used as an indication of labour productivity because their interpretation is complicated by the practice of using casual labour, especially in cutting cane.

SOURCES OF TECHNOLOGY

Since the main objective of this study is to evaluate returns on research and development in the South African Sugar Industry, it is necessary to determine, as far as possible, the sources of technology used in the production of cane.

Pretechnology era, 1848 - 1890. For the first fifty years of cane production in South Africa, that is until about 1890, when the recording of rainfall started and the variety Uba became dominant, improvement in the yield of sugarcane was due almost exclusively to the innate skills of cane growers. There are records of the introduction of sugar-making machinery and visits by persons with experience in sugar manufacture during this period (Osborn, 1964) but only craft skills seem to have been available on the production of sugarcane. Craft skill has been described as 'early technology' in which production methods are used without precise knowledge of how or why they are followed (Bannock *et al*, 1985). They are skills acquired by the diffusion of knowledge from generation to generation and among those working within an industry and not by formal or organised R&D.

By 1890 only a few varieties, obtained fortuitously rather than selected scientifically, had been introduced for cane growing in South Africa. These came mostly from Mauritius and Reunion and were described as '... ill adapted to the lower average rainfall, frequent droughts and nearly all cane diseases ...' (Dodds, nd p.26). Uba had been introduced, probably from India (Anon, 1925), only seven years previously and did not become the major variety in the Industry until about 1890. It was also unlikely that any other improved production technology had been purposefully and scientifically introduced by then.

The area and production data for the Pretechnology era, together with the derived sugar yields, are given in Appendix 3. Because records of rainfall and other yield influencing factors are not available for this period, a plot of the annual yields and the five-year moving average yield, shown in Figure 5 below, is probably the best way of representing the yield trend for that period.

Figure 5: Trend of sugar yield, 1862 - 1890.
(Data from Appendix 3)

Figure 5 illustrates the typical pattern of development of an introduced crop, or of an existing crop whose area of production is rapidly increased. In the early years, as growers gain familiarity with the crop and as production skills improve, there is an increase in yields followed by a yield plateau and finally a decline in yield as pests and diseases (in this case particularly mosaic) multiply on a new and concentrated host which usually has no inherent resistance to local pests and diseases.

From the limited and approximate data available, the yield of sugar appears to have increased from 0,5 tons to about 1,5 tons per hectare per annum. A number of yield influencing factors were probably responsible for this increase in productivity but craft skills must have been the major factor because few others were likely to have been favourable.

Imported technology era, 1890 - 1924. The improvement in both production and milling performance achieved by the Sugar Industry during the next 35 years (1890 - 1924), before there was any locally generated technology, must be attributed to the technology imported from other cane growing countries. This imported technology consisted primarily of varieties, mill design and components as well as methods of agricultural and mill production brought in as personal knowledge and experience.

Of these imported technologies, varieties, particularly Uba, were probably the main contributors to increased productivity. There is justification for this view in terms of milling technology, as well as in terms of cane production technology, because most of the early milling difficulties were related to the varietal characteristics of Uba (Anon, 1924) that became the principal variety grown for nearly fifty years, between 1890 and 1937.

The data for sugar production in the era of imported technology are given in Appendix 4. The only independent variable influencing yield, for which data are available in the period, is rainfall. However, the outputs of regression analyses given in Table 8 do not indicate significant correlation between rainfall expressed in different ways, and yield. The likely reasons for the poor correlations are that rainfall and yield records for the period are not considered accurate, rainfall recorded at a single site represented the whole cane growing area and the six-fold increase in area under cane, in only 35 years, with the consequent high proportion of new land, probably resulted in high yield variability.

In spite of high collinearity between the X_2 and X_3 factors in the equation, the latter was included to indicate a quadratic response which could result from yield depression in higher rainfall seasons.

Table 8: Results of regression analyses of yield (tons sucrose/ha/annum), on rainfall (mm), 1890 - 1925. with data from 1910 to 1918 missing.

Regression output	Rainfall factor expressed as		
	Current year rainfall	Previous year rainfall	2-year mean rainfall
Constant	0,8732	1,7183	1,4737
X_1 - time (year - 1900) t-value	0,0188 2,14	0,0226 1,70	0,0241 1,89
X_2 - mean rainfall/100 t-value	0,1659 0,61	- 0,0613 0,16	- 0,0147 0,02
X_3 - mean rainfall^2/100 t-value	- 0,0059 0,59	0,0041 0,24	0,0020 0,05
S error of yield estimate	0,5822	0,5939	0,6142
R^2	0,1983	0,2069	0,1801
df	20	19	18

As was the case in the Pretechnology era (1862 - 1890), a plot of actual rainfall and the five-year moving average, as shown in Figure 5, is probably the best way of representing the yield trend for the Imported technology era (1890 - 1924).

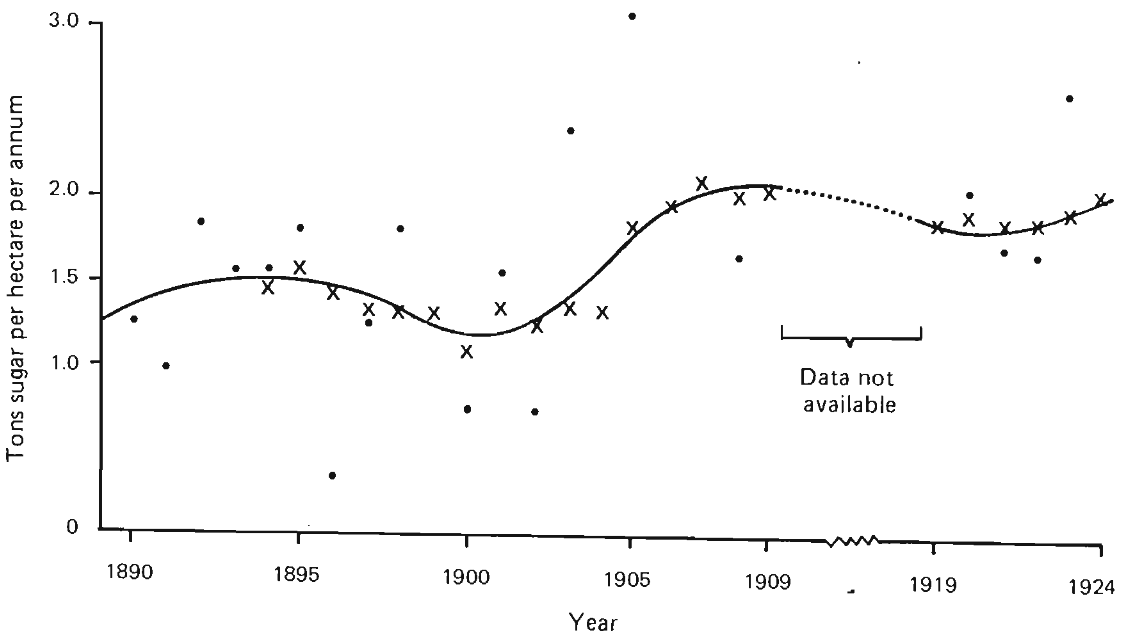

Figure 6: Trend of sugar yield, 1890 - 1924.
(Data from Appendix 4)

During the 35-year period of imported technology the per hectare yield of sugar may be estimated to have increased by approximately one ton, that is, from about 1,5 to 2,5 tons of sugar per hectare per annum which is about the same annual rate of increase achieved during the 28-year pretechnology era. As shown in Figure 6, most of the total yield increase had been achieved halfway through the period, that is by 1907, and thereafter the lack of local technologies to combat diseases, particularly, inhibited further yield increases.

As suggested for the Pretechnology era, a number of factors must have been responsible for the increase in productivity during this era but Imported technology was probably the most important of them.

The patterns of yield change during the Pretechnology and Imported technology eras, shown in Figures 5 and 6 are very similar; an initial increase in yields (due to craft skill and Imported technology in the two eras respectively) followed by static or declining yields as a result of disease.

Technological era, 1925 - 1986. As early as 1875, less than thirty years after the first importation of cane varieties, the slow development of the South African Sugar Industry was attributed to '... lack of familiarity of the proper methods of cultivating an alien cane, (and) the complications of manufacture ...'; other reasons given were the lack of capital, droughts, floods, cane fires and fluctuating prices (Joint Memorandum, 1934 p.12).

Some forty-two years later, in 1917, an eminent visiting agriculturist said of the Industry: 'Scientific assistance in relation to cane growing is very largely absent, and very real need exists for the establishment of some form of agricultural experiment station which shall deal with the agricultural problems of the industry ... if assistance of this description is not forthcoming, and a condition of intelligent co-operation between a properly equipped experiment station and the planters established, the cane growing industry in many localities must be regarded as in very serious jeopardy' (Tempany, 1917 p.14). This was said in spite of some investigations on soils, fertilizers, planting rates and variety testing, in progress at that time on the Winklespruit Experiment Station. That Station, started in 1903, was closed in 1921 because the Sugar Industry considered the site unrepresentative of the sugar belt. It was also decided that '... it had served the purpose for which it had been established, which was to investigate the problems of coastal agriculture in Natal' (SASA Experiment Station, 1975 p.4).

By the mid-1920s the Industry had become aware of the danger of relying on a single variety, Uba. 'This variety had been brought to South Africa during the 1880s and by the end of the century, due to its general hardiness, it was practically the only variety grown. Some 'soft' varieties were introduced in the early 1900s but due to the lack of quarantine facilities they contracted mosaic, which had been brought in on infected cane. Uba was resistant to this disease and in the early 1920s it was therefore still the mainstay of the Industry. However, Uba did not perform in the new sugarcane areas which had been developed in Zululand and there were signs that yields were declining. There was increased concern when this was shown to have been due to another virus disease, streak' (SASA Experiment Station, 1975 p.4).

This prompted the decision to initiate research and development locally and in 1925 the present Experiment Station was established at Mount Edgecombe, some seventy-five years after the first locally produced sugar had been marketed. An equally significant event, certainly at that time, was the erection in the same year, of a quarantine glasshouse in Durban as '... part of the campaign to obtain a replacement for Uba which (would be) ... resistant to mosaic and streak' (*op.cit.* p.5).

The Technological era can, therefore, be considered to have started with the establishment of the Experiment Station at Mount Edgecombe in 1925. However, the effects of research and development at the Experiment Station could not have been felt immediately and it was some time after 1925 that locally generated technology became available to growers.

For example, plant breeding was one of the first disciplines to be initiated at the new Experiment Station yet it was 22 years before a locally bred variety was released. Of all cane production technologies, the breeding of new varieties probably has the longest lag time but other early work at the Experiment Station was undoubtedly available to growers in a much shorter time and had a beneficial influence on productivity.

In order to facilitate R&D evaluation procedures it would be advantageous to define a stage in the generation of local technology when it was no longer necessary to import technologies for direct use locally and when, therefore, the Industry could be regarded as technologically mature. The precision of any attempt to determine such a stage quantitatively would probably be low because the necessary data are unlikely to be available. For a qualitative definition, to be used in this study, it is suggested that once research and development in the South African Sugar Industry had reached a degree of sophistication that it could freely *exchange* technology and was no longer dependent on imported technology, it could be regarded as technologically mature.

In the context of this study, technology exchange is taken to mean the free exchange of knowledge, ideas and material that technologists acquire in the conduct of their own R&D projects and which they exchange with colleagues to their mutual advantage. This implies, not that the exchanged technology has no value, but rather that there is no disadvantage or monetary loss in its exchange. The sophisticated nature of sugar technology and the location-specific nature of most cane production problems today are such that little or no technology exchanged in published papers, at conferences or even as plant breeding material, can be used directly in another locality without considerable additional R&D and adaption to local conditions.

Unhindered technology exchange, to the mutual advantage of all cane growers and millers, was a characteristic of the world's sugar industries until 1986 when South African sugar technologists were refused visas to attend and present papers at the 19th Congress of the International Society of Sugar Technologists held in Jakarta. The mature state of sugar technology in South Africa at that time, and the alternative channels of communication available, meant this restriction probably had a negligible and short-term, effect on technological standards in the local sugar industry, but it served to highlight the difference between imported and exchanged technology that is important in the evaluation of R&D.

It has already been suggested that the most valuable component of technology imported by the South African Industry, until it reached technological maturity, comprised varieties and it, therefore, seems logical to use the local development of varieties as the index of technological maturity. When the Experiment Station was founded in 1925 only the variety Uba was allowed to be grown (as a control measure of the disease mosaic). From 1932/33 this restriction on the growing of varieties other than Uba was removed and five imported varieties, POJ 2725, POJ 2878, Co 281, Co 290 and Co 301 were grown on an increasing scale. In 1944/45 a seventh imported variety, Co 331, was grown for the first time. It was not until 1945, twenty years after the establishment of the Experiment Station, that plant breeding was started but the first locally selected variety, NCo 310, was released in 1947/48. By 1954/55, only seven years later, NCo 310 was grown on half the total area under cane. Thereafter an increasing proportion of the cane area was under locally bred varieties until 1969/70 when imported varieties occupied less than 1% of the area under cane. Two imported varieties persisted in very small quantities until recently, Co 331 until 1975/76 and CB 36/14 until 1983/84; the only other imported variety still grown is J 59/3 which had been introduced from Cuba and was released in 1976. At its peak J 59/3 occupied only 0,5% of the area under cane and appears to be in decline. NCo 310 also became widely grown in other countries and Evenson (1969) reported that NCo 310 ranked tenth in terms of world sugar production between 1940 and 1964. NCo 310 can be regarded as South Africa's first major contribution in the exchange of technology with other sugar producing countries.

It would seem, therefore, appropriate to suggest 1954/55, the season in which locally produced varieties first occupied half the area under cane, as the year the Experiment Station reached technological maturity and no longer had to depend on imported technologies but has been able to exchange technologies freely with other countries' sugar industries to mutual advantage.

ESTIMATING TECHNOLOGICAL ERA PRODUCTIVITY INCREASES

The generation of technology locally, and the collection of relevant data, started with the establishment of the SASA Experiment Station in 1925 from which date estimates can be made of technology's contribution to yield increase per unit area. According to Griliches (1979) productivity, or increase in production per unit area, is best considered in the context of a production function. Ortmann (1985) used production function analysis successfully to determine the major variables influencing sugarcane production in South Africa and a similar approach is followed in the present study, using a Cobb-Douglas production function to measure the productivity in the Sugar Industry due to locally generated technology.

Method of Analysis. A series of analyses was calculated, first to determine the relevance of all independent variables for which data were available (Appendix 5) and thereafter to obtain the best fitting equation for the variables considered relevant. The variables excluded during the first series of analyses and the reasons for so doing are given in Table 9.

Table 9 : **Variables excluded from production function analyses of sucrose production (data from Appendix 5).**

Variable	Form of Data	Reason for exclusion
Varieties	Yield index	Included as expenditure items in the technology variable
Extension	Staff/Area index	
Training	Numbers trained	
Fertilizer	Tons used	Included in production costs variable
Labour	Numbers employed	
Capital	R/ha invested in cane growing	Major component of land variable
Price	R/ton sucrose received by growers	Production controlled by quotas and price determined retrospectively
Net farm income	R/ha under cane	NFI is a function of production costs, area under cane, both of which included, and price.

The independent variables that were found to have significant influences on productivity and therefore included as factors in the analysis of production, are listed in Table 10.

Table 10: Variables and their sources, used in the production function analyses of sucrose production. (Data in Appendix 5).

Variable	Form of Data
Technology	Expenditure by the Experiment Station in rand per annum, adjusted for inflation (1985 = 100).
Rainfall	Millimetres. In all analyses rainfall was non-significant but rainfall x rainfall was highly significant. See page 44 for sources of data.
Production costs	Total of the following costs, in rand per annum, adjusted for inflation (1985 = 100): Labour, including rations; Agricultural chemicals; Fuel, lubricants and maintenance; hired transport; and sundries. These production costs are derived for for the Industry as a whole from a sample of approximately 25% of all growers, stratified by Mill Group areas (18), with some adjustment to improve homogeneity, and into seven farm-size categories (from <40 to >450 hectares) and excluding Miller-cum-planters and cooperatives.
Land	Hectares under cane.

Results of analyses in which the independent variable technology was included at lag periods of nil, three, five, seven, nine and eleven years, are given in Table 11.

The equation with technology lagged three years is the only equation for which the Durbin-Watson statistic exceeds, at the 1% level, the critical upper value indicating that the null hypothesis (that there is no serial correlation) cannot be rejected. For all other equations the Durbin-Watson statistic, at both the 5% and 1% levels, is either inconclusive or rejects the null hypothesis. The t-values also indicate that the three year lag equation is the most appropriate to use in the production function analysis.

Table 11: **Results of production function analysis of sucrose production, tons per annum, at different lengths of technology lag, 1925 - 1986.**

Technology lag period	Independent variables (log form)				Adj R^2	DW	df
	Technology	$Rain^2$	Prodn costs	Land			
Unlagged							
Coefficient	2,729	0,129	0,789	0,120	0,97	1,29	62
t-value	0,29	3,41	5,57	0,45			
3-year lag							
Coefficient	0,215	0,139	0,561	-0,179	0,98	1,73	59
t-value	4,38	4,27	4,24	-0,78			
5-year lag							
Coefficient	0,198	0,146	0,538	-0,085	0,97	1,50	57
t-value	4,14	4,31	3,91	-0,37			
7-year lag							
Coefficient	0,191	0,162	0,512	0,010	0,97	1,47	55
t-value	4,41	5,03	3,87	0,48			
9-year lag							
Coefficient	0.165	0,168	0,498	0,115	0,97	1,23	53
t-value	3,46	4,89	3,50	0,50			
11-year lag							
Coefficient	0,097	0,174	0,430	0,424	0,97	1,39	51
t-value	1,94	5,21	3,00	1,79			

The lack of significance of the Land variable in the analyses, for all lag periods, was not expected and is probably accounted for by collinearity between the Land and Production Costs variables which is, in fact, indicated by the data in Appendix 5.

The positive sign of the Land variable in four of the six analyses, namely for those other than the three- and five-year lag periods, was also not expected because production is usually negatively correlated with area under crop; however, this is probably due to the inclusion of data on production under irrigation where area under cane is usually below average and yields per hectare above average.

The signs of the other independent variables are all positive as would be expected because increasing any of them should increase production. In the case of rainfall and part of production costs, namely that of nitrogenous fertilizer, excessive levels may reduce the yield of sucrose (though not usually of cane).

In considering choice of lag period, estimates of the optimum research lag, obtained in other studies, were taken into account. These are presented in Table 12.

Table 12: Optimum technology lag periods reported in the literature (Donovan, 1986).

Commodity	Lag (years)	Country and reference
Dairy	6	United States Bredahl & Peterson (1970)
Livestock	7	
Cash grains	5	
Corn	6	United States Sunnquist *et al* (1981)
Wheat	6	
Soyabeans	6	
Poultry	5	United States, Norton (1981)
Sugarcane	6	Australia, Evenson (1969)
Hybrid corn	6	United States, Griliches (1958)

Although the optimum lag periods found in other studies are between five and seven years, a three year lag period was chosen in the present study for the following reasons:

* Its statistical significances was higher than for the other lag periods tested.
* The specialised and intensive extension service (which is a major aspect of Sugar Experiment Station policy and activities but not of the studies reported in Table 12), is likely to reduce technology transfer time.
* The high *services : research* ratio which characterises the Experiment Station's operations (but not the others quoted), together with a virtually nil lag time for services, will tend to reduce the overall technology lag time.

increase in productivity due to technology. It is not possible to estimate the factor share of technology, in terms of tons sucrose (or value of sucrose) *per hectare*, from the production function equations used to determine the optimum lag period for technology, as given in Table 11.

Because, however, the returns on individual technological programmes have necessarily to be estimated (later in Chapter 6) in terms of tons sucrose per hectare, the same primary data (Appendix 5) were used in a production function analysis of sucrose yield per hectare, with the objective of using the coefficient for technology to estimate its contribution to yield of sucrose per hectare.

The resulting equation was as follows:

$$\log Y = 0{,}619 + 0{,}234\log X_1 + 0{,}141\log X_2 + 0{,}573\log X_3 - 0{,}496\log X_4 \ldots (1)$$

(t=0,44) (t=4,37) (t=4,32) (t=4,36) (t=-3,46)

Adjusted R^2 = 0,86

DW test = 1,72

df = 54

Where Y = estimated yield of sucrose in tons per hectare;

X_1 = technology, as expenditure on R&D in rand per hectare, lagged three years;

X_2 = annual rainfall in millimetres squared;

X_3 = production costs per hectare, in rand;

X_4 = land under cane in hectares.

All factors are highly significant and their signs are as expected. Whereas in the six analyses of sucrose production (Table 11) the land factor was always non-significant and varied between just positive to just negative, in this analysis of sucrose yield *per hectare*, the land factor is always significant and negative (as expected) because yield is usually negatively correlated with area under crop. Additional land brought into cultivation is often less productive for one or a number of reasons, including lower fertility, greater slope, poorer accessibility, and extended management.

Estimates of the contribution of technology, in terms of tons sucrose per hectare, to the Industry's increases in productivity during the technological era and its six decades, are calculated as the product of the increases in sucrose yield per hectare (predicted by equation

(1) and given in Appendix 6) and the coefficient of the technology factor in the equation, as shown in Table 13. This method of estimating technology's factor share is theoretically only justified under conditions of constant returns but its use to generate comparative information for management purposes is considered acceptable.

This should be tech. share of total yield.

Table 13 : **Return on technology (R&D) at the SASA Experiment Station, as tons sucrose per hectare, during the technological era (1928 - 1985) and its six decades.** (Data in Appendix 5).

Era, Decade or Period	Predicted mean yield of sucrose in tons/ha [Appendix 6]	Increase in sucrose yield tons/ha over previous period.	Technology's share of increased yield of sucrose, tons/ha [2nd column x technology coef 0,234]
Pre-technological period, 1925/6-1927/8	2,85	-	-
Technological era, 1928/9-1985/6	4,60	1,75	0,410
1st Decade 1928/9-1935/36	3,04	0,19	0,045
2nd Decade 1936/7-1945/6	3,98	0,94	0,220
3rd Decade 1946/7-1955/6	4,31	0,33	0,077
4th Decade 1956/7-1985/6	4,69	0,38	0,089
5th Decade 1966/7-1975/6	5,52	0,83	0,194
6th Decade 1976/7-1985/6	6,24	0,72	0,168

(0.72)(0.234) = 0.168

see p.120

The low productivity of technology during the third decade was due to the effects of the 1939-45 war (Beater, 1989). The great improvement in technological productivity during the fifth decade reflects the benefits of increased quantity and quality of research during sixties (Donovan, 1988). The decline in productivity of technology during the sixth decade is attributable to research resources being devoted increasingly to work on eldana, the stem boring pest of sugarcane, which re-emerged and spread rapidly during that decade (Carnegie, 1983), without producing technologies for its control. Another factor reducing the productivity of research was the lack of any other yield improving technologies produced during that decade except two varieties which by the end of the decade, had not been grown extensively enough to have a significant effect on the Industry's average yield.

Effect of milling technology on productivity. The production function analysis indicated that most of the increase in the Industry's total productivity is accounted for by the four factors, technology, rainfall, costs of production and land or area under cane. The effects of improving milling efficiency are included in the analysis only to the extent of its possible collinearity with these factors. Therefore, in estimations of productivity attributable solely to *production technology*, generated at the Sugar Experiment Station, it is not considered necessary to account for the improvements in milling efficiency. It is, however, of interest in this study to compare the productivity of milling and field production. It is considered appropriate to express the improvement in milling performance in terms of tons of sucrose supplied from the field to make a ton of sugar in the mill rather than in terms of the various criteria used by mills to calculate the efficiencies of different aspects and stages of the milling process which are not relevant for the present purpose (Thompson, 1987).

The data and calculations required to estimate the improvement in mill performance are given in Appendix 7 with the results summarised in Table 14.

Table 14 : Increases in productivity (tons sucrose per ton sugar) due to milling efficiency, 1945 - 1986.

Period or decade	Years	Mean tons sucrose per ton sugar	Percentage annual increase in productivity
1945/46 - 1949/50	5	1,1983 (a)	-
1950/51 - 1954/55	5	1,1951 (b)	0,27 (a - b)/a %
1955/56 - 1964/65	10	1,1857 (c)	0,79 (b - c)/b %
1965/66 - 1975/76	11	1,1799 (d)	0,49 (c - d)/c %
1976/77 - 1986/87	11	1,1664 (e)	1,14 (d - e)/d %

The present system of payment for cane, based on its sucrose content measured as it enters the mill yard, was a result of the Fahey Agreement (South African Sugar Journal Annual, 1925) signed in September 1926. Under this system, any improvements in milling efficieny benefits only the miller who, in effect *buys* the sucrose at the mill gate and *sells* the sugar produced from it. Only in the case of the two cooperative mills, Umfolozi and Dalton, do the growers also benefit from improvements in milling efficiency. Prior to the Fahey Agreement, growers were paid on the mass of cane they delivered to the mill, in terms of individual agreements with millers, the basis of which was the estimated final yield of sugar. Growers then had an interest in the efficiency with which millers produced sugar from their cane. This is exemplified in the agreements between growers and Zululand Sugar Millers, when that mill first opened in 1905, by a discount of one shilling per ton (about 7%) for cane of the Uba variety because it was more difficult to mill than the 'softer' varieties (*op.cit.* p.24). This change from a sugar to a sucrose basis of payment for cane took place at the time the Experiment Station was established but the Experiment Station did not hand over responsibility for milling technology and advice until 1949 when the Sugar Milling Research Institute was founded. Although, little or no R&D was conducted on milling problems at the Experiment Station, it contributed to technological improvement in the milling sector by providing advice and technical services.

The estimate of productivity increase due to technology during the Technological era includes the effects of improvement in milling efficiency and this can be attributed to the Experiment Station until 1949 when the Sugar Milling Research Institute took over responsibility for milling R&D. Since the Experiment Station's contribution to milling efficiency had been largely of an advisory and service nature, the lag period was likely to have been short and it can be assumed that the Experiment Station should not be credited with any improvement in milling efficiency after the end of the third technological decade (1955/56).

The estimated percentage increases in productivity attributable to improvements in milling and production technologies are compared in Table 15.

Table 15: Estimated percentage increases in productivity attributed to milling and production technologies, 1945 - 1986.

Period	Percentage increase in productivity due to	
	Milling technology (from Table 14)	Production technology (from Table 13)
1945/46 - 1953/54	0,27	
1946/47 - 1955/56		8,29
1954/55 - 1964/65	0,79	
1956/57 - 1965/66		8,82
1965/66 - 1975/76	0,49	
1966/67 - 1975/76		17,70
1976/77 - 1986/87	1,14	
1976/77 - 1985/86		13,04

See p 58

The production function equation used to estimate the increase in productivity due to production technology does not include a milling technology factor and any effects of milling technology that may be present are due to collinearity which are not considered significant.

In addition to production and milling technologies, as defined in this study, many industrial technologies, such as those responsible for the development of agricultural chemicals, fuels, machinery and equipment, also contribute to increased production of sucrose in the South African Sugar Industry. Most of these industrial technologies are captured in the *production costs* variable, some, for example machinery, in the *land* capital variable and possibly others are in the 15% of the variability not accounted for in the analysis.

Summary of productivity increases. A summary of the estimated total increases in productivity by the South African Sugar Industry, for the various periods and sources of technology, is given in Table 16. Data on mill performance is not available in sufficient detail before 1925 to permit an accurate conversion of yield from sugar to sucrose but for the present purpose of non-critical comparisons between eras, a ratio of 1 : 1,3 for sugar to sucrose is probably acceptable for the pre-1925 eras.

Table 16 : Total increases in productivity as tons sucrose per hectare for the eras and sources of technology in the South African Sugar Industry, 1862-1986.

Era	Source of Technology	Period	Total increases in productivity (sucrose/ha)
Pretechnology	Craft skills	1862-1890	1,0 (refer page 46)
Imported technology	Imported	1890-1924	1,0 (refer page 49)
Technological (immature phase)	Imported and locally generated	1925-1954	1,65 (refer Appendix 6)
(mature phase)	Locally generated and exchanged	1955-1986	1,85 (refer Appendix 6)

Productivity increased during the first half of the imported technology era but then declined to give an era total no better than had been achieved during the pretechnology era. This indicates that yields are unlikely to be maintained if only imported technology is available, particularly in terms of disease resistance. The influence of technology on productivity during the technological era is shown, in Table 16, to be considerable, in spite of conditions and circumstnaces during both the immature and mature phases of the technological era that reduced productivity; these have been discussed on page 59 in considering Table 13 .

A primary objective of the present sutdy is to estimate the return on R&D down to programme level as a management aid and to do this it is first necessary to define the functions of R&D that are capable of generating increases in productivity; this is done in the following chapter.

CHAPTER 4

DEFINING AGRICULTURAL COMMODITY R&D FUNCTIONS

The main objective of this study is to devise a method of assessing the return on R&D in an agricultural commodity institute that may be of value to the institute's management while, if possible, overcoming the shortcomings of previous methods.

Not all the activities and costs of an agricultural commodity research institute or experiment station are devoted to R&D. It is first necessary, therefore, to classify the institute's work according to its functions. Donovan (1986 p.98) used, for management purposes, information and data on how staff time, in all line-function departments, was allocated, as well as an analysis of departmental costs, to classify the Experiment Station's activities and costs by function. Table 17 summarises the results obtained in that survey.

Table 17: **Costs of Experiment Station functions in 1985/86 expressed as percentages of total Station costs.**

Research and Development	49,7
Technical Services	18,7
Extension	10,9
Training	10,1
Specialist advice	6,3
Education & Public Relations	3,1
Publications	1,2
Total	100,0

For the different and specific task of estimating returns on R&D, particularly if it is to be of value to management, changes need to be made in the grouping of activities given in Table 17; these are as follows:

* Training, Specialist advice, Education and Publications are all technical services for which growers are, or are soon likely to be, charged directly, at least on a marginal cost recoverable

basis, while Public Relations is a staff-function (as opposed to a line-function) the costs of which should be shared appropriately as are the other essential staff-functions such as transport, asset maintenance and operation of experiment farms.

* Extension. Included under the heading of extension, in the 1986 study (Donovan *op.cit.*) were activities that, for the purposes of estimating returns on R&D, should also be classified as technical services. These activities include conveying specialist advice to growers, organinsing and collating the results of pest, disease and other surveys, assisting in educational and training programmes, seed distribution and similar activities.

Extension staff are frequently involved in research projects; when this is to assist research staff, the work should be classified under the research function. When, however, a member of Extension staff undertakes himself, or assists others with, a research project concerned specifically with his extension area or is aimed at improving the transfer of technology from research to grower generally, the project should be classified as an extension function.

These changes in the classification of the Experiment Station's activities, shown in Table 18, reduce to three the primary functions that have to be taken into account in estimating returns on R&D.

Table 18: Re-classification of Experiment Station functions in 1985/86, with their costs expressed as percentages of total Station costs.

Research (production of technology)	49,7
Technical Services Now includes Traininig, Advice, Education and Publications	41,0
Extension (transfer of technology)	9.3

With the re-classification of certain activities as technical services, the remaining functions and costs are exclusively those concerned with the generation of technology (research) and the transfer of technology (extension).

TECHNICAL SERVICES

The recent introduction of 'user pays' policies requiring producers to pay directly (as opposed to indirectly through a levy or cess) for technical services provided by R&D institutes, is advantageous for a number of reasons, not the least of which is its implications for senior R&D management. When all technical services have to be paid for directly, senior management will be relieved of the invidious task of deciding how limited resources should be allocated between R&D and Technical Services. The commodity's policy makers representing, as they do, the growers who finance all activities, should decide, on the one hand, to what extent it is necessary for the institute to respond to demands for technical services and, on the other hand, what recommendations from senior management on research and development should be accepted as benefiting all producers of the commodity and, therefore, financed by a levy on production.

In 1983 the Experiment Station started charging for its 23 training courses for operators and labourers and now, in addition to these, charges are made for the following Advisory Packages:

* Sample (soil and leaf) Analysis and Fertilizer Advice
* Soil Surveys
* Farm Planning
* Irrigation Surveys and Advice
* Nematode Control
* Drainage Scheme Advice
* Mechanisation Advice
* Civil Engineering Advice
* Choice and Management of Varieties
* Educational courses

The Agricultural Development and Advisory Services of England and Wales adopted a *user pays* policy in April 1987 and payment is now required for virtually all its services (Moberly, 1989a). Policy changes of a similar kind are also being pursued in Australia and New Zealand (Paxton, 1988).

The charges made for technical services by the Experiment Station cover only their marginal costs; overheads and at least some staff costs are not included. As a result, the estimates of R&D programme costs will be higher, and returns lower, than they should, and would otherwise, be.

How much one function of an institute should subsidise another and, for that matter, whether any particular category of growers or non-grower clients, should obtain technical services at subsidised rates, are decisions for the policy-makers to take. Management's responsibility should be to provide policy-makers with the appropriate financial information and other data on which rational decisions can be made. For this and other good management purposes most agricultural R&D institutes would need to change their accounting system from one based on a structure in terms of scientific disciplines to one based on objectives and functions. Such an accounting system would be no more complicated nor difficult to operate but could provide much more useful information for all concerned.

For the purposes of this study, Technical Services will be regarded as self-supporting and any increase in productivity resulting from their use accrues to research and extension which were responsible respectively for generating and transferring the technologies on which the services are based.

COMMODITY EXTENSION

In an agricultural commodity R&D organisation, such as the Experiment Station, extension is an essential and integral part of its programme (Donovan, 1975) but it would be advantageous if the return on extension costs *per se* can be estimated. For evaluation purposes it is unfortunate that the objectives and content of extension vary considerably. Originally (1873) extension meant taking the advantages of University education '... to the ordinary people, where they lived and worked' (Maunder, 1972). Although *agricultural* extension was first practised in England in the 1880's, the passing of the Smith-Lever Act in 1914 by the American Congress, authorising the use of public funds to finance *agricultural and rural home development programmes* (Paarlberg, 1987), is generally considered to be the origin of statutory agricultural extension. The social connotations of extension, such as *rural home development* in the United States and in South Africa where extension has '... *the final objective of improving the quality and standard of living of rural communities*' (Bembridge, 1979), have persisted as characteristics of agricultural extension.

In the South African context, with its 'two agricultures' (Nattrass, 1981),the original social and developmental bias of extension is particularly appropriate in the '... subsistence orientated and tribally organised ...' agricultural sector. In the other South African agriculture, capital intensive farming, conventional State extension has two functions to perform. The first has a profit motive, to promote among farmers the use of improved production technology and management, while the second has social motives, to promote the protection and conservation of natural resources and to uplift rural communities. These two functions, which are commonly perceived to be antagonistic, have to be performed in the State's extension service, by the same person. Düvel (1986) suggests ways in which the extension agent can resolve this conflict situation but they are merely palliative; the solution lies in having the two different and antagonistic extension functions performed by different organisations and people.

Since the protection and conservation of natural resources and improving rural communities are primarily social responsibilities, it is appropriate for the extension agent in that field to be a public servant, motivated by social and perhaps educational philosophies. Conversely the promotion of production technology and management has the objective of increasing profitability so the extension agent with that task should be essentially profit motivated and employed by a business concern such as an agricultural commodity organisation or cooperative.

Beuckman (1984) believes that *credibility* is the key to effective extension and contends that credibility is enhanced when the extension agent is seen to be part of the organisation (in Beuckman's example, a cooperative) serving the interests of the farmer exclusively. The shortcomings of conventional State agricultural extension can only be overcome effectively when research, extension and the technical services required by a commodity are all provided by that commodity (or single interest) association as Beuckman suggests, with the State providing a separate extension service exclusively to promote the conservation and development of the natural resources that are not marketable.

The narrow and commercially orientated objectives of agricultural commodity extension typified by Huffman's (1980) definition, '... the dissemination of information on production technology, planning and management' is sometimes criticised for being counter-productive of important social objectives in agricultural development and the conservation of natural resources. However, although the definition excludes by omission the promotion of social and community objectives *per se*, it does not preclude the dissemination of technology and production methods *compatible with the prescriptions required by society and the community*. An excellent example of this is to be found in the advice on soil conservation measures given to sugarcane growers by their own commodity extension agents which comply fully with the State's soil conservation requirements. In the case of the sugar industry, the commodity's acceptance and promotion of its social obligations in such matters is further exemplified by its significant R&D input on environmental protection (see Table 19, items 31 & 32).

The estimate of returns on commodity extension constitutes an important aspect of this study and is considered in Chapter 5.

RESEARCH

With information on costs and returns on research programmes, management's recommendations on research requirements and priorities would be improved. To make these estimates, it is first necessary to classify research programmes in terms of their kind and maturity. For the purpose of this study it is postulated that there are four kinds of agricultural research programmes, Offensive or Strategic, Defensive, Precautionary and Services research.
The Experiment Station's research programmes are classified in these terms in Table 19 which also indicates the economic and biological objectives of the programmes.

Table 19: Classification of Experiment Station 1985/86 research programmes by economic and biological objectives into kinds of research.

Kinds of research		R&D Programmes
Economic objectives	Biological objectives	
Offensive Productivity increase	Crop improvement	1. Plant Breeding 2. Selection for disease resistance
	Crop protection	3. Biological control of eldana 4. Eldana biology (basic research) 5. Mosaic epidemiology (basic research) 6. Nematode biology (basic research)
Defensive Productivity maintenance	Crop protection	7. Cultural control of eldana 8. Chemical control of eldana 9. Control of pests other than eldana 10. Ratoon stunting disease 11. Smut 12. Mosaic control 13. Leaf Scald
	Crop production	14. Fertilizer trials 15. Nematicides 16. Growth regulators 17. Herbicides 18. Trashing 19. Variety agronomy 20. Soil amelioration 21. Compaction 22. Acid chlorosis
Cost reducing		23. Nitrogen fixation 24. Lysimetry
Precautionary	Crop production	25. Development of machines and equipment (11 projects) 26. Alternative fuels
Services	Crop production	27. Crop production systems 28. Machine performance and utilization 29. Analytical chemistry (7 projects) 30. Irrigation simulation and methods
	[Enviroment protection]	31. Run-off and catchment projects 32. Modelling soil and water loss

Offensive or Strategic research. Offensive research leads to '... the creation of new products, new inventions, new possibilities for a company, for an industry, for a nation' (Beattie & Reader, 1971). To this should be added that in the context of agricultural commodity R&D, the objective of offensive research is to increase productivity or profitability. Research applied to those areas '... considered likely to be economically significant in the future ... (and to) ...

emphasise the potentially relevant ...' has been described as strategic research (Harvey, 1988).

At the Experiment Station, plant breeding including selection for disease resistance, the eldana biological control programme and the nematode biology programme are current examples of offensive or strategic research. Most programmes start as offensive research but once successful, if they have to be continued at all, they would be re-classified as defensive programmes or projects.

The criterion of success in an offensive research programme is the release of a new technology or recommendation that can contribute to higher productivity. Examples of former successful offensive programmes at the Experiment Station are sugarcane nutrition, phosphorus availability, trashing, herbicides, growth regulators and the control of Ratoon stunting disease, all of which are still in the programme of work as defensive programmes or projects.

Most of the present offensive research programmes have yet to produce new technologies or are in the early stages of technology generation; in either case economic returns resulting from their adoption by growers is premature. Offensive research programmes can, therefore, be divided into three maturity categories: those from which no economic results can be expected, those on which economic results are premature and those that have failed to produce technologies of economic value or technologies that for one reason or another it is considered undesirable to recommend adoption. The latter are described as 'dry holes' which should be terminated promptly but whose costs must be included in continuing programmes with the same or similar objectives. A number of offensive research programmes are not expected to make economic returns but are conducted to produce biological information of value to other programmes; these are described as *basic research* programmes.

Basic Research. Agricultural commodity R&D is essentially 'mission orientated' (as opposed to 'speculative') and involves both applied and basic research that aims at contributing to the solution of practical problems (Arnon, 1981). Agricultural commodity R&D organisations will usually contract out their basic research requirements but occasionally, when the appropriate staff and facilities are already on hand, it can be more economic - and staff motivating - to do basic research in-house. The Experiment Station has commissioned a number of basic research projects from University departments and has retained some for conducting in-house; current examples of the latter being the Eldana Biology and Mosaic Epidemiology programmes. Returns and costs of basic research of this kind are those of the research programmes from which they were generated; for this reason there is no need to have a separate category for basic research programmes when returns are estimated for agricultural commodity organisations.

Defensive Research. The release of a new technology or recommendation seldom implies the end of research on that subject; most new technologies need to be *maintained* by what Beattie & Reader (1971) have called 'Defensive R&D' and described as necessary to facilitate or enhance the production of existing products. In the context of agricultural commodities, defensive research plays an important role in preventing the decline of productivity and in reducing the costs of production.

A high proportion of the Experiment Station's research must be categorised as defensive. Released varieties need to be assessed in terms of their interaction with different environments and their reaction with other factors of production; pests and diseases need to be monitored for changes in virulence or distribution and new or changed production inputs such as fertilizers, herbicides and growth regulators need to be tested under local conditions.

On the other hand a number of programmes are conducted as precautionary measures against the possibilities of changes in production conditions. In the Experiment Station's 1985/86 programme of work two programmes should be classified as precautionary: the development of machines and equipment (Table 19, item 25) as a precaution against possible labour shortages or strike action, and the development of alternative fuels (Table 19, item 26) as a precaution against shortages caused by sanctions or high prices.

To facilitate the estimation of returns, research programmes can be divided into three maturity categories. The first, while the adoption of a new technology is increasing, the second when adoption has reached a maximum and the third when the technology has been, or is being, superceded. For convenience, the estimation of returns on research programmes that cannot be estimated, even subjectively, are included in this last maturity category of defensive research.

Table 20 summarises the classification of the Experiment Station's R&D programme according to kind, phases of costs and returns, and maturity. Services research programmes are included in the classification for the sake of completeness but because they are self-financing, or should be, returns on them do not require estimation.

Table 20: Classification of kind, phases and maturity of Experiment Station research programmes in 1985/86.

Kind of research	Offensive research [Productivity increasing]				Defensive and precautionary research			
					[Productivity maintaining/Cost reducing]			[Services]
Stages of biological results	Pre-results		Early results		Increasing adoption of results	Maximum adoption of results		Results immediate
Costs phases	Increasing costs		Maximum costs		Relatively uniform costs		Minimum costs	Costs relatively uniform and recovered in fees
Stages of economic returns	No economic returns expected	Pre-returns	"Dry hole"	Early returns	Increasing returns	Little or no additional returns	Nil or unknown returns	Returns = fees charged for services
Maturity category of research programmes	A	B	C	D	E	F	G	—
Research programmes by category (Numbers refer to Table 19)	4 (→ 3) 5 (→ 12) 6 (→ 15)	3	8	1, 2	7, 12	10, 11, 14 15, 16, 17 18, 19, 20	9, 13, 21 22, 23, 24 25, 26	27, 28, 29 30, 31, 32

In this chapter the functions of R&D at the SASA Experiment Station have been reduced - for purposes of estimating their contribution to increases in productivity - to two, namely research and extension. Before being able to sub-divide the return on research *per se* among research programmes, it is necessary to deduct from the total return on R&D that portion attributable to extension, an estimate of which is made in the following chapter.

CHAPTER 5

EVALUATING AGRICULTURAL COMMODITY EXTENSION

The term *extension* was first used in 1873 by Cambridge University to describe the innovation of '... taking the educational advantages of the University to the ordinary people, where they lived and worked' (Maunder, 1972). *Agricultural extension* was first practised, again in England, some thirty years before the United States passed the Smith-Lever Act in 1914 which authorised the financing of agricultural extension from public funds (Paarlberg, 1987). Whereas in England the terms extension continued to be used in the context of general education, in the United States - because of the Smith-Lever Act - it became associated specifically with agricultural and rural home development programmes.

For the South African situation in general Bembridge (1979) has defined agricultural extension as '... assisting farmers to improve their level of managerial efficiency by integrating the most suitable package of farming practices into their farming enterprise, aimed at improving efficiency and profit per unit of production, with the *final objective of improving the quality and standard of living of rural communities*'.

DEVELOPMENT OF COMMODITY EXTENSION

Community Development. The original philosophy and content of extension in the United States was to promote the development of the rural community as a whole and in spite of the dramatic changes in the structure and economics of American agriculture, since that time, the strong social and educational character of extension has persisted in the United States and according to Bembridge's definition, in South Africa as well. In the South African context, with its 'two agricultures' (Nattrass, 1981), the original social and developmental bias of extension is particularly appropriate in the '... subsistence orientated and tribally organised ...' agricultural sector.

Agriculture in these developing areas is commonly regarded by the people themselves as a subsistence rather than an economic activity and where the 'basic needs' approach (Nattrass, 1986) is used to determine community needs, the promotion of agricultural production is not always, perhaps even seldom, the highest priority in community development.

Commercial Farming. In the other South African agriculture, capital intensive commercial farming, extension has two functions to perform. The first has a profit motive, to promote among farmers the use of improved production technology and management, while the second has a social motive, to promote the protection and conservation of natural resources. These two functions have, since the inception of an agricultural extension service in South Africa, been performed by the same person who is a public servant and as a result intra-personal conflict is common.

Conflict in extension. Duvel (1986) describes conflict (in the extension context), as tension caused by forces working simultaneously in opposite directions, as the interests of resource protection and commercial farming are commonly perceived to be. Duvel points out that the extent to which the extension agent himself experiences conflict depends on his personal philosophy and approach to extension and he (Duvel) suggests ways in which the extension agent can overcome the conflict he experiences. These measures are, however, merely palliative for the individual and he will inevitably perform one of the two functions with more commitment than the other. The solution lies in allocating the two different and conflicting extension functions to different organisations and people.
The protection and conservation of natural resources is a social responsibility: the extension agent in that field should therefore be a public servant motivated by social and perhaps educational philosophies. The promotion of technology and management has the objective of increasing profitability so the extension agent with that task should be essentially profit motivated and employed by a business concern.

Separating social and commercial extension. The first formal attempt to separate the social and commercial functions of agricultural extension in Southern Africa was, it is believed, made by the then Rhodesian Department of Conservation & Extension (CONEX) during the early 1970s. The demand by farmers for more specialised advice on increasingly complex production technology, the widening gap between research and the farmer and the strong commodity orientation of the National Farmers' Union, led to the separation of soil and water conservation duties from production extension duties (Carlow, 1974). While this was a bold step in the right direction, its success was limited. First, the change from *generalist* (Conservation & Extension Officer) to so-called *specialist* (Crop or Animal Husbandry Extension Specialist) did little to improve the credibility of extension personnel, with farmers or researchers, mainly because he was no closer to the source of technology than before. Secondly, the communications gap between research and the farmer was not reduced merely by changing the title and duties of the extension agent who owed direct allegiance to neither research nor the farmer. Kennan (1978) measured the effectiveness of communication of research results published in popular agricultural journals and found that few extension agents were able to pass on information effectively to farmers even after a day in face to face discussion with the researchers responsible for the information. Furthermore, he found that many extension agents were technologically ill-equipped to give any advice at all.

The communications gap between research and the farmer is a two-way gap. Equally disadvantageous to commercial agriculture is the perception '... that researchers are out of touch with farmers' problems, ... (and) that research programmes tend to be designed in isolation of such problems ...' (Cernea *et al*, 1985). Various attempts and suggestions have been made to close the communications gap. Kennan (*op. cit*) recommended that extension agents be *encouraged* to set objectives (presumably including closing the gap) and to measure progress towards their achievement but it is doubtful if *encouragement* is enough to result in action when the extension agent probably has a long list of *required* duties, including regulatory tasks. Cernea *et al (op. cit.)* concluded that '... promoting the role of the farmers in the research-extension two-way continuum would lead to more robust and more readily accepted technologies ... this endeavour would (also) provide common ground and encourage additional cooperation between the two services.' The conclusion is that the communications gap between research and the farmer will remain so long as the information to be conveyed, in either direction, has to be transmitted through a third agent responsible to neither party.

The third shortcoming of the Conex reorganisation was its incompatibility with commercial agriculture's organisational structure and *modus operandi* which was increasingly commodity orientated. Commercial farmers plan and work in terms of the commodities they produce: maize, wheat, sugarcane, tobacco, beef, milk, etc., whereas most of the research and extension services they required were organised in terms of disciplines. To put together the production technology package needed for a single commodity it was necessary for a farmer, or an extension agent, to consult as many as five branches (institutes) in two different departments. The exception to this inhibiting situation was tobacco for which the research and extension, as well as all necessary technical services, were available from a single institute and which provided an outstanding example of how much more effective the commodity structure could be.

Beuckman (1984) believes that *credibility* is the key to effective extension and contends that credibility is enhanced when the extension agent is seen to be part of the organisation (in Beuckman's example, a cooperative) serving the interest of the farmer.

Commodity extension. The shortcomings of agricultural extension, even when its social and commercial functions are separated, can only be overcome effectively, and staff wastage reduced, when research, extension and production services, are all provided by a commodity (or single interest) association as Beuckman suggests. Donovan (1975) illustrated the difference between conventional agricultural extension as provided by the State on the one hand and commodity extension on the other, in the model, Figure 7.

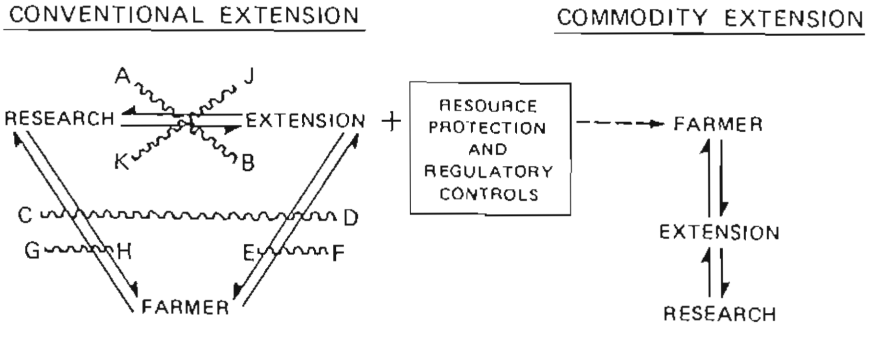

Figure 7 : Model comparing conventional and commodity extension.

In this model of conventional extension there are five barriers; the communications' barriers, AB between the separate organisation for research and extension and CD between the public (social objectives) and the private (profit motive) sectors; the credibility barrier EF between extension and the farmer, the 'ivory tower' barrier GH between research and farmer, and often a status/career barrier JK between research and extension. In a commodity R&D organisation, because research and extension are equally important components of the same organisation which has no compulsory social objectives, there are no structural or organisational reasons for the existence of barriers. If barriers are erected they can be removed by management within the commodity organisation itself.

Perhaps the most significant difference illustrated by these models is the status of the farmer in relation to research and extension. In the conventional organisation, the farmer's interests are only one of the objectives of research and extension personnel and, because research and extension are funded by the public, the farmers's interests do not always receive top priority. In a commodity organisation it is exclusively the farmers' interests, objectives and requirements that determine research and extension action. Donovan (1986) listed the six essential requirements for the successful extension of technology in a commodity R&D organisation, as follows:

+ extension must be an integral part of the commodity organisation,
+ extension agents must have no duties with conflicting objectives,
+ extension agents must have no regulatory duties to perform,
+ in his own extension area the extension agent must be the sole technical representative of his commodity R&D organisation,
+ the extension agent is as responsible for communicating information from the farmers to the R&D organisation as he is for conveying technology from the R&D organisation to the farmers, and
+ the extension agent may only convey information to farmers that is unambiguous and has been formally approved by the commodity R&D institute.

The narrow and commercially orientated objectives of agricultural commodity extension typified by Huffman's (1980) definition: '... the dissemination of information on production technology, planning and management' is sometimes criticised for being counter-productive of important social objectives in agricultural development and the conservation of natural resources. Although the definition excludes by omission the promotion of social and community objectives *per se*, it does not exclude the dissemination of technology and production methods in the form, or with the prescriptions, required by society. A good example of this is to be found in the advice on farm planning given to cane growers by their own commodity extension agents which complies with the State's soil and water conservation requirements. Furthermore, this study has shown that nearly 8% of the commodity's expenditure on research is on soil and water conservation projects. It is accepted that a few agricultural commodities may not have the financial resources to operate their own R&D organisation but even they can avoid the disadvantages of the present disciplinary research and socially orientated extension by employing contract services on an as required basis for their commodity (Donovan & Nieuwoudt, 1988).

EVALUATING COMMODITY EXTENSION

"Traditionally, it has not been considered necessary to evaluate the contribution of the extension services to the farming enterprise. Its role has been primarily one of providing a social service. This is no longer regarded as sufficient in today's 'results orientated' world. Extension, like any other service, must advertise its achievements and *establish its worth*" (Paxton & Culverwell, 1988, p.221).
Extension is considered an essential part of agricultural commodity R&D and in any estimate of R&D returns it is likely to be a major component. In the case of the Experiment Station's cost effectiveness exercise (SASA Experiment Station, 1983), extension was assumed to comprise half the total return on R&D. In other previous studies there has apparently been more confidence in the estimates of returns on research components than in those on extension. Because extension is likely to comprise a high proportion of the total return on R&D, an objective method for estimating its contribution to the total return on R&D would be advantageous.

Previous Studies. Most evaluations of extension are merely descriptive in nature and use surrogate parameters such as numbers of farmers visited, subjects discussed, time in consultation, etc. These parameters are assumed to be correlated directly with productivity and as such are used as evaluation measures. Better parameters would be measures of changes brought about in farmers' knowledge, skills and increase in the use of technology but these are more difficult to quantify and are still indirect indicators of extension effects. For an evaluation to be wholly credible it is necessary to measure changes in levels of production, caused by the adoption of technology, that are theoretically sound and empirically measurable.

Sim & Gardner (1980) conclude their summary of research and extension evaluation by saying 'Greater attention must be given to (the evaluation of) extension because the key role it plays in transferring information has not been evaluated in depth ... a framework must be devised to capture and measure as many of the impacts of research and extension as possible'.

In a review of past studies on the return of multi-product State extension, Huffman (1980) came to the following conclusions among others:

+ the marginal product of conventional extension in multi-product agriculture is a partial measure of a combination of all technical and allocative effects and cannot be applied to any particular product;
+ the return on extension is proportional to the total value of farm output but the marginal product of different extension activities differ, perhaps markedly;
+ all the effects of extension cannot be captured in one empirical model;
+ the dependence of extension on research is often not taken into account.

White & Havlicek (1982) suggest that a separate extension variable should be used in the production function. However, measuring the separate influence of extension on agricultural production has been difficult because of the high multicollinearity between these variables (research, extension and education) in time-series data. Even sophisticated econometric techniques such as ridge regression cannot overcome the problem.

From these earlier studies it is evident that methods used in the evaluation of multi-product, State funded and socially orientated extension are not suitable for estimating the return on commodity extension.

A few estimates of the return on commodity extension have been attempted and these are of more relevance in the present study. Araji (1980) used information obtained from interviews with researchers and extension agents to assess extension's contribution to the *future* effectiveness of research programmes and found it to be between 60% and 78% depending on the commodity. In an earlier paper Araji *et al* (1978) used a scoring model to estimate the return on research and extension and concluded that, depending on the commodity and nature of the research programme, 25% to 60% of the expected returns to public investment in agricultural research will not be realised without extension involvement.

Huffman (1980) found nine studies in the literature that attempted estimates of the return on extension. The estimates were, at one extreme, that extension had no significant effect on value added in farm production, to the other extreme that extension gave a social rate of return of 110 per cent. The estimates between the extremes, expressed in terms of rate of return, were in the range 1,3% to 20%.

An ex-post estimate. In an in-house exercise to estimate the *ex-post* cost effectiveness of the South African Sugar Association Experiment Station as a whole, and its component divisions and programmes (SASA Experiment Station, 1983), the decision was taken to allocate arbitrarily to extension half the gain attributed to research. In the absence, at that time, of a known and suitable method of assessing the relative contributions of research and extension, equal proportions were chosen because, at the Experiment Station, they are regarded as equally important functions in achieving the Experiment Stations goals. The decision was also justified because the exercise was to assess *cost effectiveness* and not the intrinsic value of, or return on, extension.

Results obtained in the cost effectiveness exercise are given in Section 1.3 of Appendix 1 and are summarised in Table 21 below. The costs and gains are expressed as percentages of Experiment Station totals while the percentage returns are those for the individual divisions and programmes, calculated as (Gains - Costs)/Costs %.

Table 21: Estimates of costs, gains and returns on Experiment Station divisions and programmes in 1983.

Division Programme	% of Experiment Stn total		% Return
	Costs (1)	Gains (2)	(2)-(1)/(1)
Agricultural Engineering	19,55	10,34	78
Mechanisation	9,43	6,27	93
Farm Planning	6,78	1,94	42
Irrigation & Drainage	2,61	2,09	118
Civil works	0,22	0,04	29
Agronomy	15,36	17,14	165
Herbicides & Weeds	1,73	4,20	359
Nematicides	0,86	0,83	143
Growth regulators	0,86	2,28	391
Varieties	1,44	0,09	9
General (inc. moist. stress)	2,10	1,30	92
Fertilizers	8,36	8,44	149
Plant Breeding & Protection	29,31	36,71	185
Breeding & Selection	15,12	26,88	263
Pathology	4,89	7,38	224
Entomology (inc. Eldana)	9,26	2,45	39
Extension	35,78	35,81	148
Extension & Education	25,05	21,42	127
Training	10,73	14,39	199
Experiment Station totals	100	100	148

The conclusion reached in the cost effectiveness exercise was that since the total gain from R&D expenditure was 2,29% of the value of the crop at that time, the Experiment Station could be regarded as cost effective. For the purposes of this part of the present study, it is the magnitude of the estimated returns on extension expenditure, namely 148%, that is of interest.

An ex-ante estimate. Using farm development budget data collected in a recent agro-economic study of three irrigation districts (HKS-Agriland, 1988) and the unit costs of extension in a commodity R&D institute (Donovan & Nieuwoudt, 1988), an estimate of the *potential* or *ex-ante* returns on extension is possible. The hypothesis is that through the input of additional extension it would be feasible for these particular farmers, producing wool, mohair and meat as a by-product, to increase their productivity.

The effects of additional extension input were assumed to result in an increase in pasture carrying capacity, increases in lambing and kidding percentages and in livestock slaughter mass.

Two production system models were developed in the agro-economic study but for the purposes of this study, the less productive of the two systems is used. Table 22 compares three simulated model farm budgets at the end of a period of development during which physical resources and extension input were increased. The first budget (#1) represents the present level of production, that is, without increasing physical resources or extension input. The second budget (#2) represents the production level achievable with an increase in physical resources alone (namely of 13,3% in irrigable area, from 45 to 52 hectares). The third budget (#3) represents the potential production level that could be achieved with the 13,3% increase in irrigable area together with the effects of increased extension.

The unit cost of extension in the Sugar Industry, estimated by Donovan & Nieuwoudt (*op. cit.*) as R88 560 per annum in 1985/86, can be used for estimating the cost of additional extension in the simulated model farm budgets compared in Table 22.

Table 22: **Comparison of three simulated model farm budgets in rands per annum (HKS-Agriland, 1988).**

	Model farm development budgets		
	#1 Present resources	#2 Additional irrigation	#3 Additional irrigation + extension
Gross farm income	128 951	141 239	218 662
Production expenses	79 380	83 277	106 543
Water charges	1 815	3 947	3 947
Additional extension costs	-	-	1 122
Net farm income	47 756	54 015	107 050
Fixed charges	12 112	12 112	12 112
Drawings and tax	20 000	20 000	28 000
Net cash farm income	15 644	21 903	66 938

Since the number of farms per extension agent (120), size of and distance between farms are of the same order as those for which the unit costs of extension were estimated, it is only necessary to inflate the Sugar Industry's 1985/86 extension cost (by 15% per annum) to obtain the estimate of R1 122 per farm per annum as the unit cost of additional extension in the simulated model farm budget.
The return on the 13,3% increase in irrigable area, can be calcuated in terms of net cash farm income as the difference between budgets #1 and #2, that is R6 259 per annum or 40%. The return on additional extension, which it is anticipated would result in higher productivity, can also be calculated in terms of net cash farm income as the difference between budgets #2 and #3, that is R45 035 or 206%.

PROPOSED METHOD FOR ESTIMATING RETURNS ON COMMODITY EXTENSION

A method of estimating returns on extension in agricultural commodity R&D is required that does not have the shortcomings found in existing methods. These shortcomings are mainly:

+ use of surrogate parameters or indirect measures for output,
+ assuming input (usually cost) can be equated with output,
+ the use of aggregated or mixed product data,
+ not accounting for the interaction of research and extension.

It is suggested that, at least in the case of the South African Sugar Industry, *the change in the relationship between the Industry's yield per hectare and the yield obtained by technologists in field trials, can be used as a measure of the transfer of technology or extension.* It is suggested that such an estimate overcomes most of the shortcomings of previous methods and provides an acceptable measure of the extension component in the estimate of returns on agricultural commodity R&D.

Experimental yield. The yield obtained by sugarcane technologists, mainly the staff of the Experiment Station, in field trials conducted to develop and test new technologies, is called, in this study, the *experimental yield.* Since in the conduct of field trials, technologists are required to use the 'state of the art' technology as standard practice, their yields can be considered those obtainable when available technology is fully transferred into practice. Most field trials are conducted on farms and estates throughout the industry under the standard of management *available locally* and they are subject to the same vagaries of climate and other farming hazards as the commercial crops. On the other hand the *industrial yield*, defined for this study as the average yield for the whole industry, has been achieved through the use of only that part of *available technology* that has been transferred by extension agents up to that time, and after the grower has taken risk into account.

Data are available in the files of the South African Sugar Industry Agronomists' Association for most of the field trials carried out by technologists working in the Sugar Industry, mainly Experiment Station staff. In order to make them as comparable as possible with farmers' yields the following precautions were taken in extracting the data:

+ all yields are expressed in metric tons sucrose per hectare per annum,
+ the yield year is standardised as the twelve months prior to the date of harvest,
+ non-commercial practices or technologies, i.e. those not yet available to the industry, are taken out as far as possible. For example, yields of unreleased varieties or resulting from the deliberate over- or under-application of agricultural chemicals or the use of unrecommended practices,
+ combining the yields of rainfed and irrigated field trials in the same proportions as occur in the industry as a whole.

Finally to reduce the effects of errors in the conduct of trials, faulty recording or processing of field trial data, the highest and lowest yields, in all between 10% and 20% of the total number in any year, were discarded. This made very little difference arithmetically to the mean yield but would have reduced the variance appreciably.

Sufficient and reliable field trial data are available only since 1957/58 but with the establishment of an extension service at the Experiment Station in 1954, this is not inappropriate. The yield data of 1 470 trials used in the estimate of a experimental yield. and rainfall, are given in Appendix 8.

Estimation of experimental yield. Since in the conduct of field trials the 'state of the art' technology must be used and no account taken of risk, only rainfall needs to be considered in estimating the trend of yield over time. The trend of experimental yield over the period 1957/58 to 1986/87 was estimated with equation (2):

$$Y = -26{,}87 + 1{,}02X_1 + 0{,}04X_2 - 0{,}07X_3 - 0{,}69X_4 \;\ldots\ldots \quad (2)$$
$$(t=2{,}81) \quad (t=0{,}47) \quad (t=-2{,}00) \quad (t=-2{,}74)$$

$R^2 = 0{,}53$,
$n = 30$,
$df = 25$.

Where Y = experimental yield, tons sucrose per hectare
X_1 = time (year - 1900), eg: 1957-1900 = 57, etc;
X_2 = rainfall (millimetres/100);
X_3 = X_1^2;
X_4 = time^2 (year - 1900/100)^2, eg: (1957-1900/100)^2 = 0,57^2.

The yield data for this analysis were obtained from a large number of different trials conducted throughout the industry but whose sites and distribution varied from year to year. This introduces more variability than would be the case if the same trials had been conducted on the same sites each year and results in the low R^2 value of 0,53.

The change in experimentall yield during each of the three decades is calculated, as shown in Table 23, from the yields estimated by equation (2) for the first and last year of each decade.

Table 23: Change in experimental yield (tons sucrose per hectare), 1957/58 - 1986/87 by decades.

Decade	Yield		Change in yield
	Start (1)	End (2)	(2) - (1)
4. 1957/58-1966/67	8,62	10,11	+ 1,49
5. 1967/68-1976/77	10,21	10,46	+ 0,25
6. 1977/78-1986/87	10,42	9,43	- 0,99

The trend of experimental yield, estimated by equation (2), is shown graphically in Figure 8. The apparent decline in experimental yields from the mid-1970s, shown in the figure and in Table 23, is discussed later.

The industrial yield of sucrose per hectare per annum, also shown in Figure 8, was estimated by production function analysis (page 57) with the results given in Appendix 6.

? Model specification

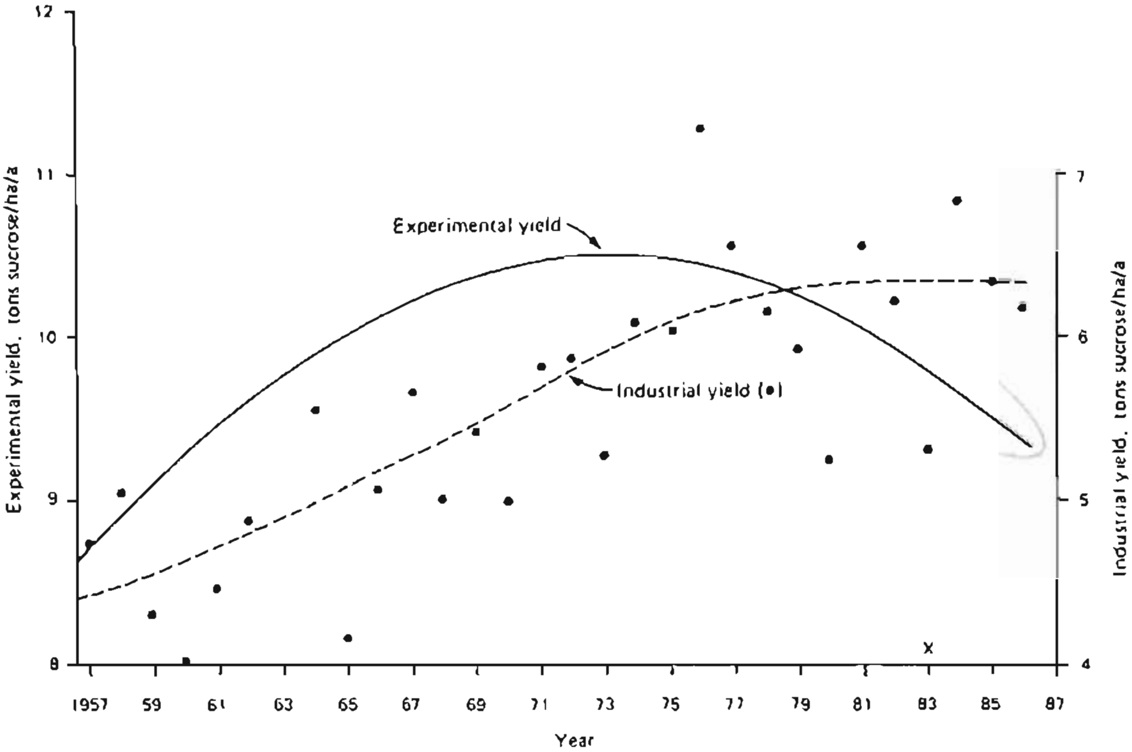

Figure 8: Comparison of experimental yield (Appendix (9) and industrial yield (Appendix 6) in tons sucrose per hectare per annum, 1957/58 - 1986/87.

Risk. In comparing the increases in yield obtained by technologists in field trials with yields achieved by the industry as a whole, it was decided not to include risk as an independent variable in the analyses. First, because in any comparison of yield between years or eras, the assumption that the risk factors are of similar magnitude is likely to be as inaccurate as any estimate of risk for different years or eras based on aggregated and often unreliable data. Difficulties such as these are likely to be even greater when estimating risk as a factor affecting changes in yield per hectare during the period 1925/26 - 1986/87.

A second and major difficulty in quantifying risk in any estimate of yield per unit area, is the circumstantial evidence that for both individual growers and miller-cum-planters, albeit for different reasons, yield per unit area is not well correlated with utility. For the individual grower the increase in marginal product over a certain level is not considered as valuable as the additional management time that it necessitates. In the case of the miller-cum-planter, utility is usually improved more by mill performance than by yield of sucrose per unit area.

A third reason for omitting risk is the effect production and price controls, as well as subsidised input costs, have had on optimum input allocation and therefore conscious risk management by cane growers. Ortmann (1985), for example, found that the marginal product for land was 2,9 times its input cost indicating its under-use as a result of quota restrictions. Conversely he found the marginal product value of irrigation water (in irrigated areas of the industry) was only 0,3 times its unit cost, indicating over-use resulting from its subsidised cost.

Since the introduction of a two-pool system of marketing in 1985 the cane grower has had to make decisions on production inputs that were previously taken for him through the mechanisms of price and production controls; risk management is therefore one of the skills the cane grower will need to improve because, as Frean (1988) said when the two-pool system of marketing was introduced: 'For the first time cane growers have faced the market and had to make a decision regarding the production of (B pool) cane'.

However, for the purpose of comparing experimental and industrial yields, risk needs to be considered because, in commercial production the cane grower can (and usually does) select input levels according to his subjective assessment of risk, whereas in conducting field trials the technologist may not. Technologists are required to use the biological optimum levels of inputs as defined by the 'state of the art' technology. This includes rainfall which has been taken into account in determining biological optima through the conduct of field trials under different ecological conditions over a number of seasons. The commercial cane growers' risk management also takes into consideration non-biological production factors such as shortage of capital, labour supply, cash-flow problems and sometimes alternative products.

These important differences in production strategies between cane growers and technologists is recognised at the Experiment Station by the requirement that all technological recommendations must be communicated to the cane grower through the local extension agent who, in consultation with and knowledge of the particular grower, can modify the recommendations in terms of the grower's risk situation.

The inclusion of risk as a factor in production function analysis used to estimate industrial yield was not possible with any degree of accuracy, for the reasons given above. It is therefore necessary either to include an arbitrary assessment of its effect if industrial and experimental yields are to be compared *per se*, or to compare the two yields in terms of their percentage change and the latter option was chosen.

Productivity of Technology and Extension. As shown in Figure 8 (page 87) and in Table 24, experimental yields increased, during the thirty year period 1957/58 - 1986/87, from 8,62 to 9,43 tons sucrose per hectare per annum, or 9,4%. During the same period industrial yield increased by some 40%, from about 4,5 to 6,3 tons sucrose per hectare per annum. The proposed hypothesis is that of the increase of 40% in industrial productivity, 9,4% was due to research and the remainder, 90,6%, was due to extension.

However, to compare the increases in experimental and industrial yields, in percentage terms, it is necessary to use a common base. Thompson's (1976) concept of a climatic potential yield provides an appropriate base for this purpose. Climatic potential yields of 20 and 12 tons sucrose per hectare for irrigation and rainfed cane respectively (Thompson, 1989) are combined in the same proportion as irrigation and rainfed cane occur in the Industry (1:4) to give an integrated climatic potential yield of 13:6 tons sucrose per hectare to be used as the base for comparing experimental and industrial yields. (See Table 26, page 93).

Of particular interest in this study and in the management of R&D, is the changes in the relationship between experimental and industrial yields with time. These changes, Figure 8 and shown in Table 24, represent the situation well for the fourth and fifth decades. The fourth decade was a productive one in terms of new technology (Donovan, 1988) and the extension service, having been established only three years earlier, had not yet had a significant impact on production. During the fifth decade the deliberate policy of developing the extension service to accelerate the rate of technology transfer, implemented in 1969, was undoubtedly effective and this is reflected in the considerable increase, from 35% to 83%, in extension's share of the total increase in productivity due to R&D at the Experiment Station.

For each decade the initial and final experimental yield, estimated by regression analysis (Appendix 8), and industrial yield, estimated by production function analysis (Appendix 6), are used, with the integrated climatic potential yield (ICPY) as the base, to estimate the relationship between them, as shown in Table 24.

Table 24: Changes in experimental and industrial yields, expressed as percentages of an integrated climatic potential yield* (13,6 tons sucrose/ha).

Yield (tons sucrose/ hectare/annum	4th decade 1956/57 - 1965/66	5th decade 1966/67 - 1975/76	6th decade 1976/77 - 1985/86
Experimental yield:			
initial yield	8,62	10,21	10,42
final yield	10,11	10,46	9,43
change in yield	1,49	0,25	- 0,99
change as % of ICPY*	10,96	1,84	- 7,2
Industrial yield:			
initial yield	4,4	5,6	6,2
final yield	5,2	6,1	6,3
change in yield	0,8	0,5	0,1
change as % of ICPY*	5,55	3,68	0,74
Ratio of experimental to industrial percentages of change, as percentages	65 : 35	33 : 67	-ve : +ve

However, the decline in experimental yield indicated for the sixth decade in Table 24, and by the yield trend shown in Figure 8, from the mid-1970s, suggests that abnormal conditions must have been responsible. Two such conditions are believed to be mainly responsible for the decline:

- Two of only five seasons since 1890 with less than 700 mm of rain occurred during the sixth decade, including the lowest on record, 606 mm in 1983/84; the long-term mean rainfall being 991 mm.
- To promote the eldana research programme, an increasing number of field trials were deliberately sited in areas of heavy eldana infestation resulting in a higher proportion of trials being conducted where eldana was prevalent.

The adverse effect of these two circumstances was not alleviated by a decade of productive technology. Apart from two new varieties, N12 and N14 (released in 1979 and 1980 respectively, but which made up only 1,4% and 6,4% of the total crop by the end of the decade), and early harvesting techniques devised to contain eldana populations but not to improve sucrose yield, no new technologies were produced during the decade.

To maintain the positive experimental yield trend that has been shown in Table 13, albeit at a very low rate of increase, it is considered appropriate to arbitrarily project the experimental yield curve from its highest point, 10,50 tons in 1974/75 and 1975/76, to 10,52 tons in 1986/87, as shown in Figure 9.

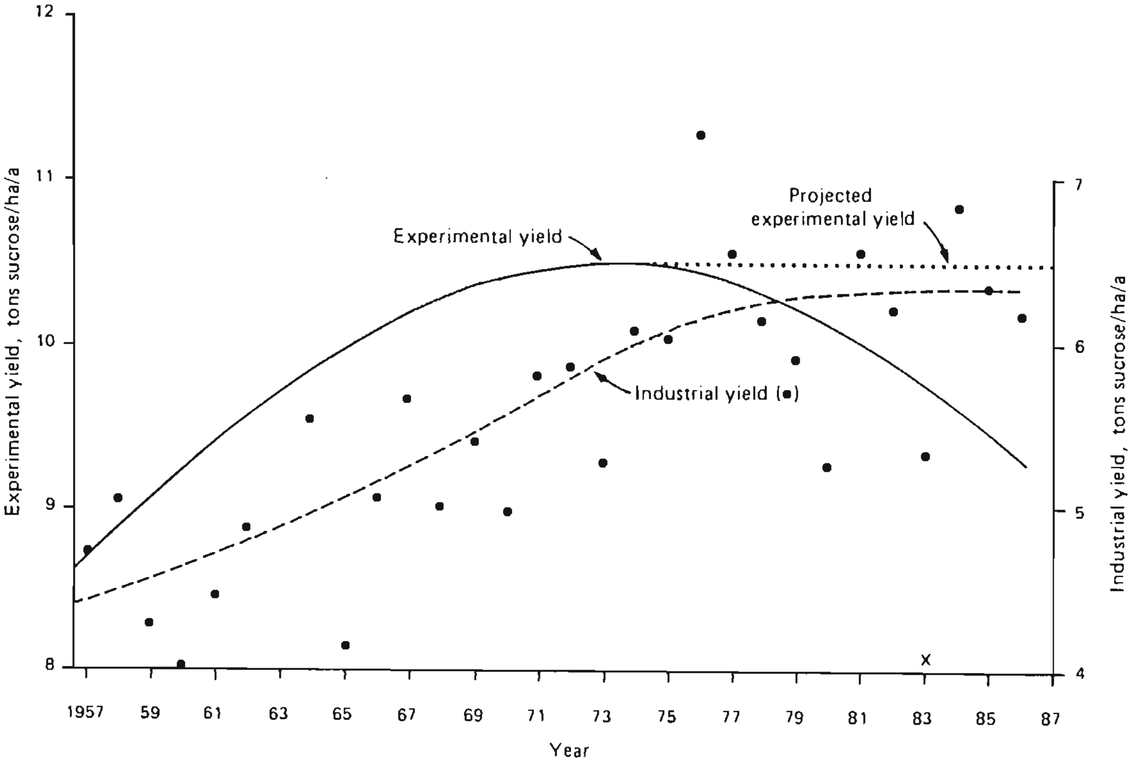

Figure 9: Comparison of *projected* experimental yield and industrial yield in tons sucrose per hectare per annum, 1957/58 - 1986/87.

The projection of the estimated experimental yield to 10,52 tons per hectare at the end of the decade is supported by the calculations in Table 25. These calculations involve *adjusting* experimental yield for the two years of exceptionally low rainfall (1980/81 and 1983/84) by substituting the yield predicted for those two years in the regression of rainfall on experimental yield (Appendix 8), and by compensating for the loss of yield through eldana infestation at the rate of 0,0625 tons sucrose for each eldana larva per 100 stalks of cane (SASA Experiment Station, 1984).

Table 25: **Calculation of an adjusted experimental yield for comparison with the projected technological yield, for the decade 1976/77 - 1985/86, tons sucrose/ha.**

Year	Rainfall (mm)	Eldana per 100 stalks	Yield adjustment for		Yield (tons sucrose per hectare)	
			rainfall (1)	eldana** (2)	actual (3)	adjusted (1+2+3)
1976/77	1 452	no data	nil	nil	10,89	10,890
1977/78	1 006	0,9	nil	+0,058	11,64	11,698
1978/79	1 037	0,9	nil	+0,058	12,09	12,148
1979/80	880	2,1	nil	+0,131	10,90	11,031
1980/81	876	6,5	+1,57*	+0,406	8,85	10,626
1981/82	1 007	8,3	nil	+0,519	8,74	9,259
1982/83	933	3,9	nil	+0,244	9,10	9,344
1983/84	606	9,0	+1,80*	+0,562	8,09	10,452
1984/85	1 415	4,8	nil	+0,300	10,21	10,510
1985/86	1 035	4,3	nil	+0,269	8,93	9,199
Mean (adjusted experimental yield for the decade)						10,516

* Yield estimated by regression (Appendix 8) minus actual yield.

** 0,0625 tons scurose for each larva per 100 stalks.

The mean adjusted experimental yield for the decade was obtained by adding to the actual yield column (3), the estimated yield shortage due to low rainfall in the two years, 1980/81 amd 1983/84, column (1), and the estimated yield loss due to eldana, column (2). The result, 10,516 tons sucrose per hectare, supports the arbitrary choice of 10,52 tons as the estimated yield for the end of the decade.

It is now possible to revise the relationship between experimental and industrial yields, and thereby the respective contributions of research and extension to the Sugar Industry's increase in productivity, by substituting the projected for the actual experimental yield in Table 24 on page 90. This is done in Table 26 with the result that the percentage contributions of research and extension to the Sugar Industry's increase in productivity, during the three decades were, respectively 65% and 35% in the first decade, 37% and 63% in the second decade and 17% and 83% in the third decade.

Table 26: Revised relationship between estimated experimental yield and industrial yield by decades, 1956/57 - 1985/86.

Yield (tons sucrose/ hectare/annum)	4th decade 1956/57 - 1965/66	5th decade 1966/67 - 1975/76	8th decade 1976/77 - 1985/86
Experimental yield:			
initial yield	8,82	10,21	10,50
final yield	10,11	10,50	10,52
change in yield	1,48	0,29	0,02
change as % of ICPY*	10,96	2,13	0,15
Industrial yield:			
initial yield	4,4	5,6	6,2
final yield	5,2	6,1	6,3
change in yield	0,8	0,5	0,1
change as % of ICPY*	5,88	3,68	0,74
Ratio of experimental to industrial percentages of change, as percentages	65 : 35	37 :63	17 : 83

* integrated climatic potential yield

It is hypothesised that the Industry's productivity, as previously estimated by production function analysis (Table 13, page 58), can be apportioned to research and extension in proportions given in Table 26 for the three decades.

Farm and field trial yields. The relationship between farm yields and yields in field trials has been examined previously for different purposes. Davidson & Martin (1965) contended that if a relationship could be established between farm and experiment yields, much time could be saved in developing and introducing new technologies. These authors investigated farm - field trial relationships for rice, sugar and wheat in different parts of Australia. For sugar, using 61 observations, they found Y = 0,023 + 0,548X the best fitting regression equation between farm yields (Y) and experiment yields (X). However, they suggest that for crops (but not for livestock) that the relationship is curvilinear with the rate of increase in farm yields *declining* with increasing experimental yields. The opposite appears to be the case in the South African Sugar Industry as is indicated in Table 26.

Within the South African Sugar Industry, the simple relationship of 9 tons of cane (or 1,125 tons sucrose) per 100 mm of water (effective rainfall) used by the crop, has been employed for more than 20 years to estimate farm production levels. This relationship is derived from a comprehensive irrigation research programme summarised in a review paper by Thompson (1976). The practical form of the relationship, Yield = 0,8E. x 9/100 was used to '... estimate the potential yield of cane in an average year in a particular region from meteorological data ...' (SASA Experiment Station, 1982). The factor 0,8 is used to reduce Class A pan evaporation to evapotranspiration on an annual basis and the factor 9/100 represents 9 tons cane per 100 mm of evapotranspiration.

In using this relationship to estimate yields obtainable by cane growers, it has become common practice to substitute 70% of the rainfall on the crop for the 0,8Eo factor, and to reduce the yield by 30%, being the assumed relationship between 'better farmer' yield and field trial yield.

Table 27 summarises the relationships reviewed and proposed in the present study between farm (industrial) yields and field trial (experimental) yields.

Table 27: Relationships developed between farm and field trial yields on sugarcane.

Production area	Reference	Farm yield as % of field trial yield
Queensland	Davidson & Martin (1965)	55
South Africa	Thompson (1976) ('better farmer' yield)	70
	Present study, 1957/58 1986/87	51 67

In view of the hypothesis that the transfer of technology can be measured by the change in the relationship between experimental and industrial yields, the question of yield limits or potential yields needs to be considered. Using Thompson's (1976) relationship between yield and meteorological factors and the results of analysis of field trials carried out for this study, it is possible to postulate potential yield levels as shown in Table 28. It has already been noted (Table 26) that over the past 30 years industrial (average farm) yield has increased more than the experimental (field trials) yield. The estimates of potential yield in Table 28 indicate that the differences between climatic potential and experimental yields and between experimental and industrial yields are now of a similar magnitude and may also have reached a similar stage in the degree of difficulty for further increase.

Table 28: **Estimates of potential yields of different kinds in tons sucrose per hectare per annum**

Kinds of yield	Yield			Reference or factors used
	Irrigated	Rainfed	Integrated	
Climatic potential	20,00	12,00	13,60	Thompson (1976)
Field trials (experimental)	15,11	10,01	10,52	See Figure 9
Better growers	10,58	7,01	7.36	70% of field trial yields (Thompson, 1976)
Average grower (industrial)	9,04	5,99	6,3	60% of field trial yields and 86% of 'better' grower yields

This suggests that it might be possible to estimate the lag in the adoption of technology from a comparison of the rate of increase in experimental and industrial yields. In such an estimate the effects of specific influences on yield that are not yet affected by research output, such as the stem-boring pest eldana, would need to be assessed separately and objectively.

CONCLUSION

Agricultural commodity extension has developed from the original community orientated extension as a result of the commercialisation and specialisation of agricultural production.

Estimating returns on the expenditure on agricultural extension has not been successful previously because no appropriate means of measuring extension effects have been found for the mixed product output of agriculture and because no satisfactory method of separating the effects of research and extension have been proposed.
For agricultural commodity extension, and specifically, for the South African Sugar Industry, it is suggested that the change in the relationship between the Industry's yield and the yield obtained by technologists in field trials, the experimental yield can be used as a measure of the transfer of technology or extension. During the 30 years 1957/58 to 1986/87 the experimental yield increased by 22%, from 8,62 to 10,52 tons sucrose per hectare, while the industrial yield increased by 43,2%, from 4,4 to 6,3 tons sucrose per hectare. It is suggested that the increase in experimental yield represents the return on the 'state of the art' technology and the increase in industrial yield, less the increase in technological yield, represents the return on the transfer of technology or extension. For evaluation purposes this means 51% and 49% of the industry's increase in productivity over the 30 years (viz. 1,85 tons sucrose, Table 16, page 62), can be attributed to technology and extension respectively. However, it is the change in the proportions attributable to technology and extension during the 30 year period that is of particular significance for management. For example, technology's contribution to the industry's productivity declined from 65% during the fourth decade, to 37% during the fifth decade and finally to 17% during the sixth decade. Conversely, Extension's contribution increased from 35% during the fourth decade to 63% during the fifth decade and finally to 83% during the sixth decade.

The objective of this proposed method of apportioning the total return on R&D between technology and extension is to obtain a better estimate of the return on technology for subdivision among research programmes. The remainder of the return on R&D is attributed to "extension" but it is outside the scope of this study, to sub-divide it among the various components of extension, such as education, training, experience and other factors.
The return on technology estimated in this chapter is apportioned among those research programmes capable of generating returns, in terms of tons of sucrose, in the following Chapter 6.

CHAPTER 6

EVALUATING COMMODITY RESEARCH PROGRAMMES

For the purposes of estimating returns,the Experiment Station's individual research programmes were considered by kind of research and category of maturity into which they were classified in Table 20 (page 73). Estimating was be done either *objectively*, when the data available was substantive, or *subjectively*. when some or all the data had to be inferred.

As shown in Table 20, the largest group, 28% of the total number of research programmes conducted by the Experiment Station in 1985/86, was in the mature category F. Most of these programmes were initiated some years ago as offensive research programmes to develop new technologies for increasing yields or reducing costs. With time, these technologies have matured through the stages of early and increasing adoption by growers until they have reached their present stage of maximum adoption when little or no further returns can be attributed to them. As many as possible of the programmes that reach the stage of maximum adoption, should be terminated and the management decision to do so, at the optimum time, would be facilitated if the levels of adoption are known or monitored.
Some of these programmes may need to be maintained in order to prevent yield decline or to provide for the testing of new or additional technologies that become available, for example fertilizer, herbicide and nematicide trials. They should be described as *maintenance* research programmes likely to give little and only occasional return on expenditure. There are also other mature research programmes that need to be continued in order to monitor production conditions and factors on a permanent basis but which generate no (or unknown) returns; these are classified in category G and typical examples are the control of pests other than eldana, monitoring leaf scald and investigating acid chlorosis. This is the second largest category in the Experiment Station's research portfolio for 1985/86, respresenting 25% of the total. Since no returns are obtained on this category of research programmes, it can also be described as *maintenance research*.

The third largest category of research programmes in 1985/86, nearly 19% of the total, is conducted to improve the technical services available to growers from the Experiment Station. No returns need be estimated for these programmes because their costs are, or should be, recovered as fees for the services.

At the other end of the maturity range are three categories of research programmes which also generate no or negligible returns; these are categories A, B and C which represent respectively research programmes:

- on which no returns can be expected (basic research), those
- that have not yet generated technologies (i.e.: biological control of eldana), and those
- that have been aborted for one reason or another (i.e.: chemical control of eldana).

These three categories together represent nearly 16% of the total research portfolio which, added to the previously discussed 72% in categories F, G and Services, on which no returns are obtained, leaves only four programmes, about 12% of the total number, in categories D and E on which returns can be expected.

OFFENSIVE OR STRATEGIC RESEARCH PROGRAMMES

Offensive research programmes are those initiated to increase productivity and profitability. Seven of the Experiment Station's 32 research programmes in 1985/86 can be classified as *offensive* or *strategic* but only one of them, Plant Breeding, was at that time making a return on expenditure. This is because the category of offensive research programmes includes basic research, those in early stages of development or those whose technologies have yet to be adopted by growers. The exception, Plant Breeding, is a mature programme in terms of development but which is producing new technologies (varieties) on an on-going basis. Of the seven varieties released from the Plant Breeding programme and which were still in production in 1985/86, four were in decline and three were increasing their share of the area under cane.

Plant Breeding. 'The search for new varieties started as soon as sugarcane began to be grown on a plantation scale. In the early days these varieties were imported in large quantities and inevitably brought in with them diseases that have continued to plague the Industry up to the present day. The Industry became at one stage solely dependent upon the variety Uba, which had originated in India. When Uba later failed, a crisis arose within the Industry, and this in turn led to the establishment of the Experiment Station' (SASA Experiment Station, 1975).

That the variety crisis was the main motivation for the Industry initiating research is further evidenced by the Sugar Association's resolution in 1921 '... that it is vital to the industry that cane diseases, the *right varieties of cane* for South Africa and proper methods of cultivation should be studied...' (SA Sugar Association, 1923). The first formal definition of objectives for the Experiment Station (SASA Experiment Station, 1924) listed 'Establishment of varieties other than Uba' as the first item and varieties have remained in that priority position through to the present. The latest Annual Report of the Experiment Station (SASA Experiment Station, 1989) still gives plant breeding pride of place among its activities.

An *objective* estimate of the return on the plant breeding programme (Table 19 #1) has been obtained by the calculation of a variety yield index (YI) for the Industry as a whole from available substantive data, as follows:

$$YI = (Pa \times Ya) + (Pb \times Yb) \ldots (Pn \times Yn)/100$$

when Pa, Pb, Pc ... Pn are the percentages of the Industry's total cane production produced by the varieties a, b, c ... n in order of their release (Appendix 9), and Ya, Yb, Yc ... Yn are the yield indices of the individual varieties (Inman-Bamber, 1988 and Appendix 10). An individual variety index is calculated as the percentage by which it was higher (or lower) than a standard variety in a series of variety trials. The standard varieties used and the percentages by which they differed from the preceding standard variety are given in the following Table 29.

Table 29: Percentage differences between standard varieties used in calculating variety yield indices.
(Appendix 10 for data)

Standard variety	Percentage difference from previous standard variety
'Other varieties'	140% of Uba
Co 331	112% of Co 301 (in 'other varieties')
NCo 310	120% of Co 331
NCo 339	93% of NCo 310
NCo 293	106% of NCo 310
NCo 376	106% of NCo 310

The first official statistical returns of the agricultural sector of the South African Sugar Industry show that, at 30 April 1923, 99,83% of the area under cane was of the Uba variety (Dodds, 1926). To protect the Industry from the effects of mosaic disease, which had been identified in 1922 and to which Uba was fortunately resistant, legislation was introduced in 1927 to prohibit the growing of any variety other than Uba (SASA Experiment Station, 1975). The recognition of Streak disease, to which Uba was highly susceptible, and the availability (after 1925) of quarantine facilities for screening introduced varieties, ended the Uba monopoly in 1931. From 1925/26 to 1930/31. therefore, the variety yield index for the Industry is that of the only variety grown, Uba which, for the purposes of this study, is taken as 100. From 1931/32 introduced varieties, and later locally-bred varieties, were released and the Industry's annual variety yield index is calculated from the percentage total cane production attributable to each variety and its yield in relation to Uba and subsequent standard varieties. The annual variety yield index is given in Appendix 12.

The objective return on the Plant Breeding programme can now be obtained from the change in the yield index for any particular period, as summarised in Table 30 below. For 1985/86 the return on plant breeding can be calculated as the percentage annual increase attributable to variety improvement during that decade, namely 0,14% (Table 30) of the annual increase in sucrose production per hectare (0.72/10 tons, Table 13, page 58) on 409 533 hectares (Appendix 5), that is: 0,14 x 0,072 x 409 533 = 4 128 tons.

Table 30: Percentage increases in yield attributable to Plant Breeding through variety improvement. (Data from Appendix 11).

Decade	Percentage yield increase	
	for the decade	mean annual for decade
1925/26 - 1935/36	12,04	1,204
1936/37 - 1945/46	17.09	1,709
1946/47 - 1955/56	23,37	2,337
1956/57 - 1965/66	7,89	0,789
1966/67 - 1975/76	2,95	0,295
1976/77 - 1985/86	1,40	0,140

In the plant breeding programme the selection for disease (Table 19 #2) is done by pathologists as well as plant breeders but the programme contributes to the same objectives as the plant breeding programme and is therefore included in the objective assessment of returns made for plant breeding above.

Biological control of eldana. The stem-boring caterpillar *Eldana saccharina* has become the most serious pest of sugarcane in South Africa during the last two decades. It is commonly found in all but the higher and cooler areas of the Industry and all varieties can be attacked (SASA Experiment Station, 1988b). Surveys of the incidence of eldana have been conducted throughout the Industry for some years and the levels of infection in different regions have been established and are continuously monitored (Thompson, 1988). The natural fluctuations in eldana infestations at any particular site, probably due to weather and climate effects, as well as the indication that infestations rise to a relatively high level before declining to a lower 'stable' level, make it difficult to estimate the efficacy of control measures. By its nature, the Biological control programme (Table 19 #3) will have a long lead time and it is still too early for results to be assessed in economic terms although biological results appear promising. Without quantitative results, the return on the programme cannot be estimated for the datum year (1985/86) but a tentative and ex-ante estimate can be made of the *potential* returns on the programme by subjectively estimating the loss caused by the pest.

Between 1985/86 and 1987/88 the average number of eldana per 100 stalks rose from 1,61 to 3,24 (Thompson, 1988) and the loss in yield for every 1 eldana per 100 stalks was estimated at 0,5 tons of cane per hectare (SASA Experiment Station, 1984). If, as Thompson (*op. cit.*) suggests, a stable eldana level of 2 eldana per 100 stalks can be accepted, the industry-wide loss of sucrose per hectare in 1987/88 would be approximately 0,0775 tons [(3,24 - 2) x 0,5 x 0,125], giving an estimated total loss to the Industry of 31 000 tons of sucrose in that year.

Eldana biology. This programme (Table 19 #4) consisted, in 1985/86, of six projects to obtain a better understanding of the nature and behaviour of the pest. Although the primary objective of these projects is to improve the chances of success in more applied work, the results will not, in themselves, be capable of assessment in economic terms. The programme must, therefore, be considered a basic research programme, and its cost will be added to those of the Biological control programme which will be the main beneficiary of the biological information it was designed to provide.

Mosaic epidemiology. This project (Table 19 #5) is the basic research component of the mosaic control programme (#12) which is to be considered later. The objective is to investigate the epidemiology of mosaic, particularly the virus-vector-host relationships, the results of which will be exclusively of biological value and not capable of economic evaluation except as part of the mosaic control programme from which it was generated.

Nematode biology. The research work on nematodes has been shared between nematologists and agronomists working together, with the former concentrating on the more basic biological aspects and the latter working on the agronomy of nematicide use under local conditions. In the recent past, projects have also been commissioned with Universities when specialized staff and facilities were not available at the Experiment Station. This programme provides an excellent example of the advantages of flexibility in management inherent in commodity controlled R&D. The nematode biology programme (Table 19 #6), consisting of two projects, has the objectives of studying the potential for biological control of nematodes and investigating the relationships between sugarcane, nematodes and environmental conditions. It is, therefore a basic research programme the costs of which must be added to those of the nematicide programme (#15) to be considered later.

DEFENSIVE RESEARCH PROGRAMMES

Defensive research is conducted to prevent yield decline, reduce costs of production or to monitor production factors and conditions. Of the Experiment Station's 18 defensive programmes in 1985/86, 11 were still making some, albeit limited return on expenditure.

Cultural control of eldana. The objective of this programme (Table 19 #7), consisting of three projects, is to assess the incidence and effects of eldana under different management conditions and in different varieties. Two of the projects are in the entomology portfolio and one in the plant breeding programme. At present the plant breeding project is simply to assess the level of susceptibility or resistance exhibited by released varieties (Nuss *et al*, 1986) and is therefore, correctly classified as defensive R&D. Work is contemplated on the breeding of varieties with resistance to eldana (Bond, 1988) and this would be classified as offensive research and part of the plant breeding programme. Since the prospects of complete control of eldana are not good and 'Once it became apparent that the problem was not a transient one ...' (Carnegie, 1987) and the pest accepted as a permanent feature of the Industry, albeit stabilized at a low level of infestation (Thompson, 1988), the priority for including eldana resistance as a major selection criterion on the plant breeding programme, must be very high.

The research programme of cultural control of eldana has demonstrated that eldana numbers in cane increase rapidly with cane age (Carnegie, 1983) and this led to the recommendation that cane should be harvested as young as possible. Murdoch (1988) concludes that harvesting cane at a younger age '... does not appear to have increased yields but it may, of course, have stayed a fall (in yield)'. The recommendation to harvest at a young age remains valid because a lower population of eldana is, in itself, a desirable situation even if other effects of harvesting young cane counteract the benefits of lower eldana numbers. A more recent project (McCulloch, 1989) has shown that the use of a chemical ripener can increase the yield of early harvested cane by between 0,7 and 1,3 tons sucrose per hectare. If returns on this programme were estimated for 1989 (instead of 1985/86) they might, therefore, be higher.

If the industry-wide increase in eldana numbers per 100 stalks from 1,61 to 3,24 between 1985/86 and 1987/88 (Thompson, 1988) and the loss in yield of 0,5 tons of cane per hectare for every 1 eldana per 100 stalks (SASA Experiment Station, 1984), are taken together with Murdoch's (1988) conclusion that the industrial yield has not declined, a subjective estimate of the return on this programme can be calculated as (3,24 - 1,61)/3 x 0,5/8 x 409 533) = 13 906 tons of sucrose in that year.

Chemical control of eldana. The results of work up to 1985/86 on this programme (Table 19 #8) were sufficiently discouraging to make its continuation undesirable from an environmental protection point of view. The programme is best considered a 'dry hole', that is, one that has not produced positive results, in economic terms, but the costs of which must be taken into account if returns on research are not to be over-estimated. Negative results are not necessarily without value, particularly biologically, because they can contribute to scientific knowledge.

The costs of this programme should (probably) be added to those of the eldana biological control programme because in the long term, the outcome of research on eldana control is most likely to be in the form of integrated control to which various methods of control contribute.

Control of pests other than eldana. For the datum year 1985/86, this programme (Table 19 #9) involved no field or laboratory work although costs were incurred in monitoring the pest situation generally. This is not always so; in preceding years experimental work was undertaken to find suitable substitutes for Dieldrin which had given good control of white grubs but the sale and use of which was subsequently prohibited. In the programme of work for the Entomology Department is the injunction 'To maintain contact with extension ...

and the industry so that problems can be recognised and subjected to investigation when necessary ...' (SASA Experiment Station, 1985). This commitment, and the type of work that results, is typical of defensive research and since even subjective assessment of yield loss, or avoidance of loss, is not possible, the costs of such a programme must be debited to the maintenance of crop protection.

Ratoon Stunting Disease (RSD). This disease causes a greater overall loss in yield than any other sugarcane disease in South Africa. It is caused by a bacterium and occurs in all cane growing areas, affecting all varieties, some more severely than others (Bailey & Bechet, 1986). Estimates of the level of infection in commercial fields, obtained from the records of the RSD diagnostic service provided by the Experiment Station in which an average of nearly 3 500 fields are sampled annually, are considered a reasonable indication of the status of RSD in the Industry (Bailey, 1988). These estimates are summarised in the following Table 31.

Table 31: Percentages of cane samples infected with RSD during three two-year periods 1982 + 1983, 1984 + 1985 and 1986 + 1987.

Periods	Years	Percentage infection
1	1982 + 1983	12,9
2	1984 + 1985	11,8
3	1986 + 1987	8,3
6-year (1982 - 1987) mean		11,0

From these data the average annual decline in RSD infection is found to be 0,77% [(12,9 - 8,3)/6] per annum on an average infection level of 11%. Bailey (*op.cit.*) has estimated that the losses caused by RSD amount to 2,5% of the industry's annual production, therefore a subjective estimate of the return on the research programme (Table 19 #10) on this disease is 0,175% (0,77/11 x 2,5) of the value of the Industry's crop in 1985/86; in terms of sucrose, 4 515 tons.

Smut. Smut is the most serious disease problem facing the Industry with regard to both potential loss of yield and the difficulty of control once it becomes severe (Bailey, 1979). Bailey's conservative

estimate of the Industry's loss in yield due to smut in 1978/79 was 50 000 tons of cane or approximately 6 000 tons of sucrose. The only effective control measure for smut is the planting of resistant varieties and the selection criterion of smut resistance is part of the Plant Breeding programme. The Smut control programme (Table 19 #11) is defensive research with the objective of developing practical and agronomic methods of maintaining, rather than increasing, yield. Pearse (1989) obtained small but significant yield increases in only two of six field trials on rogueing where smut levels were high and no increase in the two trials where smut levels were low. The trials showed, however, that rogueing effectively reduced the incidence of smut and is therefore advantageous in maintaining yields.
Bailey (1979) estimated the loss of yield caused by smut and mosaic as 50 000 and 40 000 tons of cane per annum. If the technologies developed by the research programmes on smut and mosaic control are being used on an additional 10% of the area affected by these diseases each year, the returns on these programmes can be estimated subjectively as 625 and 500 tons of sucrose in the datum year.

Mosaic. Mosaic is a virus disease which occurs frequently in sugarcane grown in the coastal hinterland and higher altitude areas of Natal (Bailey & Fox, 1987). Effective control is, like smut, only possible with the planting of resistant varieties but the cultural control measures developed in this programme (Table 19 #12) are effective in maintaining yields. The subjective estimate of the return on this research programme, is calculated in the previous paragraph, as 500 tons of sucrose in 1985/86.

Leaf scald. This is a bacterial disease presently under control because all released varieties are resistant and varieties under development in the Plant Breeding programme are routinely tested for susceptibility to the disease before release. It can be assumed, therefore, that leaf scald causes the Industry no loss. A project to improve screening techniques for leaf scald is part of the Plant Breeding programme but the cost of that part of the programme (Table 19 #13) concerned with monitoring the disease locally, and participating in the international project on variation in the leaf scald pathogen must be debited to research maintenance.

Fertilizers. Thompson (1968), reviewing the work done and results up to 1968, concluded that the major influences on fertilizer use in the sugar Industry were the increased area under cane, quota restrictions on production and world sugar prices. The situation twenty years later, as indicated in Table 32 below, suggests that fertilizer usage increased at a faster rate than the area under cane, probably due to intensive research programmes on fertilizer use and sugarcane nutrition at the Experiment Station since the 1950s which '... have played a significant part in substantially increasing cane yields ...' (Meyer & Wood, 1985).

Table 32: **Percentage increase in area under cane and use of fertilizers, expressed as decade averages.** [(Data from Thompson (1968), Meyer & Wood (1985) and Turner (1988)]

Decade	Average percentage increase in	
	area under cane	Fertilizer use
1956/57 - 1965/66	42	153
1966/67 - 1975/76	33	57
1976/77 - 1985/86	27	19

The fertilizer programme (Table 19 #14) is, at the present time, a defensive research programme to maintain yields. There are, however, four completed fertilizer R&D projects that could still be making returns and therefore need to be considered (Meyer, 1989).

A research project on soil mineralization led to the assessment of nitrogen requirements being made in terms of a soil's mineralization capacity and not only on expected yield. The potential effect of this was that on approximately 190 000 hectares of humic soils, a previous recommendation of 150 - 160 kilograms of nitrogen could be reduced to 100 kilograms per hectare without loss in yield. It is subjectively estimated, from the unit cost of nitrogen to the grower and confidential information on the amount of nitrogen sold in the datum year, that the saving effected was worth the equivalent of 2 425 tons of sucrose.

The second fertilizer project that could still be making returns was on the availability of phosphorus. Because many of the soils on which sugarcane is grown were found to be deficient in phosphorus in the virgin state, research programmes on phosphorus were amongst the earliest started after the establishment of the Experiment Station in

1925. Some forty years later work on phosphorus became necessary again because phosphorus-fixing soils came into use when part of the Natal Midlands were developed for cane growing in the late 1960s (Meyer, 1980). In that project, the response to the much higher levels of superphosphate recommended, was estimated at about 1 ton of sucrose per hectare per annum on the 50 000 hectares of phosphorus-fixing soils (SASA Experiment Station, 1983a). The changes in phosphorus consumption given in Table 33 below suggest that by 1984/85 it is unlikely that any further return can be credited to the research project and the costs of further research work on phosphorus availability must be debited to research maintenance. This is confirmed in a more recent paper by Meyer & Wood (1989) who believe that '... the amounts of P (phosphorus) used in the sugar industry have been similar to those which experimental results indicate to be necessary ...'.

An associated problem on the 50 000 hectares of phosphorus-fixing soils is aluminium toxicity. The finding in a research project was that about 5 tons of lime per hectare could increase yields by about 12 tons of cane per hectare. Information of the use of lime (Wood, 1989) indicates that about 25 000 tons are still used annually. On the assumption that the recommended rate is used (it is unlikely to be higher) and that it is applied only at re-planting (the only practical time), it will take ten years before all high aluminium soils have been treated. For 1985/86 therefore, the subjective estimate can be made that on 5 000 hectares, yields were increased by 6 tons of cane, half the experimental yield, or 0,75 tons of sucrose per hectare, a total of 3 750 tons.

Table 33: **Mean annual percentage change in fertilizer use, 1975/76 - 1979/80 and 1980/81 - 1984/85.**

Fertilizer type	1975/76 - 1979/80	1980/81 - 1984/85
All fertilizers	- 1,4	+ 4.8
Nitrogen	+ 1,0	- 1.4
Phosphorus	+ 0,5	+ 0,3
Potassium	- 1,5	+ 1,1

The fourth research project on fertilizers that could still be making returns was on potassium. In early trials by the Experiment Station yield responses to potassium were disappointing, probably because low rates of potassium were used and soil potassium levels were still relatively high (Meyer and Wood, 1985). Since then the potassium nutrition of cane has received much attention from Experiment Station and Industry agronomists. The percentage change in consumption of potassium shown in Table 33 suggests that the recommendation eminating from the research project on potassium has been implemented is supported by the conclusions after the most recent survey (Meyer *et al*, 1989) are '... that there are no large scale nutrient deficiencies, *apart from potassium* ...'. Unfortunately there are insufficient data on yield increase and area on which higher rates of potassium fertilizers were used, to allow an estimate of the returns on the research project.
The programme on fertilizers, including the four projects discussed, is a defensive research programme classified in the maturity category F because returns can still, or occasionally could, be obtained as has been shown in the case of the nitrogen and lime projects, and also because changes in input prices or types could change the economics of fertilizer use.

Nematicides. In addition to the basic research work on nematode biology conducted by nematologists, which has been discussed (page 102), a considerable and successful research programme (Table 19 #15) has been carried out on nematicides by agronomists. The effects of various factors such as soil pH and clay content, rainfall and the age at harvest on the yield responses of sugarcane to the nematicide Temik were reported by Donaldson (1985). These data may be of value in contributing to an estimate of the return on R&D responsible for the development of the nematicide itself, but this is not the objective of the present study. The return on industrial R&D put into developing nematicides, or any other production factors, is recovered through the price charged for the product. Research at the Experiment Station on nematicides is conducted because nematicides '... are an important factor limiting sugarcane yield ...' (Spaull, 1981) and its importance can be judged from data provided by Spaull & Cadet (1989) who estimate the annual loss in yield of sugarcane due to nematodes in Burkina Faso, the Ivory Coast and South Africa. The South African data are given in Table 34.

Table 34: **Estimated annual loss in yield of sugarcane due to nematodes in South Africa.** (after Spaull & Cadet, 1989).

Soil clay category	Approximate area (hectares)	Loss in yield (tons cane per ha/annum)	Estimated total loss in yield (tons cane)
2- 5% clay	35 000	19.0	665 000
6-10% clay	75 000	11,8	885 000
10-35% clay	165 000	5,8	957 000

Estimates of losses in yield for the Industry as a whole, vary from 0,9 million tons of cane in 1981 (Spaull, 1981) to 2,5 million tons of cane in 1989 (Spaull & Cadet, 1989). In the cost effectiveness exercise (SASA Experiment Station, 1983), the return on nematicide research at that time, was subjectively estimated as an annual yield increase of 0,25% on 20% of the Industry's soils; for 1985/86 this would be equivalent to 1 290 tons of sucrose. Confidential data on the sale of nematicides (May-Baker Agrichem, 1989 and Agricura Rumevita, 1989) suggest that since 1985 there has been no significant and consistent increase in the use of nematicides by cane growers, indicating that this research programme can have generated little further return after that date, 1985.

Growth regulators. The Experiment Station was the first institute to demonstrate the ripening effects of Ethrel and Polado on cane and that, under suitable irrigated conditions, artificial ripeners could increase yields substantially. An estimate of the potential return on the original offensive research programme on growth regulators would have been based on the assumption that about 17% of the Industry's area under cane could have produced an additional 3 tons of sucrose per hectare per annum (SASA Experiment Station, 1983), a total of over 200 000 tons of sucrose. However, the subjective estimate of returns on this programme was that on 17% of the area under cane an '... annual average improvement in effectiveness, or reduction of cost, of 0,5% can be anticipated ...' (SASA Experiment Station, *op. cit.*); expressed in terms of sucrose this is 1 205 tons. This estimate is likely to be valid for 1985/86 but thereafter

any increase in the use of growth regulators was probably for the purpose of reducing yield loss in cane cut early for eldana control purposes. This is confirmed by confidential information provided by the agro-chemical company which has the main share of the market for growth regulators (ICI Farmers, 1989).
The continuing work on growth regulators (Table 19 #16) is defensive research concerned with the relationship between ripeners and varieties, nitrogen fertilization, moisture stress and lodging of the crop, as well as testing phytotoxicity and recommendations proposed for new growth regulators that may come on the market.

Herbicides. Unlike the original research programme on growth regulators which had the objective of, and achieved, increased yields, the early work on herbicides was intended to reduce yield loss due to weeds. In spite of this, the work on herbicides, starting with the pioneer projects in the 1960s, has been of considerable value to the Industry. By 1983 the programme was '... probably concerned (only) with the (weed) problem situations that are causing no more than a 0,05% reduction in crop throughout the Industry' (SASA Experiment Station, 1983). In terms of sucrose this is equivalent to 1 290 tons which is taken as the subjective estimate of the return on the herbicide R&D programme in 1985/86. Sales of herbicides indicate that, as in the case of growth regulators, there has been no significant and consistent increase in the use of herbicides since 1985 (ICI Farmers' Organisation, 1989; Agricura Rumevita, 1989; May-Baker Agrichem, 1989 and Shell Chemicals, 1989). The present programme on herbicides (Table 19 #17) must, therefore, be considered defensive research to maintain productivity with, perhaps, some cost saving potential.

Trashing. An offensive research programme on the value of trash, started in the early 1960s, resulted in a potential yield increase of 9 tons of cane per hectare per annum when cane was trashed at harvest instead of burned. For a number of reasons, not the least being the higher cost of labour, the practice of trashing declined and more recent findings in the continuing, but now defensive, research programme (Table 19 #18) indicate that the practice of spreading cane tops left after burning, together with the use of herbicides, can have at least half the value of a full trash blanket. The 1983 subjective estimate of returns on this programme (SASA Experiment Station, 1983), which is probably applicable in 1985/86, was that yield is increased by 0,375 tons of sucrose per hectare on 0,5% of the area under cane; this is equivalent to 768 tons of sucrose. The increasingly strong environmental lobby against cane burning is an additional reason for continuing this programme as defensive research.

Variety agronomy. In choosing a variety to plant, a grower is committing himself to that variety for as much as ten years on a particular field; furthermore replanting is the most expensive production operation. The choice is therefore important and should be based on the available information on the variety's performance under ecological conditions as similar to those of the field as possible. This defensive research programme (Table 19 #19) has that objective as well as providing information on the interaction between varieties and such important factors as fertilizer nitrogen requirements, susceptibility to moisture stress, cutting age and the effects of ripeners. Evaluation of this kind of programme can probably only be made subjectively and in negative terms. The cost of not making the right choice of variety is estimated as 0,625% of production on 5% of the area under cane, or 806 tons of sucrose (SASA Experiment Station, 1983).

Soil amelioration. This research programme (Table 19 #20) includes a number of projects, in three departments of the Experiment Station, on how to overcome the adverse effects of bad management on some of the Industry's most potentially productive soils. Work on drainage and the amelioration of saline soils has demonstrated that in many cases, productivity can be restored. Since any form of soil amelioration is costly, research needs to continue on techniques and costs to make possible the recovery of as many hectares as economically possible. This programme typifies maintenance research on which returns are difficult to estimate but with about 0,03% of the area under cane ameliorated (in 1983) resulting in a yield increase of at least 6,25 tons of sucrose per hectare (SASA Experiment Station, 1983), a subjective estimate of the return on this programme would be the equivalent of 768 tons of sucrose.

Soil compaction. This is another research programme (Table 19 #19) on which it is impossible to estimate returns. For reasons of environmental protection and production economics it seems desirable to conduct such a programme which is therefore classified as maintenance research. Field trials have indicated that losses of ten tons of cane per hectare can result from soil compaction caused by the in-field use of heavy machinery when the soil is too wet (Meyer, 1989).

Acid chlorosis. This is a minor research project (Table 19 #22) on which the returns, if they could be estimated, would probably be very small. However, because the problem has a dramatic appearance, it is considered worth investigating for psychological reasons in the research maintenance category. The costs should be borne by the fertilizer research programme (#14).

Nitrogen fixation. This is a relatively minor but potentially important project motivated by the high cost of nitrogen fertilizer. The research is conducted on nitrogen-fixing bacteria that are naturally association with sugarcane roots. No returns can be estimated yet for this programme (Table 19 #23) and the costs should also be borne by the fertilizer research programme (#14).

Lysimetry. The likelihood of irrigation water becoming a much more expensive production factor makes it wise to have a better understanding of the crop x water interaction including the possibility of differential varietal response to applied irrigation water. This is, therefore, a typical defensive research project (Table 19 #24) that has no pay-off itself but which could maintain productivity at lower cost; its costs should be borne by the irrigation research programme (#29).

PRECAUTIONARY RESEARCH PROGRAMMES

The third category of research required in an agricultural commodity R&D institute is *Precautionary research*, that is research undertaken as a precaution against some future adverse circumstance. The return on this kind of research, not measurable in economic terms might be assessed as insurance is assessed, namely in terms of its cost (premium) in relation to the potential loss (risk) it covers. The costs of precautionary research, like the premuims on other insurance, should be a charge against overheads.

Development of machines and equipment. The cost and supply of agricultural labour in the cane growing areas of South Africa at present, makes the mechanisation of most cane production operations unnecessary, perhaps even undesirable, and uneconomic. However, the situation is likely to change at least in terms of cost, while the possibility of supply also being reduced must not be ignored. To reduce the risks of these eventualities the Agricultural Engineering department conducts 11 projects in this programme (Table 19 #25), developing machines and equipment for harvesting, transporting, transloading, planting, tilling and for other operations, as a form of insurance.

Alternative fuels. As a precaution against the shortage of liquid fossil fuels or in the event of on-farm production of ethanol from sugarcane being permitted, as it is in Brazil, this programme (Table 19 #26) was initiated. Its objectives are to investigate the practical implications of running diesel and petrol engines on pure and varied proportions of ethanol.

SERVICES RESEARCH PROGRAMMES

Six programmes undertaken at the Experiment Station in 1985/86 are described as Service research, conducted to provide or improve technical services required by sugarcane growers. With the adoption of a *user pays* policy it is incumbent on the Experiment Station to provide growers with efficient and high quality services and, because some of these services are also available commercially, to keep their costs competitive. At the same time, it would be wise to ensure that all marginal costs of providing technical services are taken into account when setting the charges for them. A primary reason for adopting a *user pays* policy was to avoid the situation in which all growers pay, through the levy, for services used by only some growers. Certain programmes and projects are conducted to back-up or to improve technical services and their costs should be recovered as part of the charges for them. There is no return *per se* on these programmes, equally their costs should not be met by the Industrial levy.

Crop production systems. In South Africa sugarcane is grown under a wide range of soil, topographical and ecological conditions. The most economical cane production systems for the variety of conditions need investigation as do particular field operations. The projects in the present programme (Table 19 #27) on cane production systems investigate, particularly from a cost reducing point of view, fertilizer handling, stool pruning and eradication, planting methods and crop spraying equipment and methods of application. The costs of this work should be recovered by the charges made for the Farm Planning Advisory Package available to growers.

Machine utilization and performance. To provide a complete and competent mechanisation advisory service for growers, it is necessary to have locally determined data on costs and performance of the machines used in the Industry. This programme (Table 19 #28) comprises six projects with this objective and its costs should be recovered by charges made for the Mechanisation Advisory Package.

Irrigation. In this programme (Table 19 #29) there are three projects involving a number of departments, on various aspects of irrigation. Investigations include short cycle irrigation for soils with limited total available moisture characteristics, methods of trickle irrigation and computer simulation of irrigation. The value of these projects to the Industry is to improve the Irrigation Surveys and Advice Package available to growers from the Experiment Station, the charges for which should include the costs of these projects.

Analytical chemistry. Most of the work done in this programme (Table 19 #30) is in support of, and to improve, the Experiment Station's fertilizer advisory service; the costs of the programme should therefore be recovered through the charges for soil surveys/sample analysis and the Fertilizer Advisory Package. The projects in this programme include investigations to improve the prediction of potassium availability, to improve the computerised foliar analysis system, to assess the value of infra-red reflectance analysis techniques, and others.

This category of research can occasionally provide opportunities for generating revenue outside the Sugar Industry which should not be neglected. It is traditional at the Experiment Station not to patent original developments and techniques. While this is logical enough in the case of findings that can only benefit sugarcane growing, there is two-fold merit in taking advantage of financial returns that might be available from leasing, selling or patenting results that can be of advantage to other industries. In addition to the merit of increased revenue is the advantage of being able to recognise, and perhaps also reward, technologists who are engaged primarily in routine type work. A recent and relevant example of this is the development at the Experiment Station, of rapid analysis of cane juice by near infra-red reflectance (Meyer & Wood, 1988 and Meyer, 1989). As a result of this development at the Experiment Station, other industries, notably in paper making, are using the technique without having to pay for any of the development costs, which have been met by those cane growers who use certain services from the Experiment Station.

Run-off and catchment projects and **Modelling soil and water loss** are two programmes (Table 19 #31 and #32) conducted to underpin and improve the Farm Planning Advisory Package available to growers from the Experiment Station. They have two other advantages, the first being an expression of the commitment of the Experiment Station to the cause of environmental protection and secondly, they provide interest and motivation for technologists who would otherwise be limited to routine service work. The costs of these programmes should be built into the charges for the appropriate advisory package unless the Sugar Industry, as distinct from the Experiment Station, wishes to take advantage of the image building value of these programmes, in which case it may decide to meet the costs out of the general levy.

SUMMARY OF ESTIMATED RETURNS ON RESEARCH PROGRAMMES

The estimates of returns on 1985/86 research programmes, made in Chapter 6, in terms of tons sucrose, are summarised in Table 35.

Table 35: Summary of returns on 1985/86 research programmes expressed in tons of sucrose.

Research Programme or Project	Basis for assessment of returns or * Reason for no assessment	Estimated returns as tons of sucrose		
		Objective	Subjective	
			Yield in-crease	Yield main-ten-ance
1. Plant Breeding	0,127% of production (see yield index, page 99)	4 128		
2. Selection for disease resistance	* Included in #1 above			
3. Biocontrol eldana	* Long lead time	Nil		
4. Eldana biology	* Basic research (include costs in #3)	Nil		
5. Mosaic epi-demiology	* Basic research (include costs in #12)	Nil		
6. Nematode biology	*Basic research (include costs in #15)	Nil		
7. Cultural control of eldana	0,5 tons cane/hectare/1 eldana/ 100 stalks			17 906
8. Chemical control of eldana	*'Dry hole' i.e. no economic results (include costs in #3)	Nil		
9. Control of other pests	* No data (include costs in research maintenance)	Nil		
10. Ratoon stunting disease	Industry crop loss 2,5% at 11% infection, declining 0,77% p.a.			4 515
11. Smut	10% reduction p.a. in industry loss			625
12. Mosaic	10% reduction p.a. in industry loss			500

Research Programme or Project	Basis for assessment of returns or * Reason for no assessment	Estimated returns as tons of sucrose		
		Objective	Subjective	
			Yield in-crease	Yield main-ten-ance
13. Leaf Scald	* All varieties resistant (include costs in #1)	Nil		
14. Fertilizers	See page 107 for methods of estimating returns on fertilizers Nitrogen Lime		 2 435 3 750	
15. Nematicides	Yield increase 0,25% on 20% of area under cane		1 290	
16. Growth regulators	Cost reduction of 0,5% on 17% of area under cane		1 205	
17. Herbicides	Yield loss of 0,05% avoided			1 290
18. Trashing	Yield increase of 0,375 tons sucrose per hectare on 0,5% of area under cane		768	
19. Variety agronomy	Wrong variety reduces yield 0,625% on 5% of area under cane			806
20. Soil ameliora-tion	Yield increase of 6,25% on 0,03% of area under cane		768	
21. Compaction	* No data on area affected or effects (include costs in #20 above)	Nil		
22. Acid chlorosis	* No data on area affected or effects (include costs in #14 above)	Nil		
23. Nitrogen fixation	* Basic research (include costs in #14 above)	Nil		
24. Lysimetry	* Basic research (include costs in charges for services to growers)	Nil		
25. Machine develop-ment	* No data, i.e. effects of labour action. Costs regarded as insurance	Nil		
26. Alterna-tive fuels	* No data on fuel shortages/ sanctions (costs = insurance)	Nil		

Research Programme or Project	Basis for assessment of returns or * Reason for no assessment	Estimated returns as tons of sucrose: Objective	Subjective: Yield increase	Subjective: Yield maintenance
27. Cropping systems	* Costs met by charges for:- - Farm Planning Advisory Package	Nil		
28. Machine utilization	- Mechanisation Advisory Package			
29. Irrigation	- Irrigation Surveys and Advice Package			
30. Analytical chemistry	- soil surveys/sample analysis and Fertilizer Advisory Package			
31. Run-off and catchment Research	* Costs met by charges for:- - Farm Planning Advisory Package			
32. Modelling soil and water loss	- Farm Planning Advisory Package			

The totals of returns, as tons sucrose, of the different categories of research in 1985/86, were:-

Yield increasing programmes:

- estimated objectively (plant breeding) 4 128
- estimated subjectively (all others) 10 216

Yield maintaining programmes:

- all estimated subjectively 21 642

Total of subjectively estimated programmes 31 858

In the following Chapter 7 the returns on research programmes are converted from tons sucrose to rand and then compared with their costs. The comparison is made specifically for that year (Donovan, 1986), fortunately a year in which no abnormal expenditure occurred and which can therefore be considered as representative as is the decade mean used for the returns of that year.

CHAPTER 7 :

RETURNS AND COSTS OF AGRICULTURAL COMMODITY R&D

Productivity in the South African Sugar Industry was estimated by production function analysis in Chapter 3 and expressed in terms of tons of sucrose per hectare per annum. The average annual increase in productivity due to production technology during the decade 1976/77 - 1986/87, was 0.168 tons sucrose per hectare per annum (Table 15, page 61). Using this mean value for the year 1985/86 when 409 533 hectares were under cane (Appendix 5), the return on production technology, generated by R&D at the Sugar Experiment Station that year, can be calculated as 68 802 (0,168 x 409 533) tons of sucrose.

In Chapter 4, the work of the Experiment Station, with the objective of increasing productivity, was defined as consisting of three primary functions, *research* to develop production technology, *extension* to transfer production technology to producers and *growers advisory services* to improve producers capability of using production technology.

In Chapter 5 a method of apportioning increases in productivity between research and extension indicated that, in 1985/86, 17% of the increase in productivity due to production technology was attributable to research and 83% to extension (Table 26, page 93). In terms of tons of sucrose, therefore, the return on the research component of R&D in 1985/86 was 11 696 (68 802 x 0,17) tons and on extension 57 106 (68 802 x 0,83) tons.

Gross returns. Of the gross return on research, namely 11 696 tons sucrose, 4 128 tons were estimated *objectively* as the return on the plant breeding programme (Table 35, page 117), leaving 7 568 tons to be apportioned among all other research programmes that can only be estimated *subjectively*. Since the total of the subjective estimates of research programmes is 10 216 tons, it is necessary to reduce them by 25,92% to come within the 7 568 tons available. To be consistent, the same reduction, 25,92%, is used to reduce the subjective estimates of the *yield maintaining* researchd programmes, from 21 642 tp 16 032 tons sucrose. The adjusted total return on the whole research component is, therefore, 23 602 tons sucrose. Table 36 lists the research programmes on which subjectively estimated returns were made in Chapter 6, their adjusted returns (74,08%) for comparison later with costs, and their adjusted returns converted to rands at the average price received by growers in 1985/86, namely R218,14 per ton of sucrose (Appendix 5).

Table 36 : **Returns on research programmes in rands after reducing the subjective estimates by 25,92%.**

Research Programmes	Estimates on returns		
	Tons sucrose		'000
	Subjective	Adjusted	Rands
Cultural control of eldana	13 906	10 302	2 247
Ratoon Stunting Disease	4 515	3 345	730
Smut disease control	625	463	101
Mosaic disease control	500	370	81
Fertilizer trials	6 185	4 582	1 000
Nematicide trials	1 290	956	209
Growth regulator trials	1 205	893	195
Herbicide trials	1 290	956	209
Trashing	768	569	124
Variety agronomy	806	597	130
Soil amelioration	768	569	124
Totals:	31 855	23 602	5 150

Costs. To estimate the return on R&D it is necessary to deduct the costs obtained from the survey of technologists time and costs of all line function activities at the Experiment Station in 1985/86 (Donovan, 1986). The cost survey was structured departmentally to provide information for management purposes but it was done in sufficient detail to allow rearrangement under the three functional categories of research, extension and growers advisory services which is necessary for the present study. There are some items of expenditure that cannot be allocated to one of the three functional categories, for example costs of liaison with organisations outside the Experiment Station and the costs of precautionary R&D which is a form of insurance. Costs of these kinds in other businesses are usually regarded as overheads and they are classified as such in this study. Table 37 below is an example of the information obtained from the eleven departments included in the cost survey carried out in 1985/86 (Donovan, *op. cit.*).

Table 37 : Pathology departmental costs 1985/86.

Programme of Work	Technologists		Assistants		Hands		Costs (R)		Total (R)
	Time %	Cost R	Time %	Cost R	Time %	Cost R	Total staff time	All other	
Services									65 968
RSD diagnosis	2,3	4 622	12,9	6 160	10,8	2 025	12 807	11 919	24 726
Specialist Advice	2,2	4 421	0,2	96			4 517	4 204	8 721
Quarantine	4,1	8 238	5,0	2 388	7,2	1 350	11 976	11 146	23 122
Education	1,8	3 617	0,2	96			3 713	3 456	7 169
Seedcane	0,5	1 005			0,8	150	1 155	1 075	2 230
Functions									144 439
Monitoring (2)	0,2	402					402	374	776
Selection (1)	21,4	43 001	7,1	3 390	31,7	4 944	52 335	48 708	101 043
* Inter-dept co-op	6,3	12 659	0,4	192	7,4	1 388	14 239	13 252	27 491
* Liaison	2,3	4 622	0,2	96	2,7	506	5 224	4 862	10 086
* Congresses	1,3	2 612					2 612	2 431	5 043
Research programmes									305 943
Mosaic (12)	22,2	44 606	44,5	21 246	20,0	3 750	69 602	64 779	134 381
Smut (11)	4,4	8 841	2,6	1 242	6,0	1 125	11 208	10 431	21 639
RSD (10)	15,1	30 342	9,4	4 489	8,2	1 538	36 369	33 849	70 218
Leaf scald (13)	0,8	1 608	0,4	192	0,2	38	1 838	1 710	3 548
Nematodes (16)	11,9	23 912	6,8	3 247	0,7	131	27 290	25 399	52 689
N-fixation (23)	0,3	603	0,2	96	0,5	94	793	738	1 531
Tissue culture (5)	1,0	2 009	1,6	764	2,7	506	3 279	3 052	6 331
* Co-ord projects	1,9	3 818	8,5	4 059	1,1	206	8 083	7 523	15 606

After allocating the appropriate items in Table 37 to growers advisory services and research programmes (which have been numbered to correspond with the programmes listed in Table 19 on page 70), there remain four items of cost, marked with asterisks, to be allocated. *Inter-departmental cooperation* and *congresses* are concerned almost exclusively with the promotion of research and are, therefore, allocated proportionately to the department's research programmes. *Liaison costs* are those incurred by technologists in maintaining contact with organisations outside the Experiment Station and must, therefore, be regarded as an overhead cost of the Station as a whole. The fourth cost, of *coordinated projects*, is allocated proportionately to the specific programmes or services concerned.

There are also a number of programmes conducted for purposes other than research and their costs require approppriate re-allocation. Six programmes, namely, *crop production systems, machine & equipment utilization, analytical chemistry, irrigation investigations, run-off & catchment projects* and *modelling soil & water loss*, are conducted to improve advisory packages and technical services available to growers; their costs should be considered recoverable as fees charged in terms of the *user pays* policy.

Five programmes, namely *eldana biology, mosaic epidemiology, nematode biology, nitrogen fixation* and the *lysimetry project*, are basic research investigations on which no economic returns can be expected. However, since their biological results are intended to promote other applied research programmes, their costs are re-allocated accordingly.

Two other programmes, the *development of machines & equipment* and the *alternative fuels project* are classified as precautionary R&D; their costs should be regarded as insurance premiums and included in overheads. Of a similar nature are two programmes, *monitoring & control of pests* (other than eldana) and the *leaf scald project* which are conducted as precautions against the outbreak of pests and diseases; these programmes are better classified as *research maintenance*.

A number of other defensive research programmes would also be classified as research maintenance when they no longer generate returns, for example the routine programmes on diseases, pests, fertilizers, herbicides and growth regulators.

There are two projects which are conducted at the behest of producers, namely the *soil compaction* and *acid chlorosis* projects. The expenditure on such work may be justified on psychological grounds but they are unlikely to generate economic returns and their costs should, therefore, also be included in overheads.

Research programmes that fail or are discontinued for various reasons before the resulting technology is recommended, are the 'dry holes' of which the *chemical control of eldana* is the only example in the datum year. The costs of such programmes have to be written off as overheads as is common practice in commercial and industrial R&D organisations.

Finally, the costs of programmes in early stages of development or of those that have yet to produce technology that can be implemented, should be regarded as loans to be repaid when economic results are obtained. The gathering of biological information and data as well as the bulking up and testing of parasitic material, can be regarded as capital accumulation for investment later in a pest control programme that is expected to produce economic returns. The Experiment Station's research programme, *biological control of eldana*, is in this category and for the purposes of estimating returns, its annual cost can be regarded as interest on the accumulated capital invested in the programme.

The result of these considerations is that the Experiment Station's departmental costs can be allocated to the three primary functions research, extension and services as well as to overheads as shown in Table 38.

Table 38 : **Allocation of Experiment Station departmental costs to Research, Extension, Services and Overheads** (in thousand rands).

Department	Research	Extension	Services	Overheads
Agricultural Engineering	11		437	329
Agronomy	386		32	20
Chemistry & Soils	143		265	59
Education & PR			127	
Entomology	73		14	780
Extension		1 084	1 171	93
Farm Planning	2		488	
Pathology	429		83	16
Plant Breeding	1 362		27	42
Publications			116	11
Training			903	4
Totals	2 406	1 084	3 663	1 354

The data in Table 38 provide interesting insight into the proportions of costs and thereby a measure of the relative importance given by the policy and management decision-makers to the three primary functions of an agricultural commodity R&D organisation. If the concept is accepted of allocating to overheads the costs of maintenance and precautionary research, as well the costs of 'dry holes' and of research programmes that are in early stages of development, then the share of all R&D costs by the, now four, functions, is as shown in Table 39.

Table 39: **Reallocation of R&D costs to functions.**

Services	43,07%
Research	28,28%
Maintenance and Precautionary research	15,92%
Extension	12,74%

An assessment of the relative importance of these functions exclusively in cost terms in this way is, however, simplistic because it is generally accepted that without the transfer of technology - the function of extension - research and, to some extent, services would be of much less value.

Rates of return. The purpose of comparing costs of research with returns of the derived benefits, is to obtain a measure of payoff in relation to research expenditure which, for convenience, is expressed as *rate of return*. Two rates are commonly used in studies of research payoff, *external rate of return* and *internal rate of return*. Griliches (1958) used the external rate of return in his estimate of the payoff of hybrid corn. To compute the external rate of return, the flow of costs and returns is accumulated, or discounted, to a particular date, using a discount rate that reflects the real opportunity cost of capital in the economy. Internal or marginal rate of return is the rate of interest which reduces the accumulated costs to equal the accumulated returns at a particular time. The external and internal rates of return, being derived from the same data and assumptions, are therefore only alternative ways of expressing the relationship between costs and returns. A third method of expressing this relationship is the *benefit:cost ratio* which is merely the numerical equivalent of the percentage average rate of return.

Rates of return studies have been criticised for a number of reasons (Ruttan, 1982), for example:

- they usually fail to take account of complementary technical inputs and related marketing and extension costs incurred to achieve the higher productivity obtained from the adoption of a new technology;
- they are very sensitive to assumptions made on the shifts of the supply curve resulting from the adoption of new technology;
- rates of return, especially the external rate of return, are very sensitive to the rate of interest chosen to discount accumulated costs and returns;
- rates of return are most often applied only to successful technological developments and thereby tend to exaggerate returns as in the case of Griliches'(1958) hybrid corn study.

The benefit:cost (B:C) ratio has also been criticised (Sassone & Schaffer, 1978) when it is used to compare the return on research projects because a project with a higher B:C may have a lower total benefit than a project with a lower B:C.

These criticisms of the early studies of rates of return, particularly those using the index number method of estimating the increase in productivity, do not apply to the same extent to more recent work especially those using the production function approach. For example, Griliches (1964) included agricultural research and a number of complemetary factors as separate variables in a Cobb-Douglas type production function study of the factors contributing to increased productivity.

Because neither the external nor marginal methods of estimating the rate of return on individual agricultural commodities have given results that can be considered more accurate than general orders of magnitude, the more recent tendency has been to pay more attention to estimating returns on aggregated and national R&D rather than to R&D on commodities (Ruttan *op. cit.*). There is also the difficulty in estimating returns on agricultural *commodity* R&D that '... All over the world there is a move towards discussing agricultural R&D programmes in terms of objectives related to national needs, such as ... preventing pollution or saving imports' (Wise, 1975). For these purposes, that is, for national policy decision-making, the use of rates of return, of whatever kind, may play an important role but there is the danger that the factors particularly amenable to mathematical analysis are the ones analysed and not necessarily the important factors decision-makers should take into account (Wise *op. cit.*).

It would seem from all these considerations that it would be better, for the purpose of estimating the return on R&D and its component programmes in an agricultural commodity organisation such as the Experiment Station, to use a rate of return suited to the particular circumstances and one that is conceptually familiar to the decision-makers concerned, rather than one devised for different purposes and less easy (for managers) to comprehend. Since the Experiment Station's Cost Effectiveness Exercise (SASA Experiment Station, 1983) used the rate of 'net return', that is [(returns - costs)/costs], it would seem appropriate to use this rate in the present study as well. So that some comparisons can be made with returns on R&D estimated in other studies, the marginal rate of return is quoted when it is given.

Net return. An important objective of this study is to demonstrate the value for management purposes of having estimates of both the costs and the returns on R&D down to programme level. To this end the departmental costs of R&D, given in Table 38, were allocated to programmes or projects, using the information available in the survey of costs and technologists time conducted in 1986 (Donovan, 1986), the results of which are given in Appendix 12. Returns, estimated previously (Table 36, page 121), are brought together with costs (Appendix 12) in Table 40 to derive estimates of net returns, in percentage terms, and benefit:cost ratios of Experiment Station functions and of those twelve programmes that generate returns.

Net return is calculated as [(returns - costs)/costs] with negative signs indicating that programme costs exceed their returns. Benefit:cost ratios are calculated as returns/costs.

Table 40 : Costs, returns, percentage net returns and benefit:cost ratios on Experiment Station 1985/86 programmes.

Programme	'000 rand		% net returns	B:C ratios
	Costs	Returns		
Whole Station programme of work	8 507	15 008	76	1,76
Whole Station excluding services	4 844	15 008	210	3,10
Extension	1 084	12 457	1 049	11,49
Research (all programmes)	3 760	5 148	37	1,37
Research (excluding maintenance and precautionary programmes)	2 744	5 148	88	1,87
Research + Extension	3 828	17 505	357	4,57
Individual Research programmes:				
Trashing (spreading tops)	4	124	3 000	31,00
Cultural control of eldana	73	2 247	2 978	30,75
Growth regulator trials	20	195	875	9,75
Ratoon Stunting Disease	78	730	836	9,36
Fertilizer trials (N & Lime)	130	1 000	669	7,69
Smut disease control	24	101	321	4,21
Nematicide trials	104	209	101	2,01
Herbicide trials	114	209	83	1,83
Soil amelioration	104	124	19	1,19
Variety agronomy	123	130	6	1,06
Plant breeding	1 474	900	- 39	0,61
Mosaic disease control	155	81	- 48	0,52

How calculated

The programmes that generate no returns, or on which returns cannot be estimated, have had their costs allocated as follows:

Basic Research Programmes

Eldana biology, R118 700 to Biological control of eldana;

Mosaic epidemiololgy, R7 000 to Mosaic disease control;

Nematode biology, R58 300 to Nematicide trials;

Nitrogen fixation, R1 700 to Fertilizer trials;

Lysimetry, R2 600 to Irrigation investigations;

Immature Research programmes (on which there are no returns but on which future returns can be expected):

Biological control of eldana, R642 800; regarded as a 'capital loan' with the cost (interest) borne as an overhead cost.

Precautionary Research programmes (overheads debited with costs):

Development of machines and equipment, R254 300;

Alternative fuels project, R63 800;

Services programmes (costs recovered as fees):

Crop production systems, R54 900;

Machine and equipment utilization, R63 700;

Analytical chemistry, R49 300;

Irrigation investigations, R37 700;

Run-off and catchment project, R34 100;

Modelling soil and water loss, R72 500.

Comparison of returns on R&D. Returns on R&D and various components of R&D, obtained in this study, are compared with a selection of those obtained in other studies, in the following Table 41.

Table 41 : Comparison of rates of return on various categories and components of R&D, expressed as net return (NR), marginal rate of return (MRR) or benefit:cost ratio (B:C). (Data from Appendix 1 and Table 40, all ex-post studies unless otherwise stated).

	NR%	MRR%	B:C
1. Research/Experiment Stations			
Scottish Plant Breeding Station			3,10
SASA Experiment Station, 1983	12		1,33
.... excluding services	77		3,03
SASA Experiment Station, 1985/86	76		1,76
.... excluding services	210		3,10
2. Research component of R&D			
SASA Experiment Station, 1983	93		1,92
SASA Experiment Station, 1985/86	37		1,37
.... excluding maintenance and precautionary programmes	88		1,87
3. Extension component of R&D			
US Western Region, mean of nine commodities, [Ex-ante]		19	
HKS-Agriland report, [Ex-ante]			4,28
SASA Experiment Station, 1983	148		1,12
SASA Experiment Station, 1985/86	1 049		11,49
Nine studies (Huffman, 1980) [Ex-ante]	1 - 20		
Extension 60% to 78% of R&D (Araji, 1980)			
and 25% to 60% of R&D (Araji *et al*, 1975)			
4. R&D (Research + Extension)			
Sugarcane, 1945-1958, Evenson (1969):			
Australia		50	
India		60	
South Africa		40	
US 'Production-oriented Research & Extension (with 13-year lag) 1939-1948		41	
1949-1958		39	
1959-1968		32	
1969-1972		28	
SASA Experiment Station, 1983	93		1,60
SASA Experiment Station, 1985/86	357		4,57

	NR%	MRR%	B:C
5. R&D on other crops			
Maize/Corn: Chile, 1940-1977		33	
Mexico, 1943-1963		35	
Mexico, 1954-1967		35 - 40	
US, 1940-1955 (Griliches)	35 - 40		
US, 1977		115	
Sorghum: US, 1943-1957 (Griliches)	20		
Wheat: Mexico, 1943-1963		90	
Australia, 1948-1969		48	
Colombia, 1953-1973		12	
Israel, 1954-1973		150	
US. 1977		97	
Soyabeans: Colombia, 1960-1971	88		
US, 1977		118	
Rice: Japan, 1915-1950		26	
Japan, 1930-1961		74	
Bolivia, 1957-1964	88		
Colombia, 1957-1972	71		
Potatoes: Mexico, 1948-1964	69		
UK, 1962-1973			1,9
Cotton: Brazil, 1924-1967	77 -110		

Conclusions. Estimates of returns on agricultural commodity R&D at Research and Experiment Stations are generally found to be of similar magnitude irrespective of the method of estimation. This is shown in Table 41 by the benefit:cost ratios obtained for the Scottish Plant Breeding Station (Simmonds, 1974) and the two estimates made at the South African Sugar Association Experiment Station in 1983 (SASA Experiment Station, 1983) and five years later in the present study. Different methods of estimating were used in these three exercises and in the case of the Scottish Plant Breeding Station, different crops in different environments and circumstances obtained. Where comparisons are possible between returns on research programmes or between commodities, the tendency for the estimates made in this study to be somewhat higher than estimates made in other studies, is due to the exclusion of the costs of services and extension in the present study and not in others.

Large differences also occur when ex-post and ex-ante estimates of returns are compared or when estimates made objectively and those

made subjectively are compared. In both cases the magnitude of the differences depends on the accuracy of forecasts of yields, costs and technology adoption rates.
Although the general conclusion is that econometric estimates of return on R&D, based on aggregated and multi-product data may be of use in broad policy consideration, particularly for budgetary purpose at national, state and even at commodity level, they are of limited use for management purposes at commodity institute level. However, an empirical method of estimating returns on R&D, as proposed in this study, appears to have potential for improving policy and management decision-making in agricultural commodity R&D institutes which have the necessary data bank and these are discussed in Chapter 8.

The main results of the estimates of return on R&D at the South African Sugar Association Experiment Station in 1985/86, obtained in this study, can be summarised as follows:

* Return on sugarcane production R&D at the Experiment Station is found to be of similar magnitude to the return estimated in the Cost Effectiveness exercise of 1983, and to the return on other crop commodities reported in the literature (Appendix 1) in spite of the different production conditions and methods of estimating. Returns on individual research programmes or commodities tend to be higher in the present study than in others because the costs of services and extension have been excluded in the present study and are usually included in other studies. For example, when services are excluded, the return on R&D in this study is improved from a net return of 76% to 210%. The relative improvement was not as great as estimated in 1983 when the return on services was double counted by estimating them separately and leaving in their effect on returns on research.
* Returns on the research component of the Experiment Station's programme of work was found, in this study, to be lower in percentage terms, than was estimated in 1983. This is due to the adjustment downwards of subjective estimates which was considered necessary to ensure that the total estimated return on R&D does not exceed the estimated total productivity of the industry, an adjustment that was not done in 1983.

* Another reason for the lower estimate of returns on research in 1985/86 than in 1983 was the different proportions in which returns were attributed to research and extension. In 1983 the ratio was *assumed* to be 1:1 while on the present study it was estimated as 1:4,9.
* The closer experimental yields and industrial yields approach their potentials, the smaller the possible gains become and since experimental yields are closer than industrial yields to the potential, gains from research are more difficult to achieve than from extension (Thompson, 1989). It is to be expected, therefore, that the research:extension ratio of gains will move, with time, in favour of extension, as this study suggests has already happened. In Table 26 (page 93) the ratio of research to extension is shown to change from 63:35 in the early sixties, to 17:83 twenty years later. From this it can be extrapolated that the 1:1 ratio used in 1983 had probably been applicable in 1967/68, sixteen years earlier. The method used in this study to estimate the research:extension ratio by which declining returns on R&D are apportioned, is not claimed to be definitive but it appears to provide an estimate of the right order and changing in the expected direction, for which reasons it is preferred to an arbitrary choice of a ratio.
* Although the overall return on research and on most individual programmes was found to be positive, two programmes had costs higher than the estimated returns on them. Of particular interest is that plant breeding is one of these two, the other being mosaic disease control programme. The low return on the plant breeding programme was due to the fact that no new variety, with a yield index higher than that of NCo376, had been released during the previous 25 years. It is possible that an estimate of return on the plant breeding programme, made at a later date, when the more recently released varieties N12 and N14 are being grown on a larger area, could give a different result.

In the following Chapter 8 the advantages, for policy and management decision-making, of having estimates of costs and returns on the functions and programmes of R&D, as well as the future management challenges at the SASA Experiment Station, are discussed.

CHAPTER 8

RETURNS ON R&D IN POLICY AND MANAGEMENT OF AGRICULTURAL COMMODITY R&D

The productivity of agricultural R&D and the efficiency of its management have become matters of greater concern in recent years. Returns on State funded agricultural R&D are usually estimated econometrically as the social benefit obtained from shifts in the supply of aggregated agricultural production as a result of new or improved technology. In those situations it is difficult, if not impossible, to apportion returns among the different functions or programmes of an R&D institute. The use of production functions, with R&D as a variable, has improved estimates but the lack of data on the components of R&D is still a limiting factor. For agricultural commodity R&D, these data should be available and if suitable methods can be devised for apportioning returns to the different components of R&D, estimates of the return on R&D can be made to improve policy and management decision-making in the commodity. In this study, returns on the components of R&D are estimated empirically from increases in sucrose production in the South African Sugar Industry and are proposed for attributing increases in productivity to different functions and programmes of R&D.

In order to discuss the importance of returns in terms of function and programmes, it is necessary to define, and differentiate between, policy and management decision-making responsibilities, in the context of agricultural commodity R&D. For this purpose, a management model for an agricultural commodity R&D institute (Donovan & Nieuwoudt, 1988) is summarised in Figure 10 below to show the relationships between the policy, management and operational (R&D generating) divisions of such an institute. The responsibilities of the policy and managerial divisions have been included in the figure because they are germane to the consideration of returns. Not specifically relevant in this discussion of returns on R&D is the subject of communications in an R&D institute but the communication channels connecting the three divisions have been included because of their critical importance to the success of R&D and therefore in the production of economic returns.

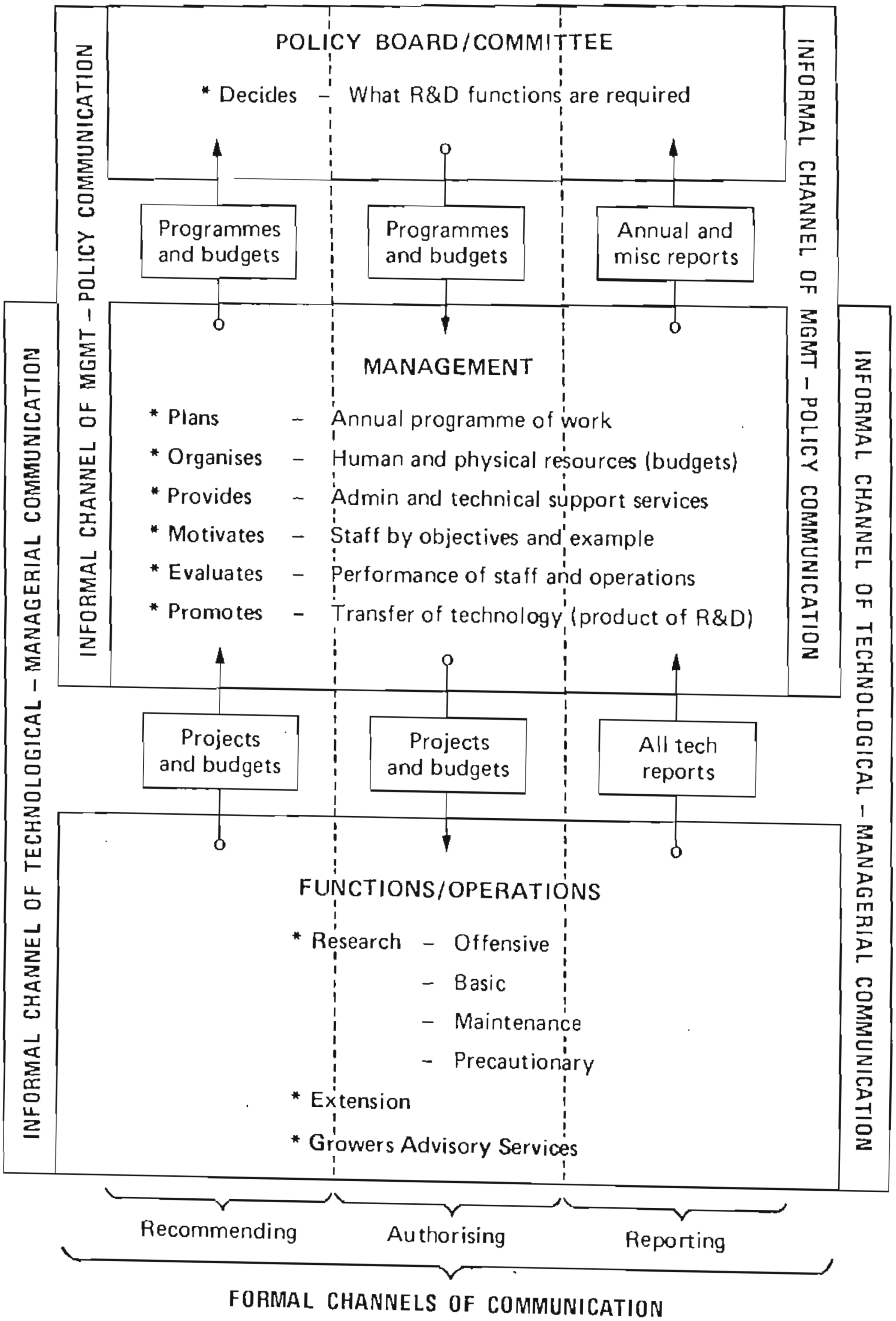

Figure 10: Management model to show the relationship between policy, management and functions in agricultural commodity R&D.

POLICY CONSIDERATIONS

Of the four principal advantages for agricultural commodities assuming responsibility for their own R&D, perhaps the most important is that decisions on what research should be done and what services are required, as well as their priorities, are taken solely by those who pay for and benefit from them (Donovan, 1988).

Costs and returns of R&D functions. Decisions by policy-makers in control of commodity R&D should be improved when taken in the knowledge of information on the costs and returns on the different functions of the whole R&D programme. For example, it has been possible to estimate, in this study, the relative costs and returns on the functions of R&D at the Experiment Station, as follows in descending order of costs (Table 42).

Table 42 : Costs and returns on R&D functions of the Experiment Station 1985/86 (thousand rand)

R&D Function	Cost	Return
Provision of Growers Advisory Services	3 664	(3 634)*
Research to generate technology	2 744	5 148
Research to maintain productivity	1 016	
Extension to transfer technology	1 084	12 457

* return on the function to provide Growers Advisory Services is in the form of fees charged in terms of the *user pays* policy.

Policy considerations involved in these data are, first, whether the fees charged for Growers Advisory Services should cover the full costs or whether some costs, or some users, should be subsidised in the interests of the Sugar Industry, environmental protection or of society in general. Secondly, to note that the return on offensive research, that is research to generate technology, exceeds the costs in spite of the costs on the most costly programme, plant breeding, exceeding returns and with the second most costly programme, *biological control of eldana*, not yet generating technology on which returns can be made. Thirdly, policy-makers need to accept that some programmes cannot, or can no longer, improve productivity but are justified at Industry expense merely to maintain present production levels. Finally, to be aware of the high return on extension and to decide whether this does not indicate under-investment and therefore an opportunity to increase investment in the most productive R&D function under present circumstances.

Subsidised Growers Advisory Services. Because it bears the full costs of its own R&D, it is a policy matter for the corporate body of sugarcane growers to decide whether any particular group of growers should pay less than the full cost of a specific advisory service. Since the costs of growers advisory services are recovered as fees, returns on R&D, estimated in terms of productivity, are not affected directly by the source of the fees, that is whether they are paid by an individual grower or by the corporate body of growers through the levy. However, if the greater use of advisory services has the tendency to increase productivity (as it should) then subsidising growers advisory services will improve the returns on R&D indirectly. The policy decision taken to subsidise growers advisory services selectively, on the grounds that raising productivity overall is in the Industry's interests, should lead to the consideration of increasing the intensity of extension in selected low productivity areas for the same reason. In addition to increasing productivity more effectively than additional research, and probably more effectively than cheaper advisory services, higher extension costs would reduce the return on extension which, in terms of the Industry's image, may be considered too high as is discussed in a later paragraph. The same reasoning can be applied to the complementary question of whether some advisory packages should be subsidised for *all* growers by the industrial levy in the interests of higher productivity and here again consideration might be given to increasing extension as a better way of increasing productivity while improving the Industry's image.

Returns on offensive research. Of the Experiment Station's thirty-two research programmes only twelve generate returns but two of these, plant breeding and mosaic disease control, were found to have costs exceding returns in 1985/86. As has been suggested earlier, this is a matter the policy-making body needs only note and be aware of the reasons. It is for management to consider this situation and, if necessary, to recommend operational changes to change or improve the position; this will be discussed later under the heading of management considerations.

It would be of interest for policy-makers to note that only two of the twelve research programmes that make returns, namely plant breeding and fertilizer trials, are classified as *offensive research*, that is programmes initiated to increase yields, and the other ten are classified as *maintenance research* (programmes retained in the portfolio to prevent yield decline). Returns on R&D are considered positive when the value of increased yield per hectare, resulting from technology adoption by growers, exceeds the cost of the research that generated the technology. Maintenance research programmes will, therefore, no less than offensive research programmes, give positive returns whenever there is a sufficient increase in productivity from the adoption of the particular technology in that specific year.

The reasons for the low returns on offensive research programmes (Table 19, page 70) are that three of them are basic research programmes on which no direct returns can be expected, one has yet to generate technology, the *biological control of eldana* programme, one proved to be a 'dry hole', the *chemical control of eldana programme*, and the remaining two, the *plant breeding* and *selection for disease resistance* programmes, taken together, have not produced a high yielding technology (variety) for some years. Some comment on the low return on plant breeding is necessary. Being the most expensive programme in the Experiment Station's portfolio, costing R1 473 700 in the datum year, 1985/86, the value of return on the programme would have had to exceed that figure to have given a positive return. Only one research programme, cultural control of eldana, gave a higher actual return than plant breeding, but it was still only 61% of programme cost. It can be seen from the individual variety indices, given in Appendix 10, that after the release of NCo376 in 1955 with a yield index of 1,99, it was twenty-four years before another variety was released with a higher yield index and that was N12, released in 1979, with a yield index of 2,08. N12, and N14 released in 1980 with a yield index of 1,98, provide the first opportunity since the mid-1960s of halting the decline in the rate of increase in the average yield index. By 1985/86 these two varieties were only contributing 1,4% and 6,4% of the Industry's total production of cane respectively and had, therefore, not yet made a significant impact on total production. The adoption of these two technologies (varieties) has increased appreciably since 1985/86 and this could result in the return on plant breeding exceeding costs in future. The question to be asked by management is whether the costs of the plant breeding programme cannot be reduced without loss of efficiency because that would contribute significantly to moving the productivity of the plant breeding programme in the right direction.

Maintenance research. Most offensive R&D programmes are initiated with the objective of improving yields or reducing costs both of which can lead to improved productivity and many of them are kept in the programme of work indefinitely. The need to improve decision-making on the termination of unproductive R&D programmes and projects is important and will be discussed later, but this matter is also important in the policy-making forum because the cost of continuing a programme that is no longer productive has to be borne by the levy and must therefore be well justified. The justification is that, *to prevent a decline in yield and productivity*, it is necessary on a continuing basis, to test new production inputs, such as herbicides, nematicides and growth regulators, to assess the effects of environment and other production factors on varieties and to monitor disease and pest levels and incidence. In accepting the need for maintenance research, policy-makers will no doubt require management to ensure that it is kept to the necessary minimum; in 1985/86 at the Experiment Station, maintenance and precautionary research represented just under 12% of the total cost of the Station and 27% of total research costs.

High returns on extension. A matter of concern for policy-makers must be the very high returns estimated on extension in this study. Even if the method of estimation used is responsible for some over-estimation, the error is unlikely to be large because the increase in industrial productivity, that has to be shared between research and extension, was itself low. Policy-makers' concern about high returns on extension will be on two counts: first, because returns of this order suggest under-investment and secondly, because abnormally high returns can create an adverse image in any enterprise and especially one as important to lower income consumers as sugar is. These concerns, and possible measures to counter them, are discussed again in the paragraph on the social context of R&D policy.

Ex-ante policy decisions. Returns on R&D are essentially returns on investment and investment decisions are usually the most important and difficult that policy-makers have to take. Success in decision-making on investment can be improved by having reliable forecasts and estimates of future trends and developments. Ex-post methods, as used in this study to estimate the returns on past and present R&D, are not usually considered suitable for estimating future returns, while ex-ante methods are generally too expensive and time-consuming for all but the large organisations.

This does not, however, relieve management of the responsibility of providing policy-makers with data, information and recommendations on prospective investment and, to be of value, these should be unambiguous and detailed, particularly with regard to likely costs, returns and lead times. If the information needed for proper decision-making is not forthcoming, the unsatisfactory result may be that management is left with the task of taking decisions for which only the policy-board has a mandate from the Industry.

Social context of R&D policy. An extremely important advantage of agricultural commodity R&D is that it avoids what Schweikhardt & Bonnen (1986) have called 'political cannibalism' in publicly funded agricultural research. As the State's resources for agricultural R&D decline '... the political leaders of research (are) forced to examine their brethren more closely and, in defensive reaction, (seek) to acquire or defend available funds in a more aggressive manner than usual.' In commodity R&D there can be no inter-institute cannibalism because there is, or should be, only one institute per source of funds, and the unequivocal objectives of a commodity R&D institute make intra-institute cannibalism unnecessary, at least at policy level decision-making, although the problem also needs to be addressed at management level.

Agricultural commodity R&D policy decision-makers are, however, faced with two *social challenges* that have impacts on, or are impacted upon by, the returns on R&D. The first of these is increasing public expectation that private enterprises (which include agricultural commodity organisations) should support materially various social and welfare services. This social challenge affects the commodity's R&D, albeit indirectly, by being a competitor for the commodity organisation's resources. Perhaps of more importance in the social context is an adverse image created by high rates of return shown on (parts of) the commodity's activities. This is another reason, if one is needed, for policy-makers to reduce any abnormally high returns on R&D by increasing investment in those functions and programmes that are giving uncommonly high returns.

The second social challenge is of much greater importance and is of more direct concern for the commodity's R&D policy-makers; it is the challenge that agricultural research organisations are insensitive to the side effects of technology. This is not the forum for discussing social and moral issues but it is worthy of note by commodity R&D policy-makers that data available from studies such as this, and even more appropriately from a routine procedure in an R&D institute for estimating the returns on R&D, can provide quantitative information for the necessary riposte. Although private research and, to a lesser extent, agricultural commodity research, may have been environmentally insensitive in the past, it is no longer valid as a general criticism and estimates of returns on R&D, such as those made in this study, can provide useful data and information in support of this situation. In 1985/86 two research programmes in the Experiment Station's portfolio had the primary objective of soil and water conservation (Table 19, #31 and #32); their combined cost was 7,7% of total cost of all research programmes. Furthermore, since no direct economic return could be obtained on those programmes, the present overall return on research expenditure is reduced by 9% as a result of their inclusion in the portfolio. The Industry's environmental sensitivity has increased recently, as has been evidenced by the Experiment Station's considerable current input on the joint investigation into the reputed damage done by hormonal herbicides in the Tala Valley of Natal.

There is also awareness and enthusiasm at technological level in the South African Sugar Industry for it to be proactive on environmental protection matters rather than '... merely reacting to public opinion and fears expressed from time to time by an often misinformed public, leading as it does to emotional claptrap which tends to harm all parties'. This call by the President of the Sugar Technologists' Association, at its annual congress in 1989, concluded with the suggestion that the Sugar Industry should appoint an Environmentalist '... who is aware of the available technology, and who will make a point of sharing it with the public and all interested bodies, someone who will condemn the misuse of a product in the industry or the violation of a soil or water conservation act, but who will also condemn vociferously false and uninformed statements by the media. Perhaps we need a credo for the Industry ... to utilize our natural resources to the maximum of our current technology whilst ensuring that we protect and, where necessary, restore the environment to the best of our ability' (Moberly, 1989b).

If the appointment of an environmentalist were accepted, the policy-board might consider it appropriate, in view of the duties described, for the incumbent to be a member of the extension staff at the Experiment Station. This would also contribute to reducing the ('poor image') high returns on extension that have been estimated in this study and would personify an Experiment Station goal, namely to 'promote the conservation of natural resources within the industry' (SASA Experiment Station, 1989).

PRESENT MANAGEMENT CONSIDERATIONS

This study of returns on R&D has also highlighted the importance of management in agricultural commodity institutes. The various aspects of costs and returns on R&D that have been found to require consideration or action by management will be discussed under the headings used in Figure 10 to catergorise the functions of management in such institutes. Although the case used in this study, for the estimation of returns on R&D, was the South African Sugar Association Experiment Station, the following comments on management are intended to be of general application to agricultural commodity R&D institutes and do not necessarily imply deficiencies in the management of the Experiment Station. On the contrary, a number of management procedures are recommended because they have been found advantageous at the Experiment Station while others are suggested because the need for them was determined in a fuller study of management at the Experiment Station (Donovan, 1986).

Programme of work. Management's two most important formal presentations to the policy-board are the proposed programme of work and the budget for the ensuing year. Both documents tend to be based on ex-post data and information but are recommending ex-ante action. The estimation of past and present returns on R&D in this study is based on an ex-post method but it '... can be ambiguous as to its prescriptions for the future' (Harvey, 1988). However, the conclusions drawn from the review of ex-ante methods of evaluating research do not offer practical alternatives that can provide policy-makers or managers with more than general and subjective, albeit expert, opinion on the prospects for investing in a particular research programme. Quantitative methods of ex-ante evaluation, such as mathematical and simulation models, have excessive costs in relation to their value in all but the very large research organisation, while at the other extreme, expert opinion, especially when pooled and extra-mural, has the potential of being no better than pooled and expert ignorance unless the experts are chosen carefully and pool their opinions by concensus. In practice, managers - like policy-makers - must take decisions with the best available information and its source is usually the Institute's appropriate research discipline leader.

The annual programme of work, the annual budget and other reports made by management to the policy-board should emphasise the economic aspects and advantages of proposals rather than their inherent scientific or technological soundness. Policy-makers will want to assess proposals in economic terms (because that is their interest and competence) and will want to assume that they are scientifically and technologically sound (because that is the reason for employing scientists or technologists as managers). All proposals should, therefore, be made to the policy-board with clearly stated objectives, with estimates of expected costs, returns and lead times, together with sensitivity analyses when these are appropriate. Wherever possible, the sensitivity analyses should include summaries of alternative strategies or programmes that were considered during planning. Procedures carried out in this way, more easily with an agricultural economist on the staff, are likely to reduce 'interference' by policy-makers in management matters while contributing to better decisions by the policy-board.

The estimates of returns on R&D obtained in this study, particularly on research programmes, suggest that information on costs and returns can be of considerable value to management during programme of work discussions with staff. It can provide an economic dimension to support:

- the discontinuation or suspension of unproductive programmes which tend to be retained in a programme of work 'just in case';
- reducing the scope, and thereby the cost, of *high cost-low return* programmes that must be retained;
- prompt termination of 'dry hole' programmes;
- reduction to a minimum of the number of precautionary research programmes in the institute's portfolio, and
- additional resources for those programmes that are proving productive.

Examples of programmes at the Experiment Station that warrant consideration for discontinuation or suspension are the soil amelioration, mosaic disease control, nematicide and herbicide trials. This study of the costs and returns has shown that the rate of annual increase in adoption of the technology they produced is now low, they no longer produce new technology and so their returns will decline rapidly. The smut disease control programme should also be monitored closely (in spite of positive return) because further progress with the control of this disease is probably limited to breeding varieties with resistance and the prospects of further advances or improvements in cultural control appear to be poor. If the nematicide and herbicide trials cannot be considered for discontinuation they may justify suspension until registration and approval of recommendations are sought for new products, rate or mixtures. This decision would be facilitated by having an estimate of their cost for comparison with the extra cost of re-establishing them *ad hoc*. The programme of fertilizer trials also justifies critical review at an annual programme of work meeting soon because it is a costly programme (R130 000 in 1985/86) and because the adoption of the technology it produced must be approaching maximum and any further adoption and can probably be realized through extension effort without continuing field trials.

For those programmes on which there is no doubt that they should continue, for example, the plant breeding and variety agronomy

programmes, management's concern should rather be with the possibilities of reducing their high costs, perhaps by re-exmaning their objectives and scope, without prejudicing their value.
Research programmes that become 'dry holes' might well be capable of diagnosis as potential 'dry holes' earlier than at present if information on costs and potential returns were routinely available at the annual programme of work meetings. The *chemical control of eldana* programme at the Experiment Station is in this category.
Estimation of returns has pointed up the very high cost of the precautionary research programme on the *development of machines and equipment*, R254 000 in 1985/86, and this indicates the need to re-examine objectives and achievements at the earliest programme of work meeting. (It is interesting to note that since 1985/86 this programme has been terminated).

As important as the need is to consider reductions and economies in unproductive research programmes, is the equally important consideration of opportunities of increasing the productivity of R&D programmes already making positive returns. This study of returns has indicated three possibilities of this kind; first, the high returns on extension, suggesting under-investment, could lead to a recommendation that the industry would benefit from more extension, particularly on a selective basis in areas of low productivity. A second possibility is that increased extension on environmental protection projects might be beneficial for the Industry as a whole. The third possibility is that more resources for those research programmes proving productive could be advantageous, for example the programmes on the *cultural control of eldana* which is making a good return on a relatively small investment of R73 000. Another is the programme on *trashing* (in its present mode of investigating the value of spreading tops) which also generates a good return on a very small investment.

Organising human and physical resources. The analysis of costs and returns in any organisation is likely to indicate the need for both economies in the use of physical resources and for higher productivity from human resources. This can be assumed to apply to agricultural commodity R&D institutes although it did not arise specifically in the present study of returns on R&D at the Experiment

Station in 1985/86. However, since organising human and physical resources is an important managerial function in agricultural commodity R&D institutes, they should be considered briefly.

The analysis of Experiment Station costs in 1985/86 (Donovan, 1986) clearly indicated that operating field stations and the transport fleet were the two major items of cost after staff remuneration; it is, therefore, at these two items that management is likely to look first for possible economies. There would seem to be little difficulty involved in achieving economies in the operation of field stations, perhaps most effectively by reducing their number, but economies in transport costs are likely to result in considerable staff demotivation. That South Africans generally regard the personal and undiscriminating use of motor vehicles as their rightful way of life, aggravating the location-of-work/public-transport syndrome, allows little alternative to the operation of a large fleet of vehicles. Reduction in transport costs will, therefore, only be possible with skilful motivation by management.

In contrast, the scope for increasing the productivity of staff at all levels, especially in management skills, by the use of in-service and other training programmes, is considerable. The only difficulty management is likely to face, in introducing training, is in taking the decision to do so, in spite of ample evidence of the benefits and of the need.

Administrative and technical support services. In order to make available, on a regular basis, the information and data on costs and returns that this study suggests can be of value to policy-makers and managers, fundamental changes would be necessary in the administrative and accounting procedures of most R&D institutes. The changes required are basic in the conceptual sense but would not be difficult or costly to introduce nor more difficult or costly to operate routinely, than systems usually employed. At present administrative and accounting functions at most R&D institutes are structured in terms of disciplinary departments with the result that the institute's accounts and other records cannot, without considerable extra work, be analysed in terms of functions and programmes which reflect the institute's objectives. It should be possible for administration to provide management, on demand, with a printout reflecting the institute's expenditure, income and revenue, as at that day, in terms of the three primary functions of research, extension and services, each subdivided into their programmes or packages. This would regularly focus the attention of the policy-board, of management and, perhaps most important, of operational staff, on the purposes and objectives of the institute. It would also provide up-to-date information on the progress of the institute's programme of work, in addition to providing the information required for budgettary control purposes. If it is necessary at all to analyse records departmentally, this can be done by appropriate coding of the functional items. It would be much more complicated to code departmental items in terms of functions because functions and programmes are subject to annual change whereas departments are subject to much less frequent change. Since most administrative and virtually all accounting operations in R&D institutes have now been computerized, the introduction of such a system could be programmed and run (by professional programmers) in parallel with the existing system for a trial period before final implementation. An additional advantage of *functional* accounts would be the opportunity they provide for meaningful delegation of responsibility for the control of expenditure. Under a departmental accounts system, control is left to administration staff who have only the authority to recommend that expenditure is curtailed or ceases, whereas under a functional accounts system, although the administrative staff would retain their authority (to recommend that expenditure is curtailed or stopped), operational managers can have the opportunity (and authority) to adjust expenditure within their total allocation among their programmes. The almost universal lack of interest among technologists in budgeting and control of expenditure has always been a problem for management in R&D institutes. The lack of interest stems from the fact that these necessary duties are regarded as chores which produce nothing of interest for the individual technologist. If, on the other hand, accounts were organised in terms of functions and programmes, technololgists would be able to relate expenditure directly to the work they do and the important task of budget control would no longer be regarded as a tiresome chore required by, and only of interest to, 'admin'.

A management problem of increasing difficulty in most scientific and technical enterprises, and particularly in R&D organisations,is that of staff recruitment and retention. The problem of retention will be discussed in the next section on motivation, but recruitment is usually considered to be an administrative function and therefore discussed here. Although the estimates of returns on R&D, made in this study, cannot identify staff efficiency as a separate contributory factor, it is axiomatic that returns are directly affected by the efficiency and attitudes of technological staff. Since first impressions are so important, and these are the impressions a candidate technologist receives from the institute's administrative staff (who are not technologists), it is suggested that staff management, development and recruitment should be a management and not an administrative responsibility.

The importance of communications is invariably emphasised in studies of R&D management (Donovan, 1986), but communication problems at operational level are seldom mentioned and so it is fortuitous that a long standing administrative problem of the lack of a prompt and accurate communication system, especially between base and satelite stations, has been solved by the recent availability of facsimile machines. Data can now be transferred promptly from field, on a satelite research site, to processor, at research headquarters, without transcription (a major source of error) and without the need for clerical staff and facilities, except a telephone service. This may not increase returns on R&D but will improve their reliability.

Motivating staff. This is probably the most important function for managers of scientific and technological R&D organisations or institutes and the contention is that it can be performed much more meaningfully if data and information are available on the costs and returns of the various components of R&D. In the following summary of some motivational methods appropriate in an R&D context, the value of economic data such as that obtained in this study,is emphasised.

In agricultural commodity R&D, goals and objectives are important motivators and should be exploited at every opportunity; furthermore, their value is enhanced when they can be expressed in terms of economic returns. Clearly stated and accepted goals and objectives can be used to counteract the undesirable practice of 'political cannibalism' which has been mentioned earlier as occurring commonly in State funded research organisations. Political cannibalism is much less likely to be a problem in commodity funded research because there is usually no competition for the funds available for R&D, but at managerial level within an institute, it manifests itself as inter-discipline or inter-programme parochialism, when resources have to be shared among a number of disciplines or programmes. Appropriate motivation, using goals and objectives, can reduce the undesirable effects of parochialism within an institute.

Another, and perhaps more important, use of goals and objectives in motivation, again enhanced by economic information, is in ensuring the correct balance in the work and attitude of technologists, that is, between the R&D goals of the institute and their personal and social goals. For some individuals, the conflict between the institutes goals and their own, or between those of the institute and what they perceive to be their commitment to social objectives, cannot be assuaged by motivation. Management's responsibility is then to counsel the individual to seek other employment where he will have less conflict of objectives and to recruit a technologist whose objectives are more compatible with those of the institute. The direct loss of productivity through conflict of goals is probably less harmful than the anti-motivation effects on others of a 'square peg in a round hole'.

A considerable number of programmes and projects in agricultural commodity R&D require a multi-discipline, integrated approach, the success of which probably depends as much on good motivation as on the standard of the individual technologist's contribution. This kind of motivation relies heavily on use, by the team leader, of the goals and objectives of the multi-discipline or coordinated project itself, as well as those of the institute as a whole.

One of the few methods of motivation that is probably not enhanced directly by data and information on R&D costs and returns is motivation by example. For that reason discussion will be brief but because of its importance, it should not be omitted completely. The attributes of an R&D manager that are probably most effective in motivating staff are: willingness to delegate duties, because that signifies confidence; encouragement of communication, particularly informal communication, because that signifies interest in the points of view of others; and a 'high-low' profile, that is a high status in a scientific or technological discipline with a low self-importance threshold.

The last method of motivation to be considered is motivation by perquisites and although they affect returns on R&D only indirectly, they justify some consideration in this study because of their high cost and assumed effect, as motivators, on an organisation's productivity. It is unfortunate that remuneration is no longer a contract between employer and employee but is usually determined by remuneration systems that are impersonal, automatic and public knowledge. Under these unsatisfactory conditions, remuneration becomes demotivating and as a result it is now common practice to use perquisites as motivators. Perquisites are, however, no more than 'incidental benefits attaching to employment' and the equity principle which has been responsible for demotivating remuneration has the same effect on perquisites of which the infamous 'company car' is the most important and very costly example. A company car is merely a part of an employee's remuneration package applicable to a particular grade in the salary scale which is itself no longer an indication of the employee's value to the organisation. Dissatisfaction and jealousies engendered by differences in model, cost, colour, numbers and types of luxury extras, now constitute the common reactions to the acquisition of a company car. For scientists and technologists employed in R&D organisations it is suggested that, in addition to the 'remuneration package' type of perquisites which, unfortunately, now cannot be withdrawn, awards should be made for achievement and that the recipient should be allowed to choose an award from a list offered by management. Suitable awards for R&D workers might include sabbatical leave, personal research time, financial and resource support for higher degree or other special studies, extra vacation leave, purchase of additional pension/medical aid benefits, educational grants for children, travel grants to attend conferences, credits for the purchase of books or equipment (personal computer), and possibly others that could be suggested by members of staff themselves. *Ad hoc* awards made for minor but important tasks done well, especially those additional to the programme of work or under pressure or adverse conditions, are useful motivators, particularly if they are presented spontaneously, publicly and preferably by the Institute's Director.

Evaluating staff performance and operations. Performance appraisal of staff has been described (Stoner, 1982) as one of the most important tasks a manager has to perform, but because it is a difficult task and because the benefits are not easily assessed, it seldom consists of more than an occasional and subjective assessment of an individual's performance. In management terms, performance appraisal means regular, disciplined appraisal *and* feed-back to the individual with the objectives of:

- keeping the individual informed of how his work is regarded,
- identifying those who merit advancement, and
- identifying members of staff who need guidance or training.

There can be little doubt that this management responsibility, if carried out conscientiously, and if merit awards and advancement, as well as guidance and training, are accepted procedures, would have a beneficial effect on an R&D organisation's productivity even if that cannot be identified in an estimate of the return on R&D.

The evaluation of operational performance, called 'controlling' by some managers, is an easier managerial task and is, therefore, more commonly performed by R&D managers. Like performance appraisal, operations evaluation will undoubtedly improve overall productivity but will probably not be quantifiable as a separate factor in an estimate of returns on R&D. Operational evaluation is of two kinds, *formative evaluation* to monitor on-going progress intermittently during an operation and *summative evaluation* which is carried out regularly, usually annually, to assess progress and results (Trigo, 1984). Formative evaluation is satisfactorily done by groups of technologists appointed for the purpose and according to the programme being evaluated. Meetings of these formative evaluation groups also serve the useful purpose of coordinating the various disciplines involved in the programme. Summative evaluation, on the other hand, is seldom carried out in a formal manner and, unlike formative evaluation, is of little value unless it is done formally, regularly and by comparing what was planned with what has been achieved, including an analysis of results. Unless, therefore, programme plans or proposals include achievement targets, objective summative evaluation is not possible.

Promoting the adoption of technology. In an agricultural commodity R&D institute, the transfer of technology to growers for adoption is the function of extension, and in this study of the returns on R&D, extension was estimated to be responsible for 83% of the total return on R&D generated at the SASA Experiment Station in 1985/86. While it is important for management to give attention to improving the low productivity of research, it is no less important to maintain the productivity of extension if the productivity of the institute's R&D is to remain positive. Since the measure used in this study to estimate extension's productivity is the change in the relationships between technologist's yield and the industry's average yield, the potential for increased yield is greater for continued high productivity from extension than from research.
Because of its permanent exposure to the client (producers of the commodity), extension is the function of an agricultural commodity R&D institute on which the whole institute is usually judged. It is, therefore, one of management's most important responsibilities to ensure that extension staff not only transfer the correct technology but also project the institute's image. Equally, extension staff have the responsibility of representing accurately and persuasively, all aspects of the institute, including policies with which they themselves may not agree.

FUTURE MANAGEMENT CHALLENGES

The present R&D scenario at the Experiment Station, which has been analysed in terms of costs and returns in this study, is one of declining returns on technology (generated by research), high returns on the transfer of technology (extension) and a new *user-pays* policy for technical services, now available as Growers Advisory Packages. The shift of returns from research to extension is shown by the change in percentage share of productivity during the last three decades, which is estimated to be from 65% : 35% in 1957/58 to 17% : 83% in 1986/87 for research and extension respectively. It is suggested that there are three main reasons for the decline in the returns on technology (research):

- first, for twenty-four years until 1979, no variety had been released with a higher yield index than NCo376 (Appendix 10);
- second, by 1985/86 most other technologies were mature, that is they were being adopted by growers on a decreasing scale (Table 20 page 73); and,
- third, heavy investment in the research programme on *biological control of eldana* for ten years without producing technology for growers to adopt and generate returns.

The main reason for the high return on extension is that average industrial yield has increased at a higher rate than the experimental yield during the last decade.

For significant change to occur in this scenario there would have to be development (by research) of *new* technologies that are capable of increasing *experimental* yields at a faster rate (at least for a limited period) than industrial yields increase. Without new technology, both experimental and industrial yields are likely to continue increasing but progressively more slowly. It was said (page 95) that experimental and industrial yields '... may have reached a similar stage in the degree of difficulty for further increase'. However, experimental yield, which is 77% of the climatic potential yield, is likely to increase at a slower rate (even with new technologies) than the industrial yield, which is only 46% of climatic potential yield and 59% of the experimental yield (Table 28).

As yields approach the climatic potential, the difficulty of developing new technologies, that can improve yields significantly, increases and the frequency of their occurrence decreases. Theoretically, the increase in experimental yield will tend to zero as the magnitude and frequency of occurrence of new technology declines. The rate of increase in industrial yields will also tend to zero, in the absence of new technology, as the technology adoption gap closes.

In commerce and industry, such a scenario would be anticipated and strategies developed to maintain profitability. The possible strategies would be to develop new products for the same market, find new markets for the existing products, or to diversify. In agriculture, and specifically for R&D in commodity agriculture, the scope for developing new products (technologies) becomes progressively less cost effective, the market is limited to the commodity because the products are mostly commodity specific and diversification would mean moving into competition with R&D organisations serving other crops.

The applicability of these strategies to agricultural R&D, and specifically R&D in commodity agriculture, are discussed briefly.

Developing new technologies. The scope for developing new technologies tends to produce diminishing returns. The increasing difficulty is exemplified by the fact that experimental yield is already an estimated 77% of the climatic yield and the diminishing returns are demonstrated by plant breeding at the Experiment Station which achieved an increase in variety yield index of over 40% in the first thirty years and less than 10% in the second thirty years (Appendix 11). Even success in developing technologies for the control of eldana will result in relatively small returns because the value of the loss in yield due to eldana, on an industry wide basis, is not high whereas the investment in the research programmes for the purpose is very high. Ironically, a successful outcome of the research programme for the biological control of eldana would be a significant scientific and technological achievement yet could have relatively little economic value for the cane growing industry. If the Industry's R&D policy-makers, were given the information on accumulated costs and likely returns on the programme, they would be able to decide at what stage to call it a 'dry hole' and write off the losses or whether the research should continue.

The development of technologies that can increase experimental yield significantly and be capable of transfer to growers in order to increase industrial yield as well, will depend on innovations such as 'strategic breeding' (Allison, 1989) of varieties adapted to younger harvesting and possibly the use of such techniques as recombinant DNA technology and tissue culture. To be of economic value to the cane growing industry, an innovation, would have to be shown capable of significantly increasing yields and/or resistance to pests and diseases or of reducing the time, and therefore the costs involved in producing a new variety. Although the opportunities for developing new or additional technologies capable of increasing yields or productivity and therefore returns on research, appear to be limited, it must remain a high priority of concern for senior management.

Future R&D strategies. In 1986 the Experiment Station was considered to be '... nearing the end of it's third phase (of growth, in Greiner's terms) with deteriorating communications and inadequate management skills the main deficiencies' (Donovan, 1986). Three years later, the present study of the costs and returns on R&D at the Experiment Station, suggests that the serious situation of declining returns on R&D, is an additional and equally important reason for undertaking an exercise in strategic planning for the next phase of the Experiment Station's evolutionary development. The following 'findings' in this study might be worthy of consideration in such an exercise of strategic planning:

That the cost of maintenance and basic research should be met from levy funds and not taken into account when returns on (offensive) research are estimated. The decision to develop new technology should be taken with as good information as possible on its cost, likely return and lead times. Having been approved as a part of the programme of work, the costs and returns of an offensive research programme should be monitored routinely by management to facilitate decision-making at the annual programme of work meetings. If the programme remains potentially valuable, and is not discarded as a 'dry hole', the resulting technology will normally generate returns until the decision is taken either to terminate it or to continue it as a maintenance research programme. Because maintenance research programmes do not normally generate positive returns but justify retention to reduce yield decline, it would seem appropriate to meet their continuing costs from the industrial levy while ensuring that they are continued as economically as possible.

Programmes of basic research, which are frequently conducted on contract off-station, might best be funded in the opposite way. On being accepted into the programme of work, a basic research programme should be financed from levy funds, with its costs under scrutiny, until it is terminated. If its biological results are of value to an offensive research programme, its costs should be transferred to that programme for purposes of estimating returns. If on the other hand, the results of a basic research programme are not of use to a current offensive research programme or 'sold' under licence or patent, it should be considered appropriate to 'write off' the cost borne by levy funds.

That the full costs of R&D programmes conducted to provide, or improve, technical services should be borne by users. Unless the full costs of providing technical services are recovered as fees charged for growers advisory packages, the returns on other components of the institute's work will be distorted. The cost of a policy decision to subsidise some packages or some users should, therefore, be borne by levy funds.

That for an agricultural commodity R&D institute a functional organisational structure is more appropriate than one based on scientific disciplines. Since the goal of agricultural commodity R&D is to improve the profitabiliity of the commodity's producers, the first level of an organisational structure should define the functions needed to achieve that goal and these are Research, Extension and Growers Advisory Services. The second level of organisational structure should define the ways in which the functions are carried out while the subsequent levels should break these down into programmes and projects. The purpose of any structure is to optimise the attainment, successively, of the goals and objectives of the organisation.

An organisational structure based on scientific disciplines, however appropriate for research institutes with scientific goals, has the disadvantages for commodity R&D institutes, first, of staff tending to regard their primary function as scientific and secondly, that in staffing programme and project teams, technologists have to be *brought together* by what they regard as detachment from their disciplines. In a functional organisational structure, staff of different disciplines are already together, facilitating a team approach and better coordination.

An added advantage of a functional organisation is that management and administration is simplified when, as in the case of the Experiment Station, an account of costs or estimates of cost effectiveness or returns on R&D, are required in terms of the Institute's goals, objectives, programmes and projects.

A final, and most important, advantage of a structure based on goals and functions is that it is better understood by the non-scientific community, the most important of whom are the commodity association members who are the producers and the 'stakeholders' who ultimately finance and therefore control the organisation (Donovan, 1981).

CONCLUSIONS

The significance for policy-makers of having estimates of returns on R&D is that:

* The advantages of a commodity controlled, mission-orientated, multi-purpose R&D institute, can be assessed in terms amenable to economic interpretation.
* Appreciation of the relative values and costs of research, extension and technical services can be obtained readily.
* The differences, in terms of costs and pay-off, between research programmes of different kinds (offensive, maintenance and precautionary) become more meaningful.
* The increasing importance of strategic and innovative research as the Industry's productivity rises and as the R&D institute's portfolio matures, can be indicated clearly.
* The contribution to social objectives can be quantified easily.

The value for management of having estimates of the returns on the different components and programmes of R&D is that:

* The Institute's annual programme of work can be formulated more realistically when information is available on costs and returns.
* Proposals for new programmes and changes in existing programmes can be made more meaningfully to the policy-board if they have economic dimensions.
* Discussions on programme priorities and emphases with lower levels of management can be less parochial if comparative information on costs and returns are available.
* Having economic values for programmes and projects can be used to emphasise objectives and to improve staff motivation.

* The routine collection of data needed to record costs and to estimate returns would necessitate desirable changes in administrative and accounting procedures.

There are no known disadvantages to using estimates of returns on R&D to improve policy and management decision-making and with appropriate changes in administrative and accounting procedures, the costs of routinely collecting the necessary data are likely to be very low.

CHAPTER 9

CONCLUSIONS

It would seem that little in the literature on research evaluation can be of direct use in deriving a practical method for estimating the return on agricultural commodity R&D, particularly when the estimates are required to improve policy and management decision-making at portfolio and programme level. However, a number of studies reported in the literature are of considerable indirect value in this quest.

When the total (social) benefits of agricudltural R&D in an aggregated form are being estimated by the economic surplus method, it is important to take elasticities of supply and demand into account. When, however, the *private* returns on R&D applied to a single commodity are being estimated, the use of the economic surplus method is probably less suitable than others because the difficulties in quantifying the effects of various controls on production, both domestic and international are considerable.

Within a single R&D portfolio, ex-post and ex-ante methods of R&D evaluation are considered more useful for higher and lower level decision-making respectively. This is because at the higher level, where the whole portfolio is under consideration, there is likely to be only a small proportion of new project proposals, whereas at the lower levels, *new* projects are likely to make up a high proportion of the total decision-making required.

For estimating the total private return on agricultural commodity R&D, methods of estimating the *cost-saving* value of R&D are as important as methods of estimating the value of *yield-increasing* R&D. Similarly, both objective and subjective methods of estimating returns are necessary.

The *Public Relations* approach is so called becasue most R&D funds have to be obtained from the public purse in competition with other, and often higher, social priorities. Because commodity R&D, in the context of the present study, is funded by producers and not by the public, it would be appropriate to call this approach *expert accounting*, and it is a useful, subjective, method of estimating returns at programme and project levels of decision-making.

Since this study is concerned with private returns on agricultural commodity R&D, the inclusion of spill-over and externality factors in any equation or model is not considered as necessary as it would be if total social returns were being estimated.

In estimates of the social returns on public sector expenditure it may be important to account for market distortions such as support programmes, price controls and production quotas. However, for estimating R&D returns on private sector investments (as is the case of agricultural commodity R&D), actual or projected market prices should be used because they represent the true costs of resources to the firm.

The benefits of foreign currency earnings on exports, increased employment opportunities, higher rural productivity, as well as the indirect benefits of employee housing, medical aid and pensions, need to be taken into account in estimating total social return on agricultural R&D. However, for evaluating the private return on commodity R&D they need only be noted and acknowledged as part of the commodity's contribution to the costs of infra-structural facilities that are important for the viability of any industry.

Although the final conclusion from the literature review, on estimating returns from agricultural commodity R&D, is that economic analysis methods can give only general and qualitative evaluations, this study indicates that an empirical method of estimating returns, using actual costs, has the potential for improving decision-making by both policy-makers and managers of commodity R&D.

Previous estimates of the returns on sugarcane R&D have given comparable results in spite of the different periods and estimation methods used, but for management purposes they have two shortcomings. The first is that they rely on unadjusted subjective assessments of R&D returns and, secondly, the estimates have no direct and quantitative relationship with the changes in production levels brought about by the R&D generated.

Yield levels during both the pre-technological era of 28 years (1862-1890), attributed to *craft skills*, and during the next 34 years (1880-1924), attributed to *imported technology*, increased initially and then declined, or remained relatively unchanged, during the second part of each of the two eras. The conclusion drawn from this pattern of yield change is that neither craft skill nor imported technology can sustain yields indefinitely and *locally generated technology* is necessary to both raise and maintain productivity.

Estimates of the contribution of locally generated technology, in terms of tons sucrose per hectare, to the Industry's increases in productivity during the technological era (1925-1985) and each of its six decades, were calculated as the factor share of technology in a production function equation. This method may be justified theoretically only under conditions of constant returns but its use to generate comparative information for management purposes is considered acceptable in this particular case. For the purposes of estimating the return on individual R&D programmes, technology's share of increases in sucrose yield, estimated in this way, needs to be shared first between research and extension.

Estimating returns on agricultural extension has not been successful previously because no approporate means of measuring extension effects have been found for the mixed product output of agriculture and because no satisfactory method of separating the effects of research and extension have been proposed. For agricultural commodity extension, and specifically for extension in the South African Sugar Industry, it is suggested that the change with time in the relationshuip between the Industry's yield and the yield obtained by technologists in field trials, can be used to measure the effects of technology transfer or extension. Applying this hypothesis to the data on industrial and experimental yields, indicates that the proportions in which the total estimated return on R&D are attributable to research and extension respectively, are 65:35 during the fourth (1956-1965) decade, 37:63 during the fifth (1968-1975) decade and 17:83 during the sixth (1976-1985) decade.

This method of estimating the research : extension ratio, is not claimed to be defifintive but it appears to provide an estimate of the right order and changing in the expected direction, for which reasons it is preferred to the only other method so far proposed, an arbitrary choice of a ratio.

Return on sugar cane production R&D at the South African Sugar Association's Experiment Station was found in the study, to be of a similar magnitude to the return estimated in the Cost Effectiveness exercise of 1983, and to the return on R&D on other crop commodities reported in the literature, in spite of different production conditions and methods of estimating.

For two reasons the return on the research component of the Experiment Station's programme of work was found to be lower in percentage terms, than was estimated in 1983. Firstly because, in this study, subjective estimates were adjusted downwards to ensure that the total estimated return on R&D did not exceed the Industry's total productivity, an adjustment that was not done in 1983. Secondly, the lower estimate of return on research in 1985/86 (than in 1983) was due to the division of total productivity between research and extension in terms of a *calculated* research : extesnion ratio of 1 : 1,49 in the present study compared with an *assumed* ratio of 1 : 1 in 1983.

The closer experimental and industrial yields approach their potentials, the smaller the possible gains become and since experimental yield is closer than industrial yield to the potential, gains from research are more difficult to achieve than from extension. The present trend for extension to be responsible for an increasing share of technological productivity is, therefore, likely to continue.

Although the overall return on research and on most individual programmes was found to be positive, two programmes had costs exceeding the returns estimated on them and of particular interest from a management and policy point of view, is that plant breeding is one of these two. The low return on the plant breeding programme is mainly due to the fact that no new variety, with a yield index higher than NCo376, had been released during the previous 25 years.

From a policy-makers point of view this study emphasises the advantages of commodity controlled R&D and offers an empirical method of assessing, in economic terms, the values and costs of research and extension. It also provides a quantitative dimension to the importance of offensive, strategic and innovative research in raising the Industry's productivity.

For management, the study provides the means for formulating the annual programme of work and budget in the (economic) terms more acceptable and better understood by policy-makers than the qualitative scientific jargon commonly used. It also facilitates discussion with staff on priorities, objectives and motivation because these can be expressed in terms amenable to economic interpretation.

The routine collection of data needed to record costs and to estimate returns would necessitate desirable changes in present administrative and accounting procedures.

CHAPTER 10

SUMMARY

The lack of information on the returns to R&D is considered a handicap to effective decision-making by policy-makers and managers in agricultural commodity organisations and the objective of this study is to find an empirical and practical method of estimating returns for that purpose.

The literature on agricultural research evaluation is mainly concerned with methods of economic analysis and little has been published that can be of direct benefit in deriving a practical method of estimating the returns on agricultural commodity R&D. This is particularly so when the objective is to improve policy and management decision-making at portfolio and programme level. Arndt & Ruttan's (1977) conclusions are apt in the context: 'Economic analysis at present, yields only gross indications of the consequences from various choices. More data on the appropriation of research benefits and on the research cost function, in addition to further theoretical and empirical testing of models, are needed to improve decision-making tools'.

Two previous estimates made of the return on sugarcane R&D, the first by Evenson (1969), using the production function approach, and the second, an empirical study by the South African Sugar Association Experiment Station (1983), gave very similar results in terms of internal and average rates of return. However, neither are suitable for management purposes, the former because it cannot be disaggregated down to portfolio or programme level and the latter because returns are estimated subjectively and not related to changes in production levels.

For the purposes of estimating returns on R&D in the South African Sugar Industry, three periods and sources of technology are defined. The first, the *pretechnology era* (1848 - 1890) when craft skill was the main or only source of technology, during which sugar yields are estimated to have increased by about one ton per hectare, from 0,5 to 1,5 tons. The second period described as the imported technology era (1890 - 1924) during which sugar yields are also estimated to have

increased by about one ton per hectare, from 1,5 to 2,5 tons. The imported technologies available during this era were varieties, mill design and components as well as methods of agricultural and mill production brought in as personal knowledge and experience by immigrants and visiting technologists. The third period, called the *technological era* (1925 - 1986) started with the establishment of the Experiment Station. During this era the importance of imported technology declined until about 1954 when, it is suggested that sugarcane R&D at the Experiment Station reached technological maturity. From that time the Industry was no longer dependent on imported technologies but was in a position to exchange technology with other sugar growing countries on a mutually advantageous basis.

The relative influences, or factor shares, of the four independent variables, technology, rainfall, production costs and area under cane, on the industrial yield of sucrose per hectare per annum, during the technological era, were estimated by production function analysis. The contribution of *production technology*, that is technology generated at the Experiment Station on the growing of cane, was considered not to be affected by productivity increases due to milling technology. During the technological era of 62 years productivity as yield of sucrose per hectare, increased by 1,65 tons during the immature phase (1925-1954) and by 1,85 tons during the mature phase (1955-1986). The estimate of annual increase in productivity due soley to production technology during the last decade (1976-1986), was 0,168 tons of sucrose per hectare (Table 16). After converting this into monetary terms, (at the price growers received for sucrose in 1985/86) this return was compared with costs to estimate the returns on R&D generated at the Experiment Station in 1986.

Not all the activities and costs of an agricultural commodity R&D institute or experiment station are devoted to R&D. The Sugar Experiment Station's activities were, therefore, classified, for the purpose of allocating costs and estimating returns, into three groups. Research (the production of technology), Extension (the transfer of technology) and Technical Services (which include advisory services, education, training and publications).

For the purpose of this study it is assumed that the *user pays* policy, introduced in 1983 and which it is intended will apply eventually to all technical services supplied on request to individual growers, will be self-supporting and therefore need not be included in estimates of returns. Until technical services are self-supporting, the returns on research and extension will be under estimated. The increase in productivity that can be expected from the use of technical services by growers would be shared by research and extension.

The activities of the two other functions, research and extension, were classified in terms of costs and returns. Since, in agricultural commodity R&D, extension need have no *social commitments*, all its costs and returns are theoretically attributable exclusively to the transfer of technology. In practice, however, the time of extension agents is spent on a number of activities that cannot be classified as technology transfer and the costs of these need to be allocated appropriately. Most of these non-extension costs would be debited to technical services but some are overhead costs, for example, time spent on 'community development' and 'environmental protection' work, which may be required in terms of the commodity organisation's social objectives.

Since an objective of this study is to estimate returns on research, if possible, down to programme level, research activities were classified according to their economic and biological objectives. *Offensive* or *Strategic research* is conducted to create new technologies or to increase productivity and profitability, the return on which should be measured by the resulting higher productivity. The costs of *Defensive research*, carried out to maintain rather than to increase yields, should be regarded as an insurance cost and carried as an overhead. Some defensive research programmes may generate higher productivity from time to time and their returns should be regarded as discounts on insurance premiums and credited to overheads. *Precautionary research*, conducted in anticipation of changing circumstances, is also a form of insurance on which no return can be estimated, and is therefore a charge against overheads. Examples of precautionary research at the Experiment Station are the development of machines and alternative fuels as precautions against future labour and fuel shortages or high costs, respectively.

Estimate of returns on extension have previously regarded extension as a State-funded and socially orientated function dealing with a wide range of products, contributing unidentifiably to agriculture's 'social returns'. In contrast, commodity extension has the specific task of technology transfer and its returns should be capable of estimation. In an ex-post study of the cost effectiveness of the Experiment Station(1983) extension and research were assumed to make equal returns on the grounds that they are equally important to the industry. In an ex-ante estimate of the value of extension in an irrigation development project in 1988, a net return (returns - costs/costs) of over 200% was obtained. Because neither of these methods is satisfactory, the hypothesis is proposed in this study that *the change in the relationship between the average yield for the Industry and the yield obtained by technologists in field trials*, can be used as a measure of the transfer of technology or extension. The industrial yield estimated previously by production function analysis is compared with the experimental yield, estimated by regression of rainfall on yield, using as the common base, climatic potential yield. During the last three decades of the technological era (1956/7 - 1985/6) experimental yields are estimated to have increased by 14% and industrial yields by 13% in relation to the climatic potential yield. In percentage terms this gives a research : extension ratio of 51 : 49 for the three decade period. Of greater interest to policy-makers and management is the change in the research : extension ratios from decade to decade during the thirty-year period and these were found to be 65:35, 37:63 and 17:83 indicating a significant change in relative contribution of research and extension to a declining total productivity.

The average return on research during the last decade (1976 - 1985), estimated as 17% of the return on production technology, is used as the return in 1986 and is apportioned among the individual programmes of research. The only programme that can be estimated *objectively*, that is by calculations from quantitative data, is plant breeding. The returns on all other research programmes are estimated *subjectively* in different ways depending on the type of data and information available. The total of these subjectively estimated returns are then reduced proportionately to equal the returns remaining after deducting the objective return attributable to plant breeding from the Industry's estimated productivity.

After converting returns, which had been estimated as sucrose per hectare, into monetary terms, they are compared with costs which had been obtained by reclassifying, to suit present purposes, the cost data from an analysis of Experiment Station activities in 1986 (Donovan, 1986).

In terms of net return, that is (return - cost)/cost, all activities of the Experiment Station had estimated returns exceeding their costs. The net return on the Station's programme of work was 76% on all research 37% and on extension 1 049%. Of the twelve individual research programmes capable of making returns, only plant breeding (-39%) and mosaic disease control (-48%) had costs exceeding returns. It is interesting to note that in real terms, plant breeding made higher returns than any other programme.
The benefit:cost ratios for R&D (excluding services) in this study, those obtained in the Experiment Station's cost effectiveness exercise in 1983, and in Simmond's (1974) estimate for the Scottish Plant Breeding Station, were all of a similar order, namely 3,10, 3,03 and 3,10 respectively.

When large differences occur between estimates of returns they are usually between ex-post and ex-ante estimates or between estimates made objectively and those made subjectively. In both cases the magnitude of the differences depends on the accuracy of the forecasts of yields, costs and technology adoption rates.

For policy decision-makers, the advantages of having costs and returns on at least the major functions of their R&D institute are considered to include the following:

* Facilitating decisions on whether the fees charged for technical services available to individual growers should cover the full costs or whether some costs, or some users, should be subsidised in the interests of the Industry, of environmental protection or of society in general.

* The opportunity to note that the costs of offensive research, that is research to generate new or improved technology, exceed the value of the resulting higher productivity.
* The importance of defensive research in maintaining yields in spite of the costs exceeding the returns on this kind of research.
* To note the high returns on extension and whether this does not indicate under-investment.
* Data and information that can improve decisions on whether and how much to invest in *social* programmes and for countering criticism that commodity R&D does not have a social conscience.

For management in agricultural commodity R&D institutes, the advantages of having data and information on the costs and returns on individual research programmes, are considered to include the following:

* Providing bases for recommending research in economic terms which are better understood by policy-makers than the biological terms commonly used.
* Cost and return information on research programmes provide an economic dimension that can improve decisions on whether a research programme should be terminated, reduced or even increased in scope.
* When reductions or economies are necessary, information on costs and returns are useful in the sensitive matter of personnel management, particularly when changes in duties or redundancy is involved.
* The advantages of having costs and returns on a routine basis can lead to changes in administrative procedures that themselves can be advantageous. Research managers tend to regard the task of cost accounting as an imposition but if the accounting is done in terms of their own programmes of research they would have a personal interest in the task.

This study of the returns on R&D in an agricultural commodity institute has identified two main future challenges for management. The first is the need to develop radically different technologies that can widen the productivity gap between experimental and industrial yields in place of some of the older programmes that face increasing degrees of difficulty and diminishing returns. The second is the need for an exercise in strategic planning, taking into account the present problems identified in the R&D scenario, particularly the funding of defensive research, how the cost of technical services should be shared between the Industry and the individual user, and the rationalisation of the institute's administrative procedures along functional lines.

The main conclusions from this study are that:
There is little in the literature directly applicable to the estimation of private returns on agricultural commodity R&D particularly when they are required to improve policy and management decision-making at programme and project level.

Ex-post and ex-ante methods of estimating returns on R&D are more useful for higher and lower level decision-making respectively, methods of estimating cost-saving R&D are as important as methods for estimating yield increasing R&D, and both objective and subjective methods, such as expert accounting, are necessary estimating procedures.

Because estimates of private return on commodity R&D and not total social return on agricultural R&D are required, spill-over and externality factors need not be considered; accounting for the effects of support programmes, price controls and production quotas can be obviated (by using actual market prices); and the social benefit spin-offs of R&D need not be taken into account.

The estimate of productivity attributed to technology alone was taken to be the factor share of technology in a production function equation, while the contributions of research and extension to increased productivity were estimated from the change in the relationship, with time, between the industrial yield and the yield obtained by technolgists in field trials. It was necessary to adjust the subjective estimates of returns on individual programmes to ensure they did not exceed the estimated total productivity attributed to technology.

As both experimental and industrial yields approach their potentials, yield increases in both become more difficult to achieve, more so for experimental than industrial yields and, new technologies are required if the returns on R&D are to remain positive.
For both R&D policy-makers and managers, estimates of a commodity institute's return on R&D, down to individual programme level, can improve decision-making and the changes in administrative and accounting procedures required to make these estimates routinely would be relatively simple, cost-effective and beneficial in terms of staff management.

REFERENCES

Agricura Rumevite (1989a). Personal communication.

Akino M & Hayami I (1975). Efficiency and equity in public research: rice breeding in Japan's economic development. *American Journal of Agricultural Economics*, 57, 1-10.

Allison JCS (1989). Personal communication.

Anon (1924). The Natal Sugar Industry. SA Sugar Association.

Anon (1925). Seventy-five years of sugar history: the story of the Industry's origin and expansion. SA Sugar Association.

Araji AA (1980). Returns to public investment in agricultural research and extension in the Western Region In: Research & Extension productivity in agriculture University of Idaho, Moscow, Idaho.

Araji AA, Sim RJ & Gardner RL (1978). Returns to agricultural Research and extension programs: an ex-ante approach. *American Journal of Agricultural Economics*, 60, 964-968.

Arndt TM & Ruttan VW (1977). Valuing the productivity of agricultural research. In: Resource allocation and productivity in *National and International Agricultural Research*. University of Minnesota Press.

Arndt TM, Dalrymple DG & Ruttan VW [Editors] (1977). Resource allocation and productivity in national and international agricultural research. University of Minnesota Press.

Arnon I (1981). Organisation and administration of agricultural research. Elsivier Publishing Co. Ltd., London.

Ayer HW & Schuh GE (1972). Social rates of return and other aspects of agricultural research: the case of cotton research in Sao Paulo, Brazil. *American Journal of Agricultural Economics*, 54, 557-569.

Bailey RA (1979). An assessment of the status of sugarcane diseases in South Africa. Proceedings SA Sugar Technologists' Association, 79, 1-9.

Bailey RA (1988). Progress in controlling RSD. *SA Sugar Journal*, 62, 389.

Bailey RA & Bechet GR (1986). Effect of ratoon-stunting disease yield and components of yield of sugarcane under rainfed conditions. Proceedings SA Sugar Technologists' Association 60, 142-147.

Bailey RA & Fox PH (1987). A preliminary report on the effect of sugarcane mosaic virus on the yield of sugarcane varieties NCo376 and N12. Proceedings SA Sugar Technologists' Association, 61, 1-4.

Bannock G, Baxter RE & Rees R (1985). Dictionary of Economics. (3rd edition) Penguin Books, Harmondsworth, England.

Beater BE (1989). Founding and development of the South African Sugar Association Experiment Station at Mount Edgecombe, Natal. Fifty years of research, 1925 - 1974. SASA Experiment Station.

Beattie CJ & Reader RD (1971). Quantitative Management in R&D. Chapman & Hall, London.

Bembridge TJ (1979). Effective agricultural extension. Address SA Institute of agricultural Extension, Natal Branch.

Beuckman EF (1984). The role of organisational involvement in influencing and promoting the credibility of the extension agent: possibilities and challenges for the agricultural cooperatives. *SA Journal of Agricultural Extension*, 13, 41.

Bond RS (1988). Progress in selecting for eldana resistance. Proceedings SA Sugar Technololgists' Association, 62, 129.

Bredahl ME & Peterson WL (1976). The productivity and allocation of research at US agricultural research stations. *American Journal of Agricultural Economics*, 58, 684-692.

Carlaw AE (1974). The field extension worker: generalist or specialist. *SA Journal of Agricultural Extension*, 3, 9.

Carnegie AJM (1983). Investigations for the control of the borer, *Eldana saccharina* Walker (Lepidoptera Puralidae). Proceedings International Scoiety of Sugar Cane Technololgists, XVIII, 2, 916-925.

Carnegie AJM (1987). A biological control programme for the Eldana borer. Sugar Cane 1987, Spring Supplement.

Castro JPR de & Schuh GE (1984). An empirical test of an economic model for establishing research priorities: a Brazil case study. In: Brazillian Agriculture & Agricultural Research. Editor L Yeganiantz. Department of Diffusion of Technology Brazilia, DF.

Cernea MM, Coulter JK & Russell JFA (1985). Building the research-extension-farmer continuum: some current issues. In: Research-extension-farmer: a two-way continuum for agricultural development. The World Bank, Washington, DC.

Dalrymple D (1977). Evaluating the impact of research on wheat and rice production. In: Resource allocation and productivity in national and international agricultural research. University of Minnesota Press.

Davidson BR & Martin BR (1965). The relationship between yields on farms and in experiments. *Australian Journal of Agricultural Economics*, 9, 2, 129-134 & 138-139.

Davis JS (1979). A comparison of alternative procedures for calculating the rate of return to agricultural research using the production function approach. University of Minnesota Department of Agricultural & Applied Economics Staff Paper.

Dodds HH (1926). The aims and objects of a sugar experiment station. SA Sugar Journal, 10, 17.

Dodds HH (nd). Sugar: the origin and development of a primary industry. SA Sugar Association.

Donaldson RA (1985). The effects of soil pH, clay content, rainfall and age at harvest on the yield response of sugarcane to Temik. Proceedings SA Sugar Technologists' Association, 59, 164-167.

Donovan AR (1981). A framework for strategic planning in Garden Cities. MBA dissertation. Graduate School of Business, University of Cape Town.

Donovan PA (1975). The integrated research, advisory and extension services of the South African Sugar Association's Experiment Station. In: Extension at the Crossroads, Symposium. SA Institute of Agricultural Extension, Rhodesian Branch.

Donovan PA (1986). Management of agricultural research and development with particular reference to the Sugar Experiment Station. M Agric Mgt thesis, University of Natal.

Donovan PA (1988). Management of research and development at the sugar industry's Experiment Station at Mount Edgecombe, Natal. *South African Journal of Science*, 84. 793 - 796.

Donovan PA & Nieuwoudt WL (1988). A model for agricultural commodity R&D. *Agrekon*, 27, 15-22.

Duncan RC (1972). Evaluating returns to research in pasture management. *Australian Journal of Agricultural Economics*, 16, 153-168.

Duvel GH (1986). Resolving the need conflict in agricultural extension. *SA Journal of Agricultural Extension*, 15, 38.

Easter KW & Norton GW (1977). Potential returns from increased research budget for the Land Grant Universities. *Agricultural Economic Research*, 29, 127-1133.

Evenson R (1969). International transmission of technology in sugarcane production. Mimeographed paper, Yale University.

Evenson R (1974). The Green Revolution in recent development experience. *American Journal of Agricultural Economics*, 56, 387-393.

Evenson R (1981). Research evaluation: policy interests and the state of the art. In: Evaluation of agricultural research, Miscellaneous publication 8-1981, Minnesota Agricultural Experiment Station.

Evenson R & Kislev Y (1973). Research productivity in wheat and maize. *Journal of Political Economy*, 81, 1309-1329.

Evenson R, Houk JP Jr & Ruttan VW (1970). Technical change and agricultural trade: three examples - sugarcane, bananas and rice. In: The technology factor in international trade, National Bureau of Economic Research. Columbia University Press.

Evenson RE, Waggoner PE & Ruttan VW (1979). Economic benefits from research: an example from agriculture. *Science* 205, 1101 - 1107.

Fishel WL [Editor] (1971a). Resource allocation in Agricultural Research. University of Minnesota Press.

Fishel WL (1971b). The Minnesota agricultural research resources allocation information system and experiment. In: Resource allocation in agricultural research. University of Minnesota.

Foster RN (1971). Estimating research payoff by internal rate of return method. *Research Management*, 13, 26-43.

Frean NH (1988). Change in farm and financial management. SA Sugar Industry Agronomists' Association.

Griliches Z (1958). Research costs and social returns: hybrid corn and related innovations. *Journal of Political Economy*, 66, 419-431.

Griliches Z (1964). Research expenditures, education and the aggregate production function. *American Economic Revue*, 54, 961-974.

Griliches Z (1979). Issues in assessing the contribution of research and development to productivity growth. *Bell Journal of Economics*, 10, 92-116.

Harvey DR (1988). Research priorities in agriculture. *Journal of Agricultural Economics*, 39, 81-97.

Hertford R, Ardila J, Rocha A & Trujillo C (1977). Productivity of agricultural research in Columbia. In: Resource allocation and productivity in national and international research. Minnesota University Press.

HKS-Agriland (1988). Tarka River Irrigation Pilot Project. Unpublished consultant's report to Department of Agriculture & Water Supply.

Huffman WE (1980). Returns to extension: an assessment. In: Research & Extension productivity in Agriculture. University of Idaho.

ICI Farmers' Organisation (1989). Personal communication.

Inman-Bamber NG (1988). Personal communication.

Joint Memorandum (1934). The joint memorandum of the SA Cane Growers' Association and the Natal Sugar Millers' Association. Presented to the Board of Trade & Industries.

Kennan PR (1978). Communication of research results. *SA Journal of Agricultural Extension*, 7, 16.

Kislev Y & Hoffman M (1978). Research and productivity in wheat in Israel. *Journal of Development Studies*, 14, 166-181.

Kislev Y & Rabiner U (1979). Economic aspects of selection in the dairy herd in Israel. *Australian Journal of Agricultural Economics*, 23, 128-146.

Knutson M & Tweeten LG (1979). Towards an optimal rate of growth in agricultural production research and extension. *American Journal of Agricultural Economics*, 61, 70-76.

Lindner RK & Jarrett FG (1978). Supply shifts and the size of research benefits. *American Journal of Agricultural Economics*, 60, 48-58.

Link AN (1982). Productivity growth, environmental regulations and the composition of R&D. *Bell Journal of Economics*, 13, 166-169.

Lu Y, Quance L & Lui CL (1978). Projecting agricultural productivity and its economic impact. *American Journal of Agricultural Economics*, 60, 976-980.

Mahlstede JP (1971). Long range planning at the Iowa Agricultural and Home Economics Experiment Station. In: Resource allocation in agricultural research. University of Minnesota.

Mangelsdorf PC (1951). Hybrid Corn: its genetic base and its significance in human affairs. In: Genetics of the 20th Century. The Macmillan Co, New York.

Maunder AH (1972). Agricultural extension, a reference manual. FAO, Rome.

May-Baker Agrichem (Pty) Ltd (1989). Personal communication.

McCulloch D (1989). The feasibility of cutting rainfed cane on the North Coast of Natal at a younger age. Proceedings SA Sugar Technologists' Association, 63, 206.

Meyer JH (1980). The role of phosphorus in the production of sugarcane in South Africa. Phosphorus In Agriculture, 78, 23-31.

Meyer JH (1988). Personal communication.

Meyer JH (1989). Rapid simultaneous rating of soil texture, organic matter, total nitrogen and nitrogen mineralisation potential by new infra-red reflectance. *SA Journal of Plant & Soil*, 6, 59-63.

Meyer JH & Wood RA (1985). Potassium nutrition of sugarcane in the South African Sugar Industry. Proceedings Potassium Symposium. Fertilizer Society of South Africa.

Meyer JH & Wood RA (1988). Rapid analysis of cane juice by near infra-red reflectance. Proceedings SA Sugar Technologists' Association, 62, 203-207.

Meyer JH & Wood RA (1989). Factors affecting phosphorus nutrition and fertilizer use by sugarcane in South Africa. Proceedings SA Sugar Technologists' Association, 63, 153.

Meyer JH, Wood RA & Harding RL (1989). Fertility trends in the South African Sugar Industry. Proceedings, SA Sugar Technologists' Association, 63, 159.

Moberly PK (1989a). Some UK experiences with payment of agricultural services. *SA Sugar Journal*, 73, 34.

Moberly PK (1989b). Presidential address. Proceedings SA Sugar Technologists' Association, 63, xii.

Murdoch MG (1987). Personal communication.

Murdoch MG (1988). Harvesting younger cane: effects on sucrose production. SA Sugar Industry Agronomists' Association.

Nagy JG & Furtan WH (1978). Economic costs and returns from crop development research: the case of rapeseed breeding in Canada. *Canadian Journal of Agricultural Economics*, 26, 1,14.

Nattrass J (1981). The South African Economy: its growth and change. Oxford University Press, Cape Town.

Nattrass J (1986). The Basic Needs approach to development in the KwaZulu/Natal context. The condenser. Tongaat-Hulett Group.

Norton GW & Davis JS (1981a). Evaluating returns to agricultural research: a review. *American Journal of Agricultural Economics* (1981a), 63, 685-699.

Norton GW & Davis JS (1981b). Review of methods used to evaluate returns to agricultural research. In: Evaluation of agricultural research. Miscellaneous publication 8-1981, University of Minnesota.

Norton GW, Fishel WL, Paulsen AA & Sunnquist WB [Editors] (1981). Evaluation of agricultural research. Proceedings Symposium, Minneapolis. University of Minnesota.

Nuss KJ, Bond RS & Atkinson PR (1986). Susceptibility of sugarcane to the borer Eldana saccharina Walker and selection for resistance. Proceedings SA Sugar Technologists' Association, 60, 153.

Oehme JF (1986). Persistent under-investment in public agricultural research. *Agricultural Economics*, 1, 53-56.

Oram PA (1985). Agricultural research and extension issues of public expenditure. In: Recurrent costs and agricultural development. [Editor J Howell] Overseas Development Institute, London.

Ortmann GF (1985). A production function analysis of the South African Sugar Industry. *SA Journal of Economics*, 53, 402-415.

Osborn RF (1964). Valiant Harvest: the founding of the South African Sugar Industry, 1846 - 1926. SA Sugar Association, Durban.

O'Riordan F (1980). Methodology: the use of benefit-cost analysis. *Canadian Farm Economics*, 15, 1-5.

Paarlberg D (1987). How the constitution shaped our agricultural institutions. In: Our American Land. USDA Yearbook of Agriculture, 1987. Washington, DC.

Pasour EC & Johnson MA (1982). Bureaucratic productivity: the case for agricultural research revisited. *Public choice*, 39, 301-317.

Paxton RH (1988). Personal communication.

Paxton RH & Culverwell TL (1988). Implementing an extension strategy. Proceedings SA Sugar Technologists' Association, 62, 221.

Pearse TL (1989). Influence of roguing on the incidence of smut in Swaziland. Proceedings SA Sugar Technologists' Association, 63, 117.

Peterson WL (1967). Returns to poultry research in the United States. *Journal of Farm Economics*, 49, 656-669.

Peterson WL (1971). The returns to investment in agricultural research in the United States. In: Resource allocation in agricultural research. University of Minnesota.

Peterson WL (1976). A note on the social returns to private research development. *American Journal of Agricultural Economics*, 58, 324-326.

Peterson WL & Hayami Y (1977). Technical change in agriculture. In: A survey of Agricultural Economic literature, Volume 1. [Editor LR Martin] University of Minnesota Press.

Pinstrup-Andersen P & Franklin D (1977). A systems approach to agricultural research resource allocation in developing countries. In: Resource allocation and productivity in national and international agricultural research. University of Minnesota Press.

Pinstrup-Andersen P, de Londono NR & Hoover E (1976). The impact of increasing food supply on human nutrition: implications of commodity priorities in agricultural research and policy. *American Journal of Agricultural Economics*, 58, 131-142.

Rausser GC, de Janny A, Schmitz A & Zilberman D (1981). Principle issues in the evaluation of public research in agriculture. In: Evaluation of Agricultural Research. University of Minnesota Press.

Republic of South Africa (1987). List of research projects, 1986. Department of Education & Training, Pretoria.

Rubenstein AH (1966). Economic evaluation of research and development: a brief survey of theory and practice. *Journal of Industrial Engineering*, 17, 615-620.

Russell DG (1975). Resource allocation in agricultural research using socio-economic evaluation and mathematical models. *Canadian Journal of Agricultural Economics*, 23, 29-52.

Ruttan VW (1980). Bureaucratic productivity: the case of agricultural research. *Public Choice*. 39, 527-547.

Ruttan VW (1982). Bureaucratic productivity: the case for agricultural research revisited - a rejoinder. *Public Choice*, 39, 319-329.

SASA Experiment Station (1924). Committee minutes, 2 October 1924.

SASA Experiment Station (1973). Annual Report, 1972/73.

SASA Experiment Station (1975). Golden Jubilee Commemorative Brochure.

SASA Experiment Station (1982). Annual Report, 1982/83.

SASA Experiment Station (1983). Assessment of cost effectiveness of Experiment Station activities.

SASA Experiment Station (1983a). Annual Report, 1983/84.

SASA Experiment Station (1984). Annual Report, 1984/85.

SASA Experiment Station (1985). Annual Report, 1985/86.

SASA Experiment Station (1986). Annual Report, 1986/87.

SASA Experiment Station (1987). Annual Report, 1987/88.

SASA Experiment Station (1988a). Personal communication (Farm Planning Department)

SASA Experiment Station (1988b). Certificate Course in Sugarcane Agriculture, notes.

SASA Experiment Station (1989). Annual Report 1988/89.

SA Cane Growers' Association (1983). Personal communication.

SA Cane Growers' Association (1988). Personal communication.

SA Sugar Association (1923). Minutes of Committee meeting.
SA Sugar Journal Annual (1925). Statistical data.

SA Sugar Journal Annual (1927/28). Sugar Production in South Africa from 1891 to 1927.

SA Sugar Technologists' Association (1980). Proceedings.

SA Sugar Year Book (1935). Statistical data.

SA Sugar Year Book (1944). Statistical data, 179-180.

SA Sugar Year Book (1952). Statistical data, 149.

Sassone PG & Schaffer WA (1978). Cost-Benefit Analysis - a handbook. Academic Press Inc, New York.

Schuh GE & Tollini H (1979). Costs and benefits of agricultural research: the state of the arts. World Bank, Washington, DC.

Schultz TW (1953). The Economic organisation of Agriculture. McGraw Hill, New York.

Schweikardt DB & Bonnen JT (1986). Policy conflicts in agricultural research: historical perspectives and today's challenges. In: The agricultural scientific enterprise - a system in transition. Westview Press Inc, Boulder, Colorado.

Scobie GM (1976). Who benefits from agricultural research? *Review of Marketing & Agricultural Economics*, 44, 197-202.

Shell Chemicals (Pty) Ltd (1989). Personal communication.

Shumway CR (1977). Models and methods used to allocate resources in agricultural research: a critical review. In: Resource allocation in national and international agricultural research, University of Minnesota Press.

Shumway CR & McCracken RJ (1975). Use of scoring models in evaluating research programs. *American Journal of agricultural Economics*, 57. 714-718.

Sim RJR & Garner R (1980). A review of research and extension evaluation in agriculture. In: Research and extension evaluation in agriculture. University of Idaho.

Simmonds NW (1974). Costs and benefits of an agricultural research institute. *R & D Management*, 5, 23-28.

Spaull VW (1981). Nematodes associated with sugarcane in South Africa. *Phytophylactica*, 13, 175-179.

Spaull VW & Cadet P (1989). Chapter 11 in: Plant-parasitic nematodes in tropical and sub-tropical agriculture. (In press) CAB International, London.

Stoner JAF (1982). Management. (2nd edition) Prentice-Hall Press, Inglewood Cliffs, New Jersey.

Sunnquist WB, Cheng Ge Cheng and Norton GW (1981). Measuring returns to research expendiutre for corn, wheat and soybeans. In: Evaluation of agricultural research. University of Minnesota Press.

Tempany HA (1971). Memorandum relative to conditions governing the sugar industry of Natal and Zululand. Unpublished report, SA Sugar Association.

Thompson GD (1968). Plant nutrition and fertilizer use with specific reference to sugarcane. Fertilizer Society of South Africa Journal, 1, 41-45.

Thompson GD (1976). Water use by sugarcane. *SA Sugar Journal*, 60, 593-600 and 627-635.

Thompson GD (1987). Personal communication.

Thompson GD (1988). Fluctuations in eldana populations. *SA Sugar Journal*, 72, 294.

Thompson GD (1989). Personal communication.

Trigo E (1984). Evaluating research programs and institutions: a management perspective. In: The planning and management of research. [Editor Deiter Elz] World Bank, Washington, DC.

Turner PET (1988). Personal communication.

Tweeten LG & Hines FK (1965). Contribution of agricultural productivity to national economic growth. *Agricultural Science Review*, III, 2, 40-45.

White FC & Havlicek J Jr (1981). International spillovers of agricultural research results and intergovernmental finance: some preliminary results. In: Evaluation of agricultural research. University of Minnesota Press.

White FC. Havelick J Jr & Otto D (1978). Agricultural Research and Extension investment needs and growth in agricultural production. Research Report, Department of Agricultural Economics, Virginia Institute & State University.

Williamson JC (1971). The Joint Department of Agriculture and State Experiment Stations study of research needs. In: Resource allocation in agricultural research. University of Minnesota.

Wise WS (1975). The role of cost-benefit analysis in planning agricultural R&D programmes. *Research Policy*, 4, 246-261.

Wise WS (1981). The theory of agricultural research benefits. *Journal of Agricultural Economics*, 32, 147-156.

Wise WS (1984). The shift of cost curves and agricultural research benefits. *Journal of Agricultural Economics*, 35, 21-30.

Wood RA (1989). Personal communication.

APPENDIX 1: SUMMARY RESULTS OF STUDIES ON THE RETURNS TO AGRICULTURAL R&D REPORTED IN THE LITERATURE WITH SOME NON-AGRICULTURAL EXAMPLES

1.1 *Production Function Studies*, expressed as marginal rates of return (Ex-post unless stated otherwise)

1.1.1 *United States data*

Commodity	Period	Return %	Literature reference
Agriculture, aggregate	1868-1926	65	Evenson, 1979
	1939-1948	41-50	Cline 1975 (q US Congress, 1986)*
	1949-1959	35 47	Griliches, 1964 Evenson 1968 (q US Congress)
	1938-1948 1949-1959 1959-1969 1967-1972	30,5 27,5 25,5 23,5	Lu & Cline, 1979 (q Ruttan 1980)
	1949-1959 1964-1974	66-100 37	Davis, 1979
	1949 1954 1959 1964 1969 1974	100 79 66 37 37 37	Davis & Peterson, 1981
• South Region	1948-1971	130	Evenson 1979
• North Region		93	
• Western Region		95	
Agricultural Technology	1927-1950	95	
Agricultural Science	1927-1950	110	
Agric. Mgt. Extension	1948-1971	45 110	
Research & Extension	1949-1958 1959-1968 1969-1972	39-47 32-39 28-35	Knutson & Tweeten, 1979

* Quoted by

continued/...

APPENDIX 1 continued

Poultry	1915-1960	21	Peterson, 1967
Poultry Dairy (6 yr. lag) Livestock (7 yr. lag) Cash grains (5 yr. lag)	1969	37 43 47 36	Bredahl & Peterson, 1976
Corn (6 yr. lag) Wheat (6 yr. lag) Soybeans (6 yr. lag)	1977	115 97 118	Sunnquist *et al*, 1981

1.1.2 *Effect of lag time on US data (Return %)*

Lag years		5	6	7	8	9	
Cash grains	1969	57	47	40	35	31	Norton, 1981
	1974	85	69	58	50	44	
Dairy	1969	50	42	35	31	27	
	1974	62	51	44	38	33	
Livestock	1969	111	89	75	64	56	
	1974	132	106	85	75	66	
Poultry	1969	56	46	39	34	30	

1.1.3 *Ex-ante study of return on research in 1990 & 1995 with and without extension on US - Western Regions' commodities, based on 1973 data (Return %)*

	1990		1995		
	+ Ext	- Ext	+ Ext	- Ext	Araji *et al*, 1978
Sheep	33,3	24,0	34,8	26,1	
Lettuce	35,8	25,0	38,3	29,5	
Tomato	45,6	30,0	47,6	32,4	
Grapes	39,9	19,2	41,7	23,0	
Apples	47,7	33,2	48,7	35,1	
Citrus	Nil	Nil	25,2	15,0	
Potatoes	104,4	69,4	104,8	70,6	
Cotton	42,4	17,9	43,7	21,6	
Rice	33,8	11,4	35,6	21,3	

continued/...

APPENDIX 1 continued

1.1.4 *Data from other countries*

Asia Rice (National research) (International research)	1956-1965 1966-1975	32-39 73-78 74-102	Evenson & Flores 1978 (q Ruttan, 1982a)
Rice ("Tropics") Rice (Phillipines)		46-71 75	Flores *et al* 1978 (q Ruttan, 1982a)
Rice (S.E. Asia) New irrigation areas Old irrigation areas Rainfed areas	1970-1990 (ex-ante)	 11-12 35-40 40-85	Barker, 1981
Australia Pasture improvement Pasture research	1948-1969	58-65	Duncan, 1972 Duncan, 1972
North Tablelands, NSW South Tablelands, NSW Wheat/Sheep zone WA		56-68 22-27 48	Marsden *et al*, 1980)
Sugarcane	1945-1958	50	Evenson, 1969
Canada Rape seed	1960-1975	95-110	Nagy & Furtan, 1978
Chile Maize	1940-1977	32-34	Yrarrazaval *et al* 1979 (q Pinstrup-Andersen, 1982)
India Agriculture, aggregated	1953-1971	40	Evenson & Jhu. 1973 (q Boyce & Evenson 1975)
Dairy	1963-1975 1960-1961	29 63	Kumar *et al* , 1977 (q Pinstrup-Andersen 1982) Kahlon *et al*, 1977
Sugarcane	1945-1958	60	Evenson, 1969
Israel Field crops Dairy farming Wheat research	1954-1973	13 94 150	Kislev & Hoffman 1978
Japan Agriculture, aggregated	1880-1938	35	Tang, 1963 (q Boyce & Evenson 1975)
Mexico Crops	1943-1963	45-93	Barletta, 1970 (q Ruttan, 1982a)
Potatoes	1948-1964	69	Barletta, 1970 (q Pinstrup-Andersen, 1982)
South Africa Sugarcane	1945-1958	40	Evenson, 1969

continued/...

APPENDIX 1 continued

1.2 *Economic Surplus Studies*, expressed as average rate of return. (Ex-post unless stated otherwise).

1.2.1 *United States data*

Agriculture, aggregated	1937-1942 1947-1952 1957-1962 1967-1972	50 51 49 34	Petersen & Fitzharris 1977
Hybrid corn Hybrid sorghum	1940-1955 1940-1957	35-40 20	Griliches, 1958
Poultry	1915-1960	21-25	Petersen 1967
Tomato harvester	1958-1969		
Without compensation for labour displaced		37-46	Schmitz & Seckler 1970
With compensation		16-28	(q Ruttan, 1982a)

1.2.2 *Data from other countries*

Australia			
Entomology research projects	1960-2000		
Blow fly & diazanon	(ex-ante)	1682	Marsden *et al* 1980
Cattle ticks, acaricides		23,3	
Cattle resistance		9,2	
Scarab beetle		-ve	
Locusts		0,001	
Sub-terranean clover stunt virus		-ve	
Fruit moths		19,7	
Fruit fly		6,2	
White wax scale		13,9	
Orchard mite		32,8	
Phasmatid		-ve	
Sirex		19,5	
Skeleton weed		141,0	
All entomology research		19,0	
Bangladesh Wheat & Rice	1961-1977	30-35	Pray, 1979 (q Evenson 1984)
Bolivia Sheep	1966-1975	44,1	Wannengren & Whitaker, 1977
Wheat Rice	1957-1964	- 48 79-96	Scobie & Posada, 1978

continued/...

APPENDIX 1 continued

Brazil Cocoa	1923-1974 1958-1974	16 60	Monteiro, 1975 (q Pinstrup-Andersen, 1982)
Cotton	1924-1967	77-110	Ayr & Schuh, 1972
Colombia Rice Soybeans Wheat Cotton	 1957-1972 1960-1971 1953-1973 1953-1972	 60-82 79-96 11-12 Nil	Hertford *et al* 1977
Japan Rice	 1915-1950 1930-1961	 25-27 73-75	Hayami & Akino, 1977
Malaysia Rubber	 1932-1973	 24	Pee 1977 (q Evenson, 1984)
Mexico Wheat Maize	 1943-1963	 90 35	Barletta 1970 (q Ruttan 1982a)
Peru Maize (only) Maize (+ agronomy)	 1954-1967	 35-40 50-55	Hines 1972 (q Ruttan, 1982a)
Punjab Agricultural research and Extension	 1906-1956 1947-1963	 34-44 23-37	Pray 1978 (q Evenson, 1984)
1.3 ***Benefit: Cost ratio studies***			
Australia Entomology research projects Blow fly & diazanon Cattle ticks, acaricides Cattle resistance Scarab beetle Locusts Sub-terranena clover stunt virus Fruit moths Fruit fly	1960-2000 (ex-ante, projects from ex-post based on 1960-1975 and dis-counted at 10%)	 680 2,7 1,0 0,2 1,1 0,14 3,2 0,6	Marsden *et al*, 1980

continued/...

APPENDIX 1 continued

White wax scale Orchard mite Phasmatid Sirex Skeleton weed Animal health All entomology research		1,5 24,0 0,37 2,5 112,0 5,0 2,3	Marsden *et al*, 1980
Asia, South East Rice breeding New irrigation areas Old irrigation areas Rainfed areas	1970-1990 (ex-ante)	1,0 - 1,9 5,0 - 6,7 6,5 -12,9	Barker, 1981
Israel Field crops Dairy farming Wheat research	1954-1973 (dis-counted at 5% & 10% re-spect-ively)	3,2 & 1,3 22,5 & 9,4 31,6 &12,5	(Calculated from Kislev & Hoffman, 1978)
South Africa - Sugarcane	1983 (ex-post)		SASA Experiment Station 1983
R&D programmes:			
Herbicides & Weeds		4,6	
Growth regulators		5,0	
General agronomy		2.1	
Variety trials		1,1	
Nematicides		2,9	
Functions:			
Variety breeding		4,2	
Extension & Education		2,4	
Services:			
Machinery advice		3,2	
Farm planning		1,4	
Civil works advice		1,3	
Irrigation & drainage		2,2	
Fertilizer advice		2,8	
Disease control		3,4	
Pest control		3,9	
Experiment Station total	2,4		

continued/...

APPENDIX 1 continued

Spain Rice breeding	1945 1955 1965 1975 1980	3,9 90,3 66,8 58,6 40,2	(Calculated from Herruzo, 1985)
United Kingdom Potatoes, varieties Pentland Crown & Pentland Dell Potatoes, other varieties Cereals Swedes Experiment station total	1962-1973 (ex-post) 1974-1997 (ex-ante)	1,9 18,4-26,1 1,6- 9,9 1,0- 4,0 0,3- 6,8 21,3-46,8	Simmonds,1974
United States Western Region research with and without extension Sheep Lettuce Tomato Grapes Apples Citrus Potatoes Cotton Rice	1973-1990 (ex-ante)	 4,6- 7,7 6,0- 3,6 13,4- 4,3 7,2- 2,2 10,0- 4,9 0,5- 0,1 36,4-13,9 9,3- 1,8 4,9- 1,2	Araji *et al* 1978

1.4 ***Non-agricultural Returns*** on various investments

Industrial innovations in the U.S.	Average rate of return %		
	Social	Private	
Electronic device	-ve	-ve	Mansfield, 1982 (method of estimating not given)
Industrial product 'H'	104	-ve	
Industrial product 'L'	-ve	13	
Chemical process 'R'	13	4	
Chemical process 'A'	32	25	
Industrial product 'A'	62	31	
Construction material	96	9	
Industrial product 'I'	113	12	
Industrial product 'G'	123	24	
Industrial product 'F'	161	40	
Industrial product 'T'	198	69	
Household cleaning device	209	214	
Thread	307	27	
Industrial product 'K'	472	127	

continued/...

APPENDIX 1 continued

Industrial Training in South Africa		Return %	Davidson, 1987
Sugar industry Company B Company F Company G Company H	1982-1983 (B:C ratio estimates)	20,0 9,1 13,3 3,3 6,0	
	Ex-ante estimates		
Transport projects in Australia	Average rate of return %	B:C ratio	Marsden *et al* 1980
Rail electrification	5-20	0,6 -2	
Rail rolling stock	12-14	1,1 -1,5	
Bus-ways	27-39	2,0 -6,7	
Tram route upgrade	9-23	0,7 -2,3	
Ferry vessels	10-11	1,0 -2,5	
Urban renewal in Australia			Marsden *et al*, 1980
Glebe Estate, Sydney	5	0,9 -1,1	
Water resource development in Australia			Marsden *et al*. 1980
Eton irrigation scheme	2-8		
Bundaburg scheme	3-8		
Upper Condamine scheme	5-14		
Mitchell River scheme	1-3		

APPENDIX 2: DISTRIBUTION OF EXPERIMENT STATION GOALS AMONG DEPARTMENTAL PROGRAMMES.

The goals of the Experiment Station are listed in its annual report where they are described as 'functions' (SASA Experiment Station, 1986). The following table sub-divides these goals, each of which is a portfolio of activities, into departmental programmes which may be services, functions or R&D programmes, many of which are conducted on a multi-disciplinary or inter-departmental basis.

Goals (=Portfolios)	Departmental programmes		
	Services	Functions	R&D
1. Develop./propagate/distribute new varieties	Extension Pathology	Plant Brdg (Xing) Plant Brdg (Slct) Chem & Soils Plant Pathology	Plant Brdg (Xing) Plant Brdg (Slct) Agronomy
2. Advise growers on the use of: a) agricultural chemicals	Agronomy Chem & Soils		Agronomy Chem & Soils
b) irrigation & drainage	Agric Eng'ing Farm Planning		Agric Eng'ing Farm Planning Chem & Soils
c) machines & equipment	Agric Eng'ing		
d) land & water management	Farm Planning		Farm Planning
e) crop production & planning	Farm Planning		Agronomy Farm Planning
f) specific problems	All departments		
3. Study/monitor/develop control measures for: a) pests	Entomology Extension	Entomology Extension	Agronomy Extension
b) diseases	Pathology Extension	Pathology	Pathology

continued/...

APPENDIX 2 continued

Goals (=Portfolios)	Departmental programmes		
	Services	Functions	R&D
4. Study cane nutritional requirements & soil/crop management relationships	Chem & Soils Farm Planning	Chem & Soils Farm Planning	Agronomy Chem & Soils Farm Planning Pathology
5. Test & develop machinery & equipment	Agric Eng'ing	Agric Eng'ing	Agric Eng'ing
6. Publish and disseminate sugarcane information	Extension Publications	Publications (with co-operation of all depts)	
7. Provide education courses	Education & PR and all depts except PB(Xing)	Education & PR	
8. Train labour	Training Extension	Training	

APPENDIX 3: SUGAR PRODUCTION STATISTICS 1862 - 1890

Season	Area under cane (hectares)*	Sugar produced (metric tons)	Annual average yield (metric tons/hectare/annum)	Five-year moving average yield (metric tons/hectare/annum)
1862	7 255	2 380	0,03	
1863	7 932	4 056	0,51	
1864	8 682	7 095	0,82	
1865	9 347	5 268	0,56	
1866	10 292	6 896	0,67	0,57
1867	3 353	5 681	1,69	0,85
1868	5 857	9 319	1,59	1,07
1869	4 663	7 901	1,69	1,24
1870	4 734	7 713	1,63	1,45
1871	5 558	9 575	1,72	1,66
1872	5 075	8 764	1,73	1,67
1873	5 178	8 622	1,67	1,69
1874	5 664	10 333	1,82	1,71
1875	6 046	10 286	1,70	1,73
1876	9 489	12 812	1,35	1,65
1877	------ Data not available ------			
1878	8 667	8 714	1,24	1,56
1879	7 135	15 351	2,66	1,75
1880	8 358	16 367	2,42	1,87
1881	9 808	12 125	1,53	1,84
1882	8 710	12 021	1,70	1,91
1883	12 611	16 718	1,64	1,99
1884	9 480	18 984	2,47	1,95
1885	15 473	15 684	1,25	1,72
1886	12 386	17 778	1,77	1,77
1887	12 695	15 801	1,54	1,73
1888	14 973	15 248	1,26	1,66
1889	15 005	15 232	1,25	1,41
1890	12 616	11 097	1,09	1,38

Data Source: SA Sugar Journal Annual, 1925 p.29.

*Calculated as area harvested x 2.

APPENDIX 4: SUGAR PRODUCTION STATISTICS AND RAINFALL 1890/91 - 1924/25

Season	Area under cane (hectares)*	Sugar produced (metric tons)	Average annual yield (metric tons/hectare)	Rainfall (mm)
1890/91	12 154	15 232	1,25	967
1891/92	10 218	10 190	0,99	820
1892/93	14 298	26 342	1,84	1 212
1893/94	10 540	16 629	1,58	1 408
1894/95	12 090	19 110	1,58	1 372
1895/96	11 424	20 596	1,80	971
1896/97	15 594	5 465	0,35	860
1897/98	14 890	18 370	1,23	1 161
1898/99	16 370	29 471	1,80	829
1899/1900	24 580	-- Data not available --		636
1900/01	21 820	16 322	0,75	1 188
1901/02	23 192	36 329	1,57	1 327
1902/03	26 592	17 650	0,66	886
1903/04	12 802	30 627	2,39	957
1904/05	11 884	17 449	1,47	865
1905/06	8 764	27 024	3,08	1 239
1906/07	10 974	21 312	1,94	1 155
1907/08	11 848	24 607	2,08	1 161
1908/09	19 854	32 500	1,64	966
1909/10	--- Data not available ---			1 196
1919/20	--- Data not available ---			1 152
1920/21	63 842	130 312	2,04	1 654
1921/22	79 757*	137 485	1,72	947
1922/23	87 327*	144 541	1,66	972
1923/24	70 172	184 448	2,63	547
1924/25	75 082	146 254	1,95	1 506

Data sources: Area harvested: 1890/91 - 1909/10 SA Sugar Journal Annual, 1925 pp.29-30.
1910/11 - 1924/25 SA Sugar Journal Annual, 1927/28 p.15.
Sugar produced: SA Sugar Year Book, 1952/53 p.149.
Rainfall : SASA Experiment Station, 1988.
1890/91 - 1923/24, Natal Estates Mill records.
1923/24 - 1924/25, Industry average.

*Calculated as area harvested x 2, except for 1921/22 and 1922/23 for which areas under cane are available.

APPENDIX 5: DATA ON ALL FACTORS USED IN ANALYSES TO ESTIMATE INDUSRIAL YIELD DURING THE TECHNOLOGICAL ERA. Those used in the final analysis are marked *. Yield is expressed as metric tons sucrose per hectare per annum. Units and sources of other factors are given on page 44.

Year	Yield	Rain *	Land *	Costs *	Technology *
1925/26	3.13	733	94 014	425	1,15
1926/27	2,59	941	102 975	434	1,07
1927/28	2,77	758	107 062	442	1,03
1928/29	2,88	843	121 455	451	1,01
1929/30	2,81	971	125 526	460	1,18
1930/31	4,02	839	117 065	469	1,30
1931/32	3,22	1 184	121 848	479	1,62
1932/33	2,83	1 229	150 737	488	1,41
1933/34	2,92	791	158 310	498	1,65
1934/35	2,69	1 136	155 303	508	1,90
1935/36	3,01	1 154	159 167	518	2,42
1936/37	3,16	1 273	160 084	528	2,38
1937/38	3,61	1 005	158 160	516	3,91
1938/39	3,71	1 024	157 360	538	3,79
1939/40	4,32	1 211	152 146	563	4,43
1940/41	4,26	1 104	149 604	630	4,19
1941/42	3,63	665	151 091	544	4,37
1942/43	4,17	1 255	151 309	544	3,35
1943/44	4,62	1 354	150 039	575	3,21
1944/45	4,86	926	150 591	631	3,27
1945/46	4,32	812	152 396	626	3,29
1946/47	3,69	813	153 463	641	3,96
1947/48	3,86	1 139	156 927	652	3,99
1948/49	4,40	895	164 495	704	4,24
1949/50	3,91	1 101	170 606	691	3,20
1950/51	4,32	989	176 293	706	3,22
1951/52	3,30	646	170 948	737	4,84
1952/53	4,21	923	185 821	740	4,86
1953/54	4,23	861	204 653	749	4,36
1954/55	4,36	992	213 253	826	5,03
1955/56	4,72	1 200	215 926	863	5,12

continued/...

LE

APPENDIX 5 continued

Year	Yield	Rain *	Land *	Costs *	Technology *
1956/57	4,23	974	227 606	847	5,17
1957/58	4,49	1 242	231 782	824	5,46
1958/59	5,27	1 281	239 522	924	5,81
1959/60	4,72	847	249 292	879	5,34
1960/61	4,31	906	255 521	743	6,65
1961/62	4,58	1 179	257 629	766	7,32
1962/63	5,03	866	246 419	971	8,39
1963/64	5,47	793	249 657	1 090	12,11
1964/65	5,94	1 093	291 248	978	21,71
1965/66	3,75	737	326 966	740	15,60
1966/67	5,92	995	338 543	882	15,27
1967/68	6,45	982	336 672	1 049	15,27
1968/69	5,34	764	330 731	970	17,92
1969/70	5,76	1 011	330 295	983	14,13
1970/71	5,00	784	330 429	963	15,04
1971/72	6,58	1 238	344 979	1 039	14,22
1972/73	6,46	1 117	341 741	1 090	19,16
1973/74	5,91	797	348 687	1 062	19,14
1974/75	6,34	1 133	361 460	1 116	24,46
1975/76	5.86	895	364 634	1 219	21,04
1976/77	6,55	1 452	365 883	1 256	28,71
1977/78	6,67	1 106	378 881	1 213	22,57
1978/79	6,31	1 037	380 502	1 115	27,93
1979/80	6,27	880	393 551	1 154	22,69
1980/81	4,77	676	395 751	1 087	24,10
1981/82	6,07	1 007	400 402	1 285	30,35
1982/83	6,21	933	409 263	1 252	26,31
1983/84	4.04	606	408 000	1 164	24,02
1984/85	~~6,72~~ 6.70	1 415	409 634 ✓	1 194	24,22
1985/86	~~6,30~~ 5.98	1 035	~~409 533~~ 413 139	1 254	24,22
1986/87	~~5,70~~ 5.79	966	404 ~~244~~ 218	1 249	21,41
87/88	6.44	1004	392 819	1238	24.82
88/89	6.56	1802	381 717	1292	23.62
89/90	6.62	1020	370 987	1315	25.34
90/91	6.23	1122	374568	127[illegible]	24.76
91/92	6.92	1048	378143	1254	26.26
92/93	4.64	662	385697	1071	27.09
93/94	3.67	596	383978		
94/95					

continued/.

APPENDIX 5 continued

Year	Labour	Capital	Price	NFI[⊕]
1925/26			220,18	
1926/27			216,32	
1927/28			239,65	
1928/29			241,23	
1929/30			231,25	
1930/31			251,85	
1931/32			231,37	
1932/33			269,60	
1933/34			272,16	
1934/35			237,60	
1935/36			267,65	
1936/37	311,73	1 730	255,96	232
1937/38	299,81	1 796	259,44	295
1938/39	317,96	1 926	255,74	312
1939/40	326,18	2 036	246,18	390
1940/41	367,24	2 086	228,28	349
1941/42	321,59	2 063	224,29	206
1942/43	338,96	2 090	201,94	302
1943/44	337,68	2 188	191,45	307
1944/45	365,49	2 282	192,25	321
1945/46	361,39	2 417	221,81	251
1946/47	371,33	2 493	215,20	309
1947/48	370,38	2 544	236,71	327
1948/49	386,95	2 634	249,39	386
1949/50	377,65	2 729	245,18	241
1950/51	364,46	2 717	245,45	371
1951/52	379,60	2 690	238,50	169
1952/53	363,50	2 806	280,58	361
1953/54	362,95	2 962	295,52	340
1954/55	398,70	3 287	286,39	353
1955/56	409,09	3 273	287,00	403
1956/57	411,23	3 395	276,32	233
1957/58	386,19	3 525	267,20	292

[⊕] NFI = Net farm income

continued/...

APPENDIX 5 continued

Year	Labour	Capital	Price	NFI
1958/59	432,94	3 765	269,66	386
1959/60	429,34	3 983	264,63	291
1960/61	373,58	4 220	268,37	398
1961/62	380,64	4 464	263,60	457
1962/63	420,87	4 762	261,27	433
1963/64	453,64	5 008	313,34	633
1964/65	420,67	5 187	267,76	382
1965/66	353,26	5 381	237,70	35
1966/67	405,00	5 590	243,33	518
1967/68	478,29	5 932	235,27	485
1968/69	445,03	6 172	243,97	360
1969/70	410,89	6 348	264,56	550
1970/71	405,12	6 423	265,06	394
1971/72	397,93	6 486	236,09	524
1972/73	441,28	6 372	226,17	400
1973/74	442,28	6 137	252,69	438
1974/75	451,37	6 403	271,17	427
1975/76	482,10	5 692	354,17	640
1976/77	514,82	5 036	299,12	474
1977/78	485,75	5 202	274,05	361
1978/79	461,58	4 505	269,56	375
1979/80	433,26	3 868	273,69	341
1980/81	409,43	4 310	335,10	343
1981/82	447.41	5 186	282,74	247
1982/83	458,08	5 758	265,84	186
1983/84	445,74	6 044	336,20	129
1984/85	432,22	6 257	226,37	292
1985/86	404,77	6 091	218,14	189
1986/87	410,47	5 021	233,00	310

continued/...

APPENDIX 5 continued

Year	Varieties	Fertilizer	Extension	Training	Productivity
1925/26	100	33	1,06		
1926/27	100	33	0,97		
1927/28	100	33	0,93		
1928/29	100	33	0,82		
1929/30	100	33	0,80		
1930/31	100	33	0,85		
1931/32	100	33	0,82		
1932/33	100	33	0,66		
1933/34	102	33	0,63		
1934/35	106	33	0,64		
1935/36	112	33	0,63		
1936/37	119	33	0,62		
1937/38	124	33	0,63		
1938/39	127	33	0,64		
1939/40	128	33	0,66		
1940/41	131	33	0,67		
1941/42	133	33	0,66		
1942/43	136	33	0,66		
1943/44	137	33	0,67		
1944/45	138	33	0,66		
1945/46	139	33	0,66		
1946/47	139	33	0,65		
1947/48	140	33	0,64		
1948/49	140	33	0,61		
1949/50	142	33	0,59		
1950/51	149	33	0,57		
1951/52	152	33	0,58		
1952/53	161	33	0,54		14,93
1953/54	164	35	0,49		
1954/55	168	44	0,94		
1955/56	172	55	1,85		
1956/57	174	62	2,64		
1957/58	176	63	3,45		
1958/59	177	93	3,34		
1959/60	177	98	3,21		

continued/...

APPENDIX 5 continued

Year	Varieties	Fertilizer	Extension	Training	Productivity
1960/61	181	62	2,35		
1961/62	183	42	2,33		10,21
1962/63	182	58	3,25		
1963/64	183	150	6,81		
1964/65	181	156	6,18		
1965/66	187	135	5,51		
1966/67	190	114	6,50		
1967/68	190	113	7,13		7,64
1968/69	191	123	8,16		8,69
1969/70	193	123	7,57		7,60
1970/71	193	150	8,47		8,57
1971/72	194	150	8,12		6,51
1972/73	194	150	8,19		6,46
1973/74	195	174	8,89		6,75
1974/75	195	169	9,13		6,24
1975/76	195	181	8,78		5,86
1976/77	196	158	9,29	1 613	5,62
1977/78	196	178	8,79	3 121	5,62
1978/79	196	155	8,94	3 784	5,61
1979/80	197	164	8,64	4 589	5,55
1980/81	197	189	8,72	4 791	6,74
1981/82	198	190	10,49	4 871	5,37
1982/83	198	168	10,26	4 827	5,26
1983/84	198	129	9,74	4 518	7,54
1984/85	198	194	9,64	3 702	4,64
1985/86	198	194	9,65	4 177	5,03
1986/87			9,63		5,14

APPENDIX 6: INDUSTRIAL YIELD DURING THE TECHNOLOGICAL ERA.
Estimated by production function analysis in tons sucrose per hectare.

Year	Yield
1925/26	2,86
1926/27	2,94
1927/28	2,75
1928/29	2,78
1929/30	2,89
1930/31	2,93
1931/32	3,30
1932/33	3,11
1933/34	2,77
1934/35	3,20
1935/36	3,30
1936/37	3,53
1937/38	3,46
1938/39	3,71
1939/40	4,20
1940/41	4,52
1941/42	3,61
1942/43	4,29
1943/44	4,46
1944/45	4,16
1945/46	3,89
1946/47	3,98
1947/48	4,43
1948/49	4,30
1949/50	4,43
1950/51	4,23
1951/52	3,95
1952/53	4,26
1953/54	4,09
1954/55	4,52
1955/56	4,88

Year	Yield
1956/57	4,46
1957/58	4,73
1958/59	5,06
1959/60	4,31
1960/61	4,00
1961/62	4,45
1962/63	4,88
1963/64	5,32
1964/65	5,55
1965/66	4,17
1966/67	5,07
1967/68	5,65
1968/69	5,01
1969/70	5,43
1970/71	4,99
1971/72	5,80
1972/73	5,84
1973/74	5,28
1974/75	6,08
1975/76	6,08
1976/77	7,26
1977/78	6,54
1978/79	6,16
1979/80	5,93
1980/81	5,25
1981/82	6,55
1982/83	6,23
1983/84	5,31
1984/85	6,83
1985/86	6,35
1986/87	6,17

APPENDIX 7: DATA & CALCULATIONS FOR ESTIMATING PRODUCTIVITY OF MILLING TECHNOLOGY AS SUCROSE/HECTARE/ANNUM, 1945/46 - 1986/87.

Year	Sucrose produced (tons)	Sugar made (tons)	Tons sucrose to make 1 ton sugar	Mean for the period	Productivity (tons sucrose per hectare)
1945/46	602 522	501 704	1,2010		
1946/47	517 298	430 703	1,2011		
1947/48	555 898	464 483	1,1968		
1948/49	665 022	550 521	1,2080		
1949/50	603 003	509 041	1,1846	1,1983 (a)	
1950/51	735 942	622 146	1,1829		
1951/52	582 084	483 081	1,2049		0,0032 (a)-(b)
1952/53	720 020	607 985	1,1843		
1953/54	784 785	658 098	1,1925	1,1951 (b)	
1954/55	891 770	751 653	1,1864		
1955/56	1 009 803	851 829	1,1855		
1956/57	919 980	769 878	1,1950		
1957/58	1 023 891	870 781	1,1758		
1958/59	1 232 104	1 023 184	1,2042		
1959/60	1 136 559	946 467	1,2008		0,0094 (b)-(c)
1960/61	1 077 805	902 071	1,1948		
1961/62	1 177 464	996 797	1,1812		
1962/63	1 302 600	1 082 525	1,2033		
1963/64	1 348 225	1 147 320	1,1751		
1964/65	1 485 588	1 265 928	1,1735	1,1857 (c)	
1965/66	1 093 758	908 803	1,2035		
1966/67	1 925 968	1 627 581	1,1833		
1967/68	2 192 036	1 822 266	1,2029		
1968/69	1 801 314	1 565 382	1,1507		
1969/70	1 912 160	1 622 499	1,1785		0,0058 (c)-(d)
1970/71	1 659 690	1 398 872	1,1864		
1971/72	2 173 772	1 864 665	1,1658		
1972/73	2 230 332	1 914 601	1,1649		
1973/74	2 056 176	1 731 575	1,1875		
1974/75	2 215 210	1 883 195	1,1763		
1975/76	2 123 946	1 801 088	1,1793	1,1799 (d)	
1976/77	2 391 532	2 041 520	1,1714		
1977/78	2 441 827	2 083 877	1,1718		
1978/79	2 380 399	2 070 232	1,1498		
1979/80	2 387 599	2 074 762	1,1508		
1980/81	1 877 883	1 610 868	1,1658		
1981/82	2 384 557	2 055 441	1,1601		0,0135 (d)-(e)
1982/83	2 490 058	2 125 993	1,1712		
1983/84	1 656 972	1 377 718	1,2027		
1984/85	2 743 881	2 369 695	1,1579		
1985/86	2 469 717	2 117 415	1,1664		
1986/87	2 340 727	2 013 836	1,1623	1,1664 (e)	

APPENDIX 8 : EXPERIMENTAL YIELD AND RAINFALL, 1957/58 - 1985/86.

Year	Yield (metric tons/ha/a)		Rainfall (mm)
	Actual	Predicted by Regression Analysis	
1957/58	8,83	8,62	1 242
1958/59	10,50	8,84	1 281
1959/60	8,62	9,05	847
1960/61	8,78	9,24	906
1961/62	11,16	9,42	1 179
1962/63	9.70	9,59	866
1963/64	9.36	9,74	793
1964/65	10,45	9,88	1 039
1965/66	6,85	10,00	737
1966/67	10,24	10,11	995
1967/68	10,13	10,21	982
1968/69	9,50	10,29	764
1969/70	9.03	10,36	1 011
1970/71	10.02	10,42	784
1971/72	11,67	10,46	1 238
1972/73	12,05	10,49	1 117
1973/74	10,28	10,50	797
1974/75	10,79	10,50	1 133
1975/76	10,51	10,49	895
1976/77	10,89	10,46	1 452
1977/78	11,64	10,42	1 106
1978/79	12,09	10,37	1 037
1979/80	10,90	10,30	880
1980/81	8,65	10,22	676
1981/82	8,74	10,12	1 007
1982/83	9,10	10,01	933
1983/84	8,09	9,89	606
1984/85	10,21	9,75	1 415
1985/86	8.93	9,60	1 035
1986/87	10,95	9,43	966
MEAN	9,96	9,96	991

APPENDIX 9: VARIETIES BY PERCENTAGE OF THE TOTAL INDUSTRIAL PRODUCTION OF CANE.

Season	Uba	Other varieties	Co331	NCo310	NCo339	NCo293	NCo292	NCo376	NCo382	N50/211	N55/805	N52/219	N12	N14
1925/26 - 1931/32	100	-												
1932/33	98,90	1.10												
1933/34	95,80	4,20												
1934/35	85,10	14,99												
1935/36	69,90	30.10												
1936/37	53,50	46,50												
1937/38	41,20	58,60												
1938/39	32,20	67,80												
1939/40	30,20	69,60												
1940/41	23,20	76,60												
1941/42	16,60	83,40												
1942/43	11,10	86,90												
1943/44 (a)	8.0	92,00												
1944/45	4,25	95,62	0,13 (b)											
1945/46	2,83	96,57	0,60 (b)											
1946/47	1,91	97,44	0,65 (b)											
1947/48	1,53	96,81	1,66											
1948/49	0,72 (c)	96,67	2,54	0,07 (b)										
1949/50	0,30 (c)	92,80	4,21	2,60										
1950/51	0,23 (c)	76,83	7,67	15,07										
1951/52	0,16 (c)	66,21	12,51	21,12										
1952/53	0,13 (c)	46,14	15,67	37,66										
1953/54	0	36,83	22,01	41,35										
1954/55		25,32	25,27	49,41										
1955/56		16,53	23,46	55,66	1,35	1,00								
1956/57		14,65	23,16	57,00	1,77	3,22								
1957/58		11,77	20,92	60,05	4,26	3,00								
1958/59		8,63	18,63	59,42	3,91	4,05	2,12	2,54						
1959/60 (a)		7,00	15	59,00	4,00	4,50	2,50	8,00						
1960/61		5,20	12,61	59,06	4,74	4,94	2,63	10,42						
1961/62		4,90	8,97	55,65	4,75	5,23	2,36	17,03	1,11					
1962/63		5,94	9,59	54,90	3,67	4,62	2,52	15,04	1,93					
1963/64		5,25	6,32	50,75	3,23	4,93	2,03	21,45	1,61	1,23				
1964/65		12,00	4,41	48,91	2,57	3,72	1,32	23,38	2,37	2,54				
1965/66		3,50	2,90	44,50	0	5,10	0	35,70	4,20	4,10				
1966/67		2,00 (d)	2,10	36,00		6,60		41,50	5,50	4,10				
1967/68		2,40	1,50	38,50		7,20		48,00	7,60	4,40				
1968/69		3,70	1,60	22,10		9,30		53,70	7,70	3,60				
1969/70		4,50	0	21,29		5,90		58,60	5,70	4,00				
1970/71		4,30		18,50		8,20		59,50	6,20	2,30	2,00			
1971/72		3,70		16,50		6,60		61,00	5,10	1,90	5,20			
1972/73		3,76		15,20		7,20		60,69	5,10	1,00	7,20			
1973/74		3,60		12,70		6,70		63,70	3,90	0	9,20			
1974/75		15,50		8,50		6,00		54,60	2,90		9,60			
1975/76		15,00		8,40		5,50		56,50	2,90		11,70			
1976/77		11,10		7,00		5,20		61,70	2,50		10,40			
1977/78		11,10		5,00		5,50		63,50	2,20		10,40			
1978/79		12,00		5,60		6,20		65,40	1,60		90			
1979/80		10,50		4,00		7,50		66,00	1,60		3,40			
1980/81		11,60		6,60		6,40		67,20	1,20		6,60			
1981/82		10,60		4,80		5,60		71,60	0		60	1,20		
1982/83		13,30		4,40		7,20		69,40			4,10	1,60		
1983/84		14,70		3,50		8,20		67,50			3,40	1,50		1,20
1984/85		15,60		1,60		7,60		68,70			2,70	1,10		2,70
1985/86		18,30		2,10		7,70		60,90			2,20	1,10	1,40	6,40

Notes on Appendix 9.

(a) Data not available. Percentage estimated.

(b) Percentage <1 for new varieties added to previous variety, i.e. Co331 to other varieties and NCo310 to Co331.

(c) Percentages <1 for old varieties added to next oldest, in this case to other varieties.

(d) No longer includes original four 'other varieties' from here on 'other varieties' means *unidentified and mixed varieties* for which the index is the wieghted average of indices of all other varieties in the industrial total. The sudden increase from 3,6% in 1973/4 to 15.5% in 1974/5 is not explained.

APPENDIX 10: INDIVIDUAL VARIETY INDICES

Variety	Exceeds 1% of crop in:-	Below 1% of crop in:-	Yield index	References to data used
Uba	1883	1947/48	1,00	
Other varieties (POJs CO281 Co290 Co301)	1931/32	1965/66	1,40	Estimate by Dodds (1941)
Mixed and unidentified varieties	1966/67	-	1,9 to 67/8 1,91 in 68/9 1,93 to 70/1 1,94 to 73/4 1,95 to 75/6 1,96 to 78/9 1,97 to 80/1 1,98 to 85/6	Weighted averages of indices of all varieties used by the industry.
Co331	1944/45	1969/70	1,57	Data ex 13 field trials SASJ (1940) pp 395, 617, 194 SASJ (1941) pp 447, 449, 559 SASJ (1942) p 47/1 SASJ (1943) pp 315, 401, 403
NCo310	1949/50		1,88	Data ex 58 field trials Inman-Bamber (1988)
NCo339	1955/56	1964/65	1,75	SASA Experiment Station (1984)
NCo293	1955/56	1980/81	2,00	Data ex 59 field trials Inman-Bamber (1988)
NCo292	1958/59	1964/65	1,4	Data ex 13 field trials Agronomists Assoc. (1966) Data ex 23 trials Bond (1988) Data ex 2 reports SASTA (1960)
NCo376	1958/59		1,99	Data ex 338 field trials Inman-Bamber (1988)
NCo382	1961/62	1973/74	1,61	SASA Experiment Station (1984)
N50/211	1963/64	1972/73	1,57	SASA Experiment Station (1984)
N55/805	1970/71		1,87	Data ex 155 field trials Inman-Bamber (1988)
N52/219	1981/82		1,89	SASA Experiment Station (1984)
N14	1983/84		1,98	Data ex 90 field trials Inman-Bamber (1988)
N12	1985/86		2,08	Data ex 84 field trials (Inman-Bamber (1988)

APPENDIX 11: ANNUAL VARIETY YIELD INDEX
[Percentage of each variety produced x its yield index]

Year	Yield Index	Year	Yield Index
1925/26	100,00	1956/57	173,85
1926/27	100,00	1957/58	175,67
1927/28	100,00	1958/59	177,26
1928/29	100,00	1959/60	179,69
1929/30	100,00	1960/61	181,30
1930/31	100,00	1961/62	183,32
1931/32	100,00	1962/63	182,53
1932/33	100,44	1963/64	182,77
1933/34	101,68	1964/65	181.27
1934/35	105,96	1965/66	187,56
1935/36	112,04	1966/67	190,01
1936/37	118,60	1967/68	190,28
1937/38	123,52	1968/69	191,29
1938/39	127,12	1969/70	192,61
1939/40	127,92	1970/71	193,23
1940/41	130,72	1971/72	193,71
1941/42	133,36	1972/73	193,99
1942/43	135,56	1973/74	194,89
1943/44	136,80	1974/75	195,14
1944/45	138,30	1975/76	195,61
1945/46	138,87	1976/77	195,65
1946/47	139,24	1977/78	196,03
1947/48	139,67	1978/79	196,32
1948/49	140,44	1979/80	196,81
1949/50	141,88	1980/81	196,81
1950/51	148,57	1981/82	197,58
1951/52	152,26	1982/83	197,80
1952/53	160,87	1983/84	197,98
1953/54	163,58	1984/85	198,28
1954/55	168,01	1985/86	198,35
1955/56	171,78		

APPENDIX 12: EXPERIMENT STATION R&D PROGRAMME COSTS IN 1985/86 (to the nearest hundred rand)

Programme	Cost (R)
Plant Breeding and Selection for disease resistance.	1 473 700
Biological control of eldana	524 100
Development of machines and equipment	254 300
Mosaic disease control	148 400
Control of pests other than eldana	131 700
Fertilizer trials	129 200
Variety agronomy	122 900
Eldana biology	118 700
Herbicide trials	113 700
Soil amelioration	104 100
Ratoon Stunting disease	77 600
Cultural control of eldana	72 600
Modelling soil and water loss	72 500
Alternative fuels	63 800
Machine utilization	63 700
Nematode biology	58 300
Crop production systems	54 900
Chemical control of eldana	49 600
Analytical chemistry	49 300
Nematicide trials	45 600
Irrigation investigations	35 100
Run-off and catchment projects	34 100
Acid chlorosis	33 200
Smut disease control	24 000
Growth regulator trials	20 500
Soil compaction	14 800
Mosaic epidemiology	7 000
Trashing	4 400
Leaf scald	3 900
Lysimetry	2 600
Nitrogen fixation	1 700