

**AN ECONOMIC ANALYSIS OF PUBLICLY FUNDED VEGETABLE
RESEARCH IN SOUTH AFRICA: 1980-2012**

By

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DECLARATION

I, Manana Rancho hereby declare that this dissertation that I submit for the degree of Master of Science to the University of Pretoria has not previously been submitted by me or any other person for degree purposes at any other tertiary institution.

Signature: _____

Date: _____

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ABSTRACT

AN ECONOMIC ANALYSIS OF PUBLICLY FUNDED VEGETABLE RESEARCH IN SOUTH AFRICA: 1980-2012

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Public investment in agricultural research has been declining in inflation-adjusted terms over the years in South Africa. This has created a need to evaluate agricultural research and provide evidence of the benefits derived from agricultural research investments. Economic evaluations of agricultural research have been conducted in South Africa and have shown positive returns to agricultural research investments. The studies have been conducted at national, enterprise, institute, crop and project levels. Similar evaluation studies have also been conducted specifically for research conducted by the Agricultural Research Council (ARC) of South Africa, the principal public research organization in the country. These studies were focused on grain, livestock, deciduous fruit and some ornamental plants research.

With the exception of sweet potato research, the economic returns to vegetable research have not yet been estimated in South Africa and as such, the returns to vegetable research, at national, crop or institute levels are not yet known. This study therefore aims to conduct an economic analysis of vegetable research for the period 1980 to 2012. The analysis focused on publicly funded vegetable research in South Africa and included evaluating the contribution of Agricultural Research Council's Vegetable and Ornamental Plant Institute (ARC-VOPI) to vegetable cultivars developed over the years, evaluating the trend in public vegetable research investments over the period 1980 to 2012 and estimating the marginal internal rate of return to vegetable research.

A Plant Breeders' Rights analysis was conducted to evaluate ARC-VOPI's contribution to vegetable cultivars developed over the years. This involved analysing the ownership of registered cultivars among 14 selected commercial vegetables as recorded in the South African Plant Variety Journal from 1966 until 2013.

The analysis revealed that 41 percent of the registered commercial vegetable cultivars over that period were owned by foreign companies and 37 percent of the cultivars were owned by domestic private companies. The public sector only accounted for 17 percent of the cultivars and this was concentrated in four vegetable commodities, two of which were bred by ARC-VOPI, i.e. sweet potatoes and potatoes.

The relatively low involvement of ARC-VOPI in the breeding of vegetables was due to, among other reasons, the general decline in vegetable research investments over the years. The institute went from investing about R15 million in inflation-adjusted 2010 values in vegetable research in the 1980s to about R5 million in 2012. The decline particularly occurred from the early 1990s when changes in funding policy were introduced, not only at the institute but within the ARC as a whole. In addition, the mandate to service resource-poor agriculture given to the institute in the early 1990s resulted in 20 percent of the institute's funds being redistributed to this sector alone.

The marginal internal rate of return to public vegetable research investments was estimated to be 39 percent. This rate of return implies that a R100 increase in vegetable research yields marginal gains of R39 to the vegetable industry. The rate of return was estimated using an *ex-post* production function with a polynomial distribution lag. This rate of return is significant and consistent with findings in previous studies which estimated rates of return of between 40 percent and 78 percent for other ARC institutes, thus providing justification for increasing investments in vegetable research.

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LIST OF ABBREVIATIONS

ARC:	Agricultural Research Council
ARC-GCI:	Agricultural Research Council-Grain Crop Institute
ARC-VOPI:	Agricultural Research Council-Vegetable and Ornamental Plant Institute
PBR:	Plant Breeders' Rights

UN: United Nations
UPOV: International Union for the Protection of New Varieties of Plants
USA: United States of America
WIPO: World Intellectual Property Organisation

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The world's population is approximately 7.2 billion currently and is projected to increase by almost one billion within the next twelve years, reaching 8.1 billion by 2025 and 9.6 billion in 2050 (United Nations, 2012). Ninety-seven percent of this population increase is expected to occur in developing countries in Africa, Asia, and Latin America, with most of the growth expected in Africa (Swaminathan, 1995; United Nations, 2012).

In South Africa, the population is currently about 52 million and is expected to increase to about 54 million in 2020 and further to 55 million in 2025 (World Bank, 2014). By 2050, it is projected that the total South African population will be approximately 62 million (World Bank, 2014). This is about a 2.3 fold increase in the population from 1980, which stood at about 27 million.

According to the World Bank (2014), the distribution of the South African population between urban and rural areas was 48 percent and 52 percent respectively in 1980. Currently, that distribution is about 36 percent and 64 percent for the rural and urban areas respectively. This is also expected to change by 2050 to 77 percent of the South African population residing in urban areas and the remaining 23 percent residing in rural areas.

For the agricultural industry, this expected growth in the population means increasing agricultural production to meet the expected future increase in food demand. However, even with today's population about 842 million people do not have adequate food supplies, and in 2010 about 1.22 billion people from the developing world lived in abject poverty, barely surviving on USD1.25 a day for food, shelter, and other essential needs (FAO, 2013; World Bank, 2014). The current and future global challenge is food security, which will require at least a doubling or even a tripling of food production by the year 2050 to meet the needs of the rapidly growing global population. Sub-Saharan Africa will need to more than triple its crop production by 2050 to provide adequate food per capita (United Nations, 2012).

Compounding the problem is that this additional demand on agriculture is to be met with limited resources such as water and arable land. The International Food Policy Research Institute (IFPRI) has reported that arable land on which global food production depends has been rapidly degrading and about 24 percent of the global land area has been affected by land degradation. This is equivalent to an annual loss of about one percent of global land area which could produce 20 million tons of grain each year or one percent of the global annual grain production (IFPRI, 2011). At the same time, water has become increasingly scarce due to salinization, pollution, the degradation of water-related ecosystems as well as changing rainfall and weather patterns due to climate change (FAO, 2013). In addition global input prices have also been increasing thus increasing the volatility of agricultural production and creating a need for better food production methods. These have mainly been driven by high fuel, electricity, fertiliser, pesticides, herbicides and other chemical costs.

These factors have made agricultural production increasingly difficult, requiring more to be produced with less. Given this, the role of agricultural research in the development of better quality inputs and technologies to increase agricultural production and productivity has become even more important. Through agricultural research, technological improvements that are necessary to meet future demands for food can be achieved.

Nonetheless, trends in agricultural research spending have been very poor, particularly in Africa. Beintema and Stads (2010) show that public investment in sub-Saharan Africa has been growing at a relatively slow rate of around one percent from 1976 to 1991. In the period 1991 to 2000 the rate was in decline at negative 0.2 percent. There was, however, positive growth in public agricultural research investment in Africa of about 2.4 percent from 2001 to 2008, although this was still very low.

In 2008, total global public spending on agricultural research was about USD 31.7 billion. This was a 22 percent increase from total global spending in agricultural research in 2000 (Beintema, Stads, Fugile and Heisey, 2012). High income countries accounted for about 51 percent of the total global public investment in agricultural research in 2008 and low and middle-income countries accounted for the remaining 49 percent (Beintema *et al.*, 2012). From the 49 percent, middle-income countries accounted for about 46 percent and low-income countries accounted for only three percent.

Conversely, the main drivers of agricultural research investments in 2008 were certain middle and low income countries followed by certain high income countries. Specifically China, accounted for about USD 2.1 billion of the growth in public investment in agricultural research from 2000 to 2008, followed by India with about USD 0.6 billion and the United States of America with about USD 0.5 billion. These were followed by Brazil, Argentina, Iran, Japan, Nigeria and Russia, each with a contribution of about USD 0.2 billion (Beintema *et al.*, 2012). In Sub-Saharan Africa, though an overall positive growth of about 2.4 percent in agricultural research investment between 2001 and 2008 was achieved, in some countries, investments in agricultural research ranged from about negative 0.2 percent to about negative 12.0 percent per year over the same period (Beintema *et al.*, 2012).

Given that agriculture is a principal sector in most developing countries where most population growth is expected to occur in future, it follows that significantly increasing agricultural research investment particularly in these countries is essential. This is even more important in Africa where agricultural production is required to increase three-fold by 2050 to meet expected future food demand.

In order to achieve the necessary increase in agricultural research investment, it is very important that research organisations provide evidence of the benefits derived from investments in agricultural research and also provide the necessary justification and motivation for increasing public investment in agricultural research. This is so because of the increased competition for limited public resources between sectors and between industries. Within agriculture, competition for public resources occurs among sectors, i.e. horticulture, livestock and field crops, and even between different areas of focus within agricultural industries, such as agricultural extension, agricultural research, agricultural production systems etc. Providing evidence of the benefits derived from public investment in agricultural research will require measuring the returns and estimating the benefits of the research investments and matching these against the research costs incurred.

1.2 PROBLEM STATEMENT

In South Africa, the ARC is the principal public agricultural research organisation that conducts and disseminates research to the rest of the industry. The research is conducted by the various institutes of the ARC and focuses on vegetables, grain crops, livestock, fruits, ornamental plants

and natural resources among others. The organisation therefore carries the responsibility of producing public agricultural research to help meet current and future demands for food, not only in South Africa, but in other countries through spill-over effects.

The mandate of the ARC according to the Agricultural Research Act, Act No. 86 of 1990 (as amended by Act 27 of 2001) is to conduct research, drive research and development, drive technology development and the transfer (dissemination) of information in order to:

- Promote agriculture and related industries
- Contribute to a better quality of life
- Facilitate/ensure natural resource conservation, and
- Alleviate poverty.

The ARC has been doing so for a number of years and has, through various research outputs, contributed to the growth of various agricultural industries including the vegetable industry. The vegetable industry is one of the agricultural industries in the country that plays an important role in reducing food insecurity and poverty.

Vegetable research is conducted by the Vegetable and Ornamental Plant Institute of the ARC (ARC-VOPI). The institute has been conducting research for many years since its establishment in 1949. Through vegetable research and factors such as, good management practices, favourable climate, soil and temperature conditions, and fertiliser use, among others, vegetable production has increased in the country from about 2.4 million tons in 1980 to about 4.8 million tons in 2012 (DAFF, 2013a). This was a two-fold increase in vegetable production in a period of about 32 years.

The per capita consumption of vegetables, on the other hand, remained relatively constant over the period 1980 to 2012, with some fluctuations in certain years. Vegetable consumption per capita in 1980 was about 42.54 kg per annum, excluding potato per capita consumption which was about 22 kg per annum (DAFF, 2013a). By the end of the 1980s, the per capita consumption of vegetables (including potato consumption) had increased to about 81.04 kg per annum.

Between the years 1990 and 1999, the per capita consumption of vegetables fluctuated between 75.32 kg per annum and 78.08 kg per annum (DAFF, 2013a). After 1999, the per capita consumption of vegetables decreased to reach about 68.46 in 2002. There was an increase from

2004, from about 77.52 kg per annum to about 81.74 kg per annum in 2012 (DAFF, 2013a). The 2012 per capita consumption of vegetables was at about the same level as the per capita consumption of vegetables in the late 1980s. The main drivers of the increase in the per capita consumption of vegetables from the early 2000s have been improved lifestyles as more and more consumers become health conscious (Ntombela, 2012). This increase in the per capita consumption is expected to continue.

The area planted to vegetables in South Africa has been decreasing in recent years, different from the 1980s and 1990s. In 1980, the area planted with vegetables was about 100 005 hectares. This increased to about 138 137 hectares in 1993 and further up to 150 011 hectares in 2002 (CSS, 1980, 1993 and 2002). By 2007, the area planted with vegetables had decreased to about 118 279 hectares, a total of about 31 732 hectares of land gone out of vegetable production over a period of 5 years. Vegetable production nonetheless continued to increase (CSS, 2007). This highlighted the important role of vegetable research in developing yield-improving technologies.

Given the expected increase in food demand by 2050 and the declining area necessary for planted vegetables, increasing vegetable production to meet future demands would require getting the most out of the limited land available, i.e. producing with better inputs (seeds, fertilisers, etc.). Further investment in vegetable research is required to develop those improved technologies.

Similar to trends in public investment in agricultural research in the rest of Sub-Saharan Africa, public investment in agricultural research in South Africa has been relatively low over the years. Between 1911 and 1998, Liebenberg, (2013) shows that in South Africa, research and development accounted for a fluctuating but generally increasing share of agricultural spending from 28.8 percent in 1911 to 74 percent in 1998. However, between 1998 and 2011, it declined to a 46.5 percent spending share by 2011.

Part of the decline in expenditure on agricultural research in South Africa, particularly in the 1990s, was due to structural and policy changes introduced by the democratic government, which included the deregulation of the agricultural sector. The result was that state funding for agricultural research that was aimed at benefiting white commercial farmers was redirected to focus on the research needs of small-scale farmers (Carter, 1999). In addition, the establishment of the ARC in 1992 resulted in funding policies which aimed to reduce the dependency of the

organisation (and hence its function of agricultural research) on state support. The organisation in its first four years of establishment had to source 30 percent of its funding from external sources and in 1997 there were further budgetary cuts under the new competitive parliamentary grant system (ARC-VOPI, 2013c; Liebenberg, 2013).

These changes have created a need for a more careful allocation of scarce funds within the ARC. It has, therefore, become vital that the costs and benefits of research conducted at the various research institutes of the ARC be evaluated to provide decision-makers with a guide to the economic returns of the funds spent (Carter, 1999). This would also serve as evidence and provide motivation for increasing investments to the organisation for agricultural research.

Numerous studies have been conducted to estimate the economic returns to agricultural research by the various institutes of the ARC as well as other agricultural industries in South Africa not related to the ARC, such as the sugar industry. With the exception of sweet potato research in the period 1952 to 1995, no study has quantified the economic returns to vegetable research in South Africa. As such, the economic benefits of vegetable research investments are not yet known and there is thus little motivation for furthering public investments in vegetable research.

1.3 OBJECTIVES

The main objective of this study was to conduct an economic analysis of public vegetable research in South Africa from 1980 to 2012. Through this, the contribution of ARC-VOPI to vegetable research in the country was assessed. The study determined the participation of the institute in the breeding of vegetable cultivars over the years as these cultivars were assets through which earnings were generated and reinvested in vegetable research. In addition, the vegetable research investment history of the institute was evaluated to determine what the trend had been over time. From this research investment, the economic rate of return to public vegetable research for the period 1980 to 2012 was estimated.

The study therefore had the following three specific objectives in conducting an economic analysis of vegetable research in South Africa:

- To determine the contribution of ARC-VOPI to vegetable cultivars developed and released in the period 1980 to 2012.
- To evaluate the vegetable research investments of the institute over the period 1980 to 2012.

- To estimate the economic rate of return to public investments in vegetable research from 1980 to 2012.

1.4 SCOPE OF THE STUDY

The study focused on the vegetable industry of South Africa. The analysis was limited to public sector vegetable research investment conducted at ARC-VOPI (referred to as the institute) over the years and did not include investments in vegetable research by the private sector. Due to the intensity of data required when evaluating agricultural research and the limitations of available data, the analysis of the study was limited to the period of 1980 to 2012.

1.5 OUTLINE OF CHAPTERS

The study is organised into eight chapters.

The next chapter (Chapter Two) gives a review of related literature on the economic rate of return to agricultural research, with a specific focus on South African literature. Chapter Three discusses methods and procedures followed in the evaluation of agricultural research. Chapter Four gives an analysis of vegetable cultivars released from 1980 to 2012, giving a perspective on how the institute performed compared to the private sector. Chapter Five gives the evolution of the institute, in terms of its research focus over the years. In Chapter Six, the research investment trends of the institute over time, from 1980 to 2012, are analysed. In Chapter Seven, the economic rate of return to vegetable research from 1980 to 2012 is estimated using the institute's vegetable research expenditures and Chapter Eight summarises the results and presents the conclusions and recommendations of the study.

CHAPTER 2

A REVIEW OF STUDIES ON RATES OF RETURN TO AGRICULTURAL RESEARCH IN SOUTH AFRICA

2.1 INTRODUCTION

Public funding for agricultural research has become scarce as competition for public funds has increased over the years. This has made it more and more important for the agricultural sector to provide evidence of the benefits derived from agricultural research investments. Therefore, numerous studies have been conducted seeking to estimate the returns to investments in agricultural research.

Regardless of the level of analysis, studies have shown that investing in agricultural research is beneficial. In addition, the findings of the studies estimating the returns to agricultural research inform policy and funding decisions among different research programmes and at the same time provide valuable lessons for the selection and design of research programmes.

In South Africa, the rates of return to agricultural research have been estimated in the maize, livestock, sugar and wine grape industries. In addition, specific studies have been conducted for the ARC seeking to estimate the returns to the research conducted by the various institutes of the organisation.

This chapter reviews the studies conducted in the various industries of the agricultural sector in South Africa to determine the focus of those studies and to identify the research gap that may exist. The first section reviews the studies conducted for the ARC, followed by a review of other agricultural research evaluation studies that have been conducted in the rest of the sector and, lastly, the conclusion.

2.2 A REVIEW OF RATES OF RETURN TO VARIOUS PROGRAMMES OF THE AGRICULTURAL RESEARCH COUNCIL

Thirtle, Townsend, Amandi, Lusigi and Van Zyl, (1998) reviewed studies that estimated the rate of return to agricultural research conducted in various industries for the period 1947 to 1998. The studies were conducted at national (aggregate) and institute level as well as at the

level of enterprises, projects and crops. With the exception of the studies conducted at the national level and the enterprise level, i.e. the returns to total agricultural research, the returns to agricultural extension and the returns to horticulture, field crops and livestock, all other studies reviewed were those conducted for the ARC and its various institutes. The results of these studies are shown in Figure 2.1.

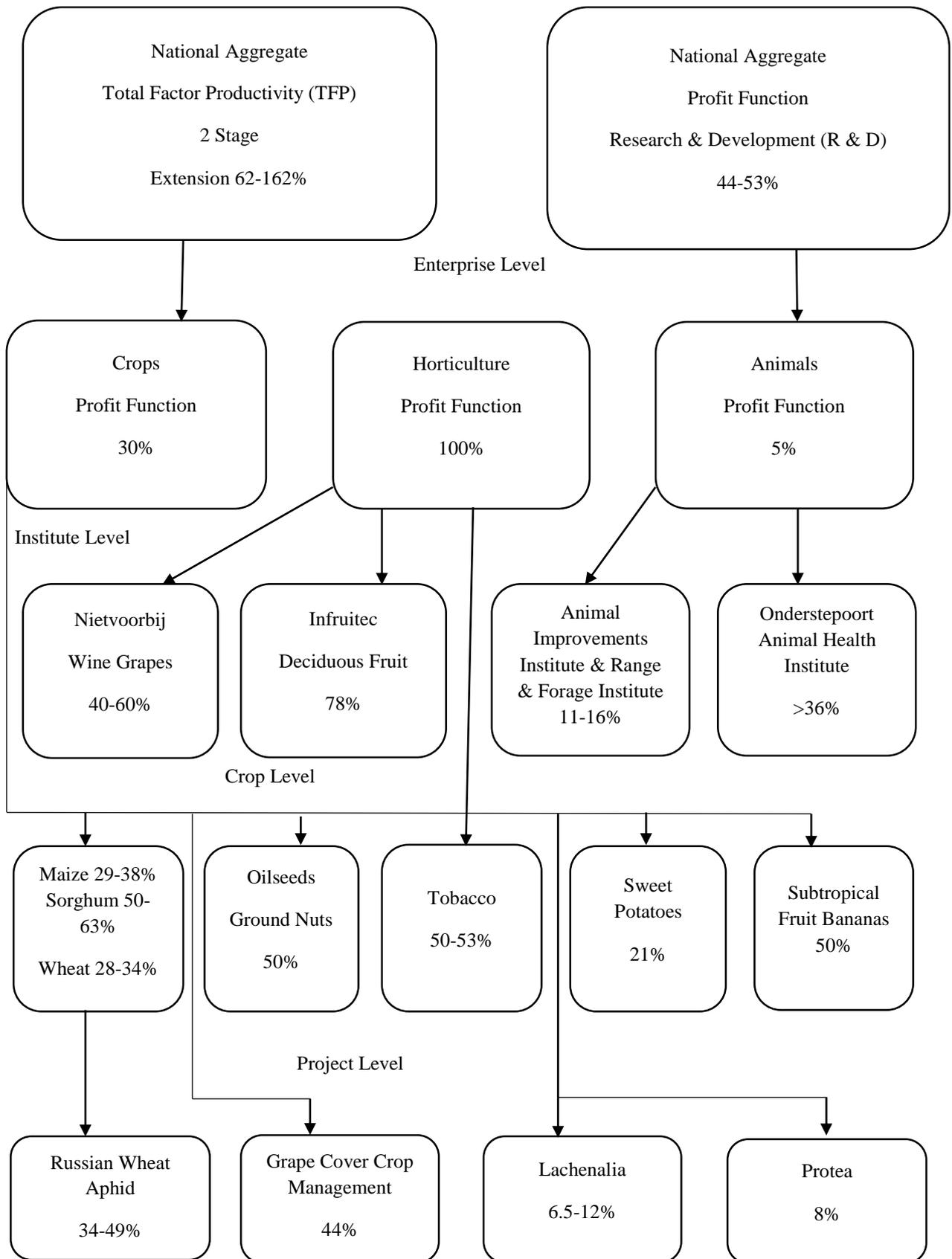


Figure 2.1: Disaggregating the returns to Research and Development

Source: Thirtle *et al.*, 1998

Two studies were conducted at the aggregate level estimating the returns to agricultural research and the returns to agricultural extension. In estimating the returns to agricultural research, a profit function approach was taken. The study estimated that the lag between agricultural research and the impact on the industry is approximately five years and that the return to agricultural research is about 44 percent in South Africa. This rate of return was slightly lower than the rate of return to agricultural extension, which was found to be about 64 percent. All else being equal, this suggested that there was an under-investment in the generation and diffusion of agricultural technology (Thirtle *et al.*, 1998).

Disaggregating this rate of return to agricultural research further to the enterprise level, Van Zyl, (1996) estimated the rates of return to be about 100 percent, 30 percent and 5 percent for horticulture, field crops and the livestock industries respectively. These disaggregated rates of return were also estimated using the profit function approach. Similar to the lag length at the aggregate agricultural research level, the lag estimated in these three industries was also found to be five years.

Five institute level rates of return studies have been conducted for the ARC. The institutes were Nietvoorbij, Infruitec, Animal Improvements Institute, Range and Forage Institute, and Onderstepoort Animal Health Institute. The studies employed the production function approach to estimate the rates of return, though in the studies conducted for Infruitec, the Animal Improvement, and Range and Forage Institutes, the supply response approach was taken¹.

The rate of return estimated at the institute level ranged from between 11 and 16 percent for the Animal Improvement Institute, to just over 36 percent for Onderstepoort Animal Health Institute, between 40 and 60 percent for Nietvoorbij (wine grapes) and to about 78 percent for Infruitec (deciduous fruits) (Thirtle *et al.*, 1998).

The institute level rates of return for livestock were much higher than the enterprise level rate of return. This was because at the institute level of analysis, animal health expenditures were modelled separately and were used to explain the decline in animal losses. Animal health expenditures were thus included to capture the value of maintenance research (Thirtle *et al.*, 1998).

¹ The supply response approach is a variant of the production function approach.

In the case of Infruitec and Nietvoorbij, the rates of return were lower than the enterprise level rate of return for horticulture, i.e. 60 percent and 78 percent for Infruitec and Nietvoorbij respectively versus 100 percent for horticulture. This could be expected, given that the rate of return to research tends to increase with the increase in the level of aggregation.

The crop level studies for maize and wheat yielded rates of return of between 29 and 39 percent and between 28 and 34 percent respectively. The Economic Capital Model of Output and Area and Yield Model were used to estimate the rate of return to maize research and the Economic Capital Model of Supply and Yield Model were used in the evaluation of wheat research. To model the lag structure, both studies used the second order polynomial distribution, the gamma distribution and the beta distribution. The lag length for maize research was estimated to be about eight years while the lag length for wheat research was about 15 years, almost twice the lag length for maize research.

Using a similar approach to that taken in the evaluation of wheat research, a rate of return of between 50 percent and 63 percent was estimated for sorghum research. The length of the lag was estimated to be about 13 years, almost the same lag length as the wheat research lag. The rate of return estimated for sorghum research was higher than all the rates of return estimated for all the other commodities at crop level. This indicated that there had been severe under-investment in sorghum research.

The rate of return to groundnuts and tobacco research were also high, ranging between 50 percent and 53 percent. The average lag length for groundnuts and tobacco research were estimated to be about six years and 16 years respectively. The lag length for tobacco research was found to have a lead period of two years, indicating that the benefits to tobacco research were only derived two years after the research investment had been made. The crop level analysis for sweet potatoes also indicated a lead period of three years for the crop. The lag length for sweet potato research was found to be relatively long, about 22 years, and the rate of return to sweet potato research was estimated to be about 21 percent. The rate of return was estimated using the supply response approach. This rate of return was much lower than the aggregate rate of return estimated for horticulture.

At the project level, the rate of return to the Russian Wheat Aphid research was estimated to be between 35 percent and 49 percent, the highest rate of return among the project level research evaluations. The rate of return was estimated using an ex-ante economic surplus method. With

the exception of the rate of return to grape cover crop research, all the rates of return at the project level were estimated using an ex-ante economic surplus method. The rates of return estimated for ornamental plants research were much lower than the returns estimated for all the other projects. The rates of return to ornamental plant research were between 6.5 percent and 12 percent for lachenalia and 8 percent for protea. The relatively low returns for these ornamental plants were due to the long gestation period of the flowers which led to slow results in the breeding programmes and even longer lags before financial benefits could be generated by growers (Thirtle *et al.*, 1998).

From these studies, it was concluded that the ARC had been successful in its research and development (R&D) and in exploiting spill-overs from foreign research and development systems (Thirtle *et al.*, 1998).

The following section reviews rate of return studies that have been conducted in other industries of the agricultural sector of South Africa.

2.3 RATE OF RETURN STUDIES IN OTHER AGRICULTURAL INDUSTRIES

The estimation of the rate of return in other agricultural industries has been done in the maize industry, livestock industry, wine grape industry and the sugar industry. These studies and their findings are summarised in Table 2.1 below.

Table 2.1: Rate of Return to Agricultural Research in South Africa

Study and Period	Method	Lag Model	Lag length (Years)	Rate of Return
Assessing the Benefits of Research Expenditure on Maize Production in South Africa, 1950-1995	Production Function & Output Supply Equation	Second-order Polynomial Distribution Lag Gamma Distribution Beta Distribution	12 years	28.84 – 39.84 percent
Cattle Improvement Scheme in South Africa: Measuring the Returns to Research Investments, 1970-1996	Akino-Hayami Index-Number Approach			44 – 51 percent
Estimation of the Wine Grape Research and Technology Development in South Africa, 1980-1994	Production Function	Second-order Polynomial Distribution	7 years	40 percent
The Rate of Return on R&D in the South African Sugar Industry, 1925-2001	Ridge Regression of Production Function		3 years	17 percent

Source: Thirtle *et al.*, (1998), Mokoena, Townsend and Kirsten (1999), and Nieuwoudt and Nieuwoudt (2004)

In the maize industry, the rate of return to research was estimated using the production function approach and the supply response approach (a variant of the production function approach) with different lag structures, i.e. Almon polynomial lag, the gamma distribution and the beta distribution. The study made use of maize yields per ton as the dependent variable in the production function approach and total maize output as the dependent variable in the supply response approach. The lag length estimated for the polynomial lag was found to be 12 years with the maximum impact of research on maize yields occurring after the sixth year. The gamma and beta distributions also indicated that the maximum impact of research on yields occurs after the sixth year.

In the production function approach, changes in maize yields were explained by changes in research expenditure, extension expenditure and the weather. The research and extension expenditures were not combined as one, as has been done in other studies, but were included as separate expenditure variables. Conventional inputs and other variables that affect maize yields

were not included in the model due to the challenge of obtaining relevant data and were therefore captured in the residual of the model. The function is shown in equation 2.1 below:

$$YIELD = f(EXT, RD, RAIN) \quad (2.1)$$

Where: *YIELD* is maize tons per hectare

RD is the research expenditure

EXT is a two year moving average of expenditures and

RAIN is regional rainfall.

The supply response approach, on the other hand, uses prices to explain changes in the output supply. In the study, the change in total maize output was explained by: the price of maize, the price of competing products (sorghum, sunflowers and groundnuts), the price of fertiliser and the cost of labour. In addition, weather, public research expenditure and extension expenditures were included, see equation 2.2.

$$Outputm = f(Pm, Ps, Psun, Pnuts, Pfert, Plab, RISK, RD, RAIN) \quad (2.2)$$

Where: *Pm* is the price of maize

Ps is the price of sorghum

Psun is the price of sunflowers

Pnuts is the price of groundnuts

Pfert is the price of fertiliser

Plab the price of labour

RISK is the price risk variable

RAIN representing the weather and

RD is the research expenditures

Different rates of returns were found for the different lag structures. The maize yield per ton with the second order Almon polynomial distribution with end point restrictions gave a rate of return of about 28.84 percent, while the same lag structure with total maize output as the dependent variable yielded a rate of return of about 30.32 percent.

The maize yield function with the beta and gamma distributions gave slightly higher rates of returns than the polynomial distribution. This was caused by the higher elasticities of the beta and gamma distributions (Townsend, Van Zyl and Thirtle, 1997). The gamma distribution

model gave a rate of return of about 36.87 percent while the beta distribution model gave a rate of return of about 39.84 percent (Townsend *et al.*, 1997).

These different rates of return estimated for the maize industry using different lag structures indicated that the estimate of the rate of return is dependent on the choice of model and more importantly on the variables included in the model.

A rate of return of between 28.84 and 39.84 is high and justifies increasing research investments in the maize industry. The proposed increase in research investments in the maize industry was recommended to be funded through a producer levy which would be possible for the large-scale commercial farmers who had been the primary beneficiaries of publicly funded maize research in South Africa (Townsend *et al.*, 1997).

In the livestock industry Mokoena, Townsend and Kirsten (1999) evaluated the returns to two cattle improvement schemes; the National Dairy Cattle Performance and Progeny Testing Scheme, and the National Beef Cattle Performance and Progeny Testing Scheme over the period 1970 to 1996. The study made use of the Akino-Hayami index number approach, a variation of the economic surplus method. The Akino-Hayami model measures the gains from research relative to pre-innovation market equilibrium emphasising the cost-reducing nature of innovations (Mokoena *et al.*, 1999).

Different rates of return were found for the National Dairy Cattle and Beef Cattle performance and progeny testing schemes. The returns on research investment in the dairy scheme were estimated to be about 51 percent while the returns to the investment in the beef scheme were estimated to be about 44 percent (Mokoena *et al.*, 1999). This implied that for every one Rand invested in these research schemes, annual profits generated were 51 cents and 44 cents for the dairy and beef schemes respectively (Mokoena *et al.*, 1999).

These rates of return were higher than the rates of return estimated for the Aggregate Animal Improvement Schemes, though it would be expected that the aggregate rate of return would be higher than the individual cattle schemes' returns. The difference in the rate of return at the aggregated and disaggregated levels was a result of the difference in the methods used to estimate the rates of return in the evaluations. Similar to the findings by Townsend *et al.*, (1997), the main beneficiaries of the investment in the National Dairy Cattle and the Beef Cattle performance and progeny testing schemes were found to have been large-scale commercial

farmers. The research gap in the industry was found to be in the development of appropriate technology suitable for the wider South African clientele, including small-scale farmers.

Table 2.1 also shows the rate of return estimated in the wine-grape industry for the period 1980 to 1994. The rate of return was estimated to be about 40 percent by Townsend and Van Zyl (1998). The evaluation of wine grape research used a production function approach with the Almon polynomial distribution lag. The lag was first applied with no restrictions and then with restrictions (near end, far end and both ends) to the second, third and fourth order polynomials (Townsend and Van Zyl, 1998).

Unlike the study conducted in the maize industry, which used both yields per ton and total maize output, only wine grapes per ton were used as the dependent variable in the study. The change in wine grape yields was explained by changes in the weather and research expenditures. The research expenditure did not include extension expenditure as was the case in the maize research evaluation study. All the other factors that affect wine grape yields that were not included in the model, such as conventional inputs and private investments, were captured by the residual term in the model: as shown by equation 2.3 below:

$$\ln YIELD_t = \ln \alpha_0 + \ln \alpha_1 WEATHER + \sum_{i=1}^n \beta_i \ln RD_{t-i} + u_t \quad (2.3)$$

Where: *YIELD* is the wine grape tons per hectare

RD is the research expenditures

WEATHER is the weather variable

β is the elasticity of research expenditure at various lag lengths

n is the maximum lag of research expenditure that affects *YIELD*

u_t is the residual

The study estimated two models with the same dependent and independent variables. However, in the second model, the wine-grape yields were adjusted for quality changes because the wine grape industry conducted both yield improving and quality improving research.

The rate of return studies which were reviewed above for the maize, livestock and wine-grape industries all estimated the returns to public investment in research. Evaluations of private investments in agricultural research are very scarce, both internationally and locally, although private investments in agricultural research have increased over the years. The absence of

evaluations of private investments in agricultural research is due to the challenge of obtaining highly confidential private sector investment expenditure data.

In South Africa, only one study has estimated the rate of return to private investments in agricultural research. The study is listed in the last row of Table 2.1. The evaluation was conducted in the sugar industry for the years 1925 to 2001, a period of about 75 years. The sugar industry is a special case in South Africa as the industry is highly regulated and the research conducted is privately funded.

The study employed an ex-post production function with a ridge regression to estimate the returns. The yields of sucrose in tons per hectare were used as the dependent variable. Changes in sucrose yields were explained by real expenditure on research, rainfall, the cost of capital and labour, land under sugar cane in hectares and a dummy variable to determine the years over which research had the greatest impact on industry output: this is shown in equation 2.4. The research expenditure was estimated to have a lag of three years (Nieuwoudt and Nieuwoudt, 2004).

$$\text{Log } Y = \ln RD + \ln Rain + \ln Cost + \ln Land + (Dummy) * (\log R\&D) \quad (2.4)$$

Where: Y is the estimated yield of sucrose in tons per ha

RD is real expenditure of research in Rand per ha, lagged three years

$Rain$ is annual rainfall

$Cost$ is the production cost of capital and labour per ha in Rand

$Land$ is land under cane in hectares

$Dummy$ is 1 for 1959 to 1979, otherwise zero.

With a ridge regression a small bias of the estimators is included in the model at the expense of having more precision. This was because a small bias of the estimators with a higher probability of being close to the true parameter values was preferred over estimators without bias and far from the true parameter values (Nieuwoudt and Nieuwoudt, 2004). Using this approach, a rate of return of about 17 percent was estimated for the sugar industry, implying that for every R100 increase in research investment in the sugar industry, benefits derived would amount to R17. Although appearing high, this rate of return was relatively low compared to the rates estimated in other agricultural industries. This rate of return most likely reflected the true rate of return to private investments in agricultural research as there are no distortionary impacts of taxes which are a problem in the case of publicly funded agricultural research (Nieuwoudt and Nieuwoudt, 2004).

The rates of returns estimated in these studies were in some cases tested for robustness by estimating the net present value and benefit/cost ratios. This was done in the study conducted by Mokoena *et al.*, (1999) in the livestock industry and by Nieuwoudt and Nieuwoudt, (2004) in the sugar industry.

2.4 CONCLUSION

This chapter reviewed the rates of return to agricultural research estimated in various industries in South Africa, including the studies that were specifically evaluated for the ARC. All the studies, regardless of the level of aggregation, yielded positive and high rates of returns that justified increasing investment in agricultural research. At the enterprise level, the rate of return was found to be highest for horticulture at 100 percent, followed by field crops with returns of about 30 percent and lastly livestock research with returns of about 5 percent.

What was evident from the studies reviewed was that the majority of the rates of return were estimated for the field crop sector and the horticultural sector. Within horticulture, the rate of return evaluations concentrated on fruits, specifically deciduous fruits and wine grapes. A few studies were conducted estimating the rate of return to ornamental plant research and only one study focused on vegetable research, i.e. sweet potato research. Given that the vegetable industry comprised many other sub-industries in which research was and still is conducted, there was a gap in the knowledge of the returns derived from research in those sub-industries.

What was also evident from the studies reviewed was that the largest number of the studies employed an ex-post production function approach. The most commonly used lag structure was the second-order polynomial distribution lag. A few studies did, however, make use of the economic surplus approach. The studies evaluated at the project level for the ARC used an ex-ante economic surplus approach, and the study evaluating the returns to the dairy and beef cattle research schemes used an ex-post economic surplus approach. These two methods, the production function and the economic surplus methods, are the two most popular among all agricultural research evaluation methods. In the next chapter these two methods are discussed in more detail to determine the most appropriate method to use in this study.

CHAPTER 3

METHODS AND PROCEDURES

3.1 INTRODUCTION

The previous chapter briefly touched on two research evaluation methods that were most commonly used in the evaluation of agricultural research in various agricultural industries in South Africa. Other methods have also been developed and used over the years to evaluate the returns to agricultural research investments. The methods have been categorised into those used to evaluate ex-ante research programmes and those used to evaluate ex-post research programmes. Ex-ante evaluation methods include benefit-cost analysis, simulation models and mathematical programming. Ex-post evaluation methods include the economic surplus approach and parametric approaches. The parametric approaches consist of primal approaches (the production function, supply response functions and productivity functions) and dual procedures (profit functions and cost functions).

Though also used, these other methods are not as common in agricultural research evaluation literature as the production function method and the economic surplus methods (also known as the consumer and producer surplus method). Therefore, the purpose of this chapter is to evaluate these two most commonly used ex-post agricultural research evaluation methods to determine the most appropriate method to use in the study. In addition, the chapter discusses the Almon Polynomial lag which was found to be the most commonly used lag structure in ex-post agricultural research evaluation studies.

3.2 ECONOMIC SURPLUS APPROACH

The economic surplus approach measures benefits and costs to consumers and producers associated with a technically-induced shift of the supply curve. The producer surplus is measured as the area above the supply curve and below the price. In Figure 3.1, this is represented by area B+D before the technically-induced shift of the supply curve. The consumer surplus, on the other hand, is measured as the area below the demand curve and above the price, area A in Figure 3.1, before the technically-induced shift of the supply curve. Assuming a parallel shift of the supply curve, technical change due to research causes the supply curve to

shift from S_0 to S_1 . This reduces the price from P_0 to P_1 and increases quantity from Q_0 to Q_1 in Figure 3.1. The producer surplus increases and becomes area DEG and the consumer surplus becomes area ABCF. Consumers gain area B+C+F and producers lose area B but gain area E+G. The overall gain to society is therefore C+E+F+G.

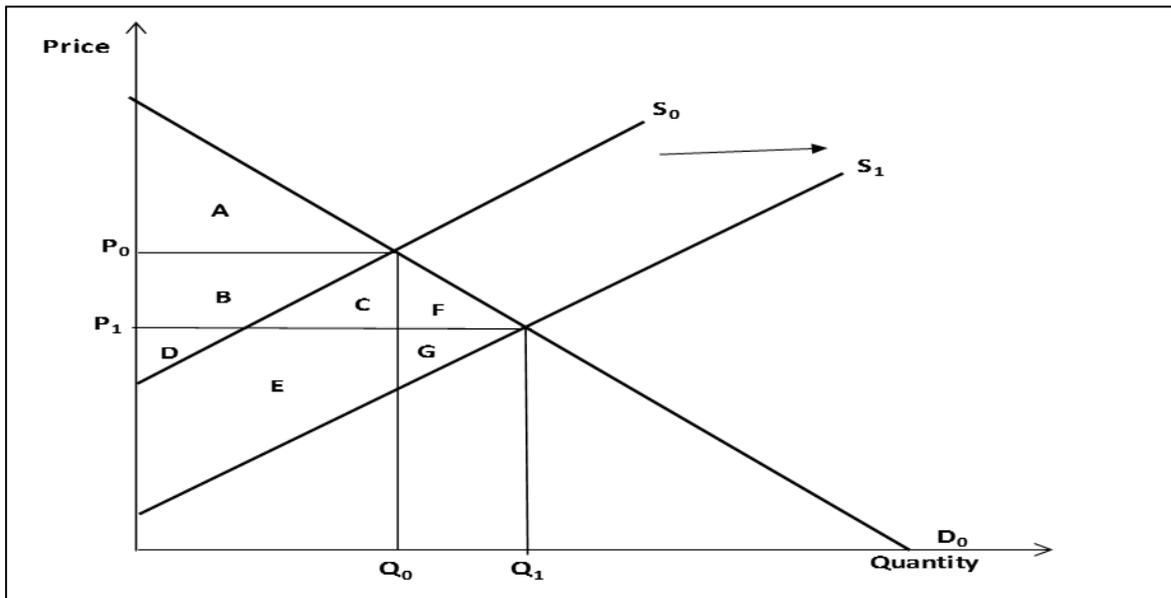


Figure 3.1: Economic Surplus Model

Source: Morgan, 1999

Figure 3.1 assumes a parallel shift of the supply curve. Other shifts of the supply curve have also been assumed, such as a proportional shift (Peterson, 1967), four shifts (Linder, Jarrett and Rose 1978 in Norton and Davis, 1981) and a pivotal shift (Akino and Hayami, 1975).

In estimating the surplus gain resulting from a parallel shift in the supply curve and a linear demand curve as assumed in Figure 3.1, Hertford and Schmitz (1977) use the following formulae:

Change in consumer surplus:

$$= \frac{KP_1Q_1}{n+e} \left(1 - \frac{1}{2} \frac{Kn}{n+e} \right) \quad (3.1)$$

Change in producer surplus:

$$= KQ_1P_1 \left\{ 1 - \frac{1}{n+1} \left[1 - \frac{1}{2} K \left(\frac{2n+e}{n+e} \right) \right] \right\} \quad (3.2)$$

Change in total net social surplus:

$$= KQ_1P_1 \left(1 + \frac{1}{2} \frac{K}{n+e} \right) \quad (3.3)$$

Where: Q_1 is the quantity of the good after the shift in supply

P_1 is the price of the good after the shift in supply

n is the absolute value of the demand elasticity

e is the supply elasticity and

K is defined as the horizontal distance between supply curve before the shift (S_0) and the supply curve after the shift (S_1), i.e. $K = \frac{Q_1 - Q_0}{Q_1}$

Once the benefit or the gain in surplus has been estimated, the next step involves estimating the average rate of return to research investment. The aggregate benefit as a result of the supply shift is compared with the costs and expenditures associated with the research that brought about the shift of the supply curve. This is done by discounting the aggregate benefits and the costs to the same time period (t). Once discounted, the comparison between the benefits and costs is a direct reflection of the return on investment in research, i.e. the internal rate of return (Morgan, 1999).

The consumer and producer surplus method was first used in 1953 by Schultz. Schultz (1953) attempted a major quantitative evaluation of agricultural research investments by calculating the value of inputs saved through more efficient production techniques compared to the cost of research and development. He calculated the increase in consumer surplus resulting from the savings in inputs under the special conditions of the completely elastic supply and the completely inelastic demand curve (Norton and Davis, 1981).

Since Schultz's work, there have been many consumer-producer surplus (CS) research evaluation studies, including the study by Griliches (1958). Griliches (1958) calculated the loss in net social surplus if hybrid corn were to disappear. His analysis assumed that adoption of hybrid corn shifted the supply curve for corn downward or to the right. He estimated returns for the polar cases of perfectly elastic and perfectly inelastic supply curves, implicitly assuming a unitary demand elasticity (Norton and Davis, 1981).

Since then, variations of the consumer and producer surplus method have been used with the main difference being the assumptions made about the nature of the shift of the supply curve and the specifications of the demand and supply functions. Variations have included parallel shifts of the supply curve (vertical and horizontal), proportional shifts, pivot shifts as well as the inclusion of a kink in the supply curve, resulting in four shifts of the curve.

The consumer and producer surplus method has several advantages which have made it a very popular approach to measuring the impact of agricultural research. These advantages include analysing particular rather than aggregate effects of research and thus focusing on particular technologies or research programmes with great emphasis on cause-effect relationships (Heisey, King, Rubenstein, Bucks and Welsh, 2010). The method also allows for vertical disaggregation of benefits over producers, consumers and other market participants as well as a horizontal disaggregation of benefits over countries, regions and agro-ecological zones (Heisey, *et al.*, 2010). Lastly, the method can be used in both ex-ante and ex-post agricultural research evaluation studies, which makes it relatively more flexible.

The method does have some shortcomings that do not always make it an appropriate method to use when evaluating the returns to agricultural research. Firstly, the method tends to focus on successful research programmes and not on all research programmes, which may underestimate the total research cost incurred. The method also focuses on particular rather than aggregate research programmes and thus cannot be applied to aggregate research evaluation studies. The approach can also omit the effects of minor improvements in practices as it focuses on specific technologies developed by research (Heisey *et al.*, 2010; Morris, Dubin and Pokhrel, 1992). In addition, the method does not capture the effects of other investments on agricultural production such as education, infrastructure and farm programmes (Heisey *et al.*, 2010). These shortcomings are, however, addressed by the production function method which was first used by Griliches (1964) and later by Peterson (1967). The method is discussed in the next section.

3.3 PRODUCTION FUNCTION APPROACH

The production function approach is a form of multiple regression or correlation analysis and is the most common econometric method used to estimate the economic benefits of agricultural research. The production function approach is based on the premise that the level of output associated with the production process is causally dependent on the amount of input(s) used in the process (Morgan, 1999).

The basic model used in the production function (PF) approach specifies that agricultural output in time (t) (i.e. Q_t) depends on the quantities of conventional inputs, X_t ; various “quasi-fixed” factors, such as public investment in infrastructure (including roads, communications and irrigation); Z_t , the flow of services from the stock of knowledge; K_t (which can be represented

as a technology index, τ), and uncontrolled factors such as weather and pests, U_t (Alston, Norton, and Pardey, 1998):

$$Q_t = f(X_t, Z_t, \tau, U_t) \quad (3.4)$$

The technology index (τ) includes lagged research expenditures that generate new technology and extension expenditures that transmit the results to farmers thereby diffusing the technology and the educational level of farmers which affects their creative and managerial abilities and skills in appraising, adopting and adapting exogenous technologies (Townsend and Van Zyl, 1998).

Most of the econometric models have used the well-known Cobb-Douglas production function with different lag structures. By assuming the logarithm of inputs and outputs, the Cobb-Douglas function gives:

$$\ln Y = \ln \alpha_0 + \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \dots + \alpha_n \ln X_n + \alpha_T \ln \tau \quad (3.5)$$

Where: $\ln Y$ is the output or production

$X_1 \dots X_n$ are the respective input variables

τ is the technology variable (represented by research and extension expenditure)

$\alpha_1 \dots \alpha_n$ are the coefficients to be estimated, expressing the change in Y with respect to a change in a particular X variable holding other variables constant.

Because equation (3.5) is linear in logarithms, the coefficients of the input variables ($\alpha_1 \dots \alpha_n$) are output elasticities of the input variables. Likewise, the coefficient of τ (α_T) is the output elasticity of research and extension expenditures. This approach is used because it is inherently difficult to measure the output of the research process directly (Townsend and Van Zyl, 1998).

The impact of research on output is not immediate, therefore when the relationship between output and research is modelled, it is important to capture the lagged effect. There are various lag distribution structures used to model the relationship between output and research investments. Alston *et al.*, (1998) list the following lag structures; the logistic curve form (Griliches, 1958) the inverted “V” or “U”-shaped distribution (Evenson, 1967), the trapezoidal distribution (Huffman and Evenson, 1992) and the polynomial lag distribution (Cline, 1975; Davis, 1975), the most common being the Almon polynomial lag distribution (Alston *et al.*, 1998; Townsend and Van Zyl, 1998). This lag structure is discussed in more detail in the next section.

3.3.1 Almon polynomial distribution lag

The polynomial lag hypothesises that the lag distribution, β_T is a smooth function of the lag T . Smoothness being interpreted as the function that can be approximated closely by a polynomial of fairly low order (Hall, 1967); i.e.:

$$\beta_T = \alpha_1 + \alpha_2 T + \alpha_3 T^2 + \dots \alpha_N T^{N-1} \quad (3.6)$$

Where N is the polynomial order and is usually less than 6.

Bischoff (1967) modified the basic method (equation 3.6) by introducing what he called “zero restrictions”. A zero restriction is used to impose *a priori*, the hypothesis that the lag distribution approaches zero at one or both ends. If the method of polynomial approximation is used in estimating the lag distribution, zero restrictions are imposed by limiting the components $z_{t,j}$ to those corresponding to polynomials which meet the restrictions.

Now in normalised form, the basic polynomial lag function (3.6) is:

$$\beta_T = \alpha_1 + \alpha_2 \left(\frac{T+1}{p+1}\right) + \alpha_3 \left(\frac{T+1}{p+1}\right)^2 + \dots \alpha_N \left(\frac{T+1}{p+1}\right)^{N-1} \quad (3.7)$$

If a zero restriction is imposed at the near end, the equation (3.7) is modified by eliminating the constant term:

$$\beta_T = \alpha_1 \left(\frac{T+1}{p+1}\right) + \alpha_2 \left(\frac{T+1}{p+1}\right)^2 + \dots \alpha_{N-1} \left(\frac{T+1}{p+1}\right)^{N-1} \quad (3.8)$$

This form of the distributed lag function always has small coefficients for the shortest lags. The name "zero restriction" is derived from the fact that if a hypothetical β_1 were calculated from equation (3.8), it would be zero no matter what values the α -coefficients had.

A zero restriction is imposed at the far end in a similar way. Instead of equation (3.8), we use:

$$\beta_T = \alpha_1 \left(1 - \frac{T+1}{p+1}\right) + \alpha_2 \left[\left(\frac{T+1}{p+1}\right)^2 - \frac{T+1}{p+1}\right] + \dots + \alpha_{N-1} \left[\left(\frac{T+1}{p+1}\right)^{N-1} - \frac{T+1}{p+1}\right] \quad (3.9)$$

In this case, a hypothetical p is always zero, so that the lag function is constrained to be close to zero for the longest lags.

Finally, zero restrictions may be imposed at both ends by dropping the first term from the equation (3.9):

$$\beta_T = \alpha_1 \left[\left(\frac{T+1}{p+1}\right)^2 - \frac{T+1}{p+1}\right] + \alpha_2 \left[\left(\frac{T+1}{p+1}\right)^3 - \frac{T+1}{p+1}\right] + \dots + \alpha_{N-2} \left[\left(\frac{T+1}{p+1}\right)^{N-1} - \frac{T+1}{p+1}\right] \quad (3.10)$$

Equation (3.10) is the form which Almon proposed.

Imposing restrictions on the lag structure at both ends implies that the t-statistic of the lagged research variable will be equal for all the lagged research variables. Once the research coefficients have been estimated following the Almon polynomial structure, the Marginal Internal Rate of Return (MIRR) is estimated in a two-stage procedure (Thirtle and Bottomley, 1988).

The first step involves calculating the value of the marginal product of research:

The elasticities (coefficients) of the lagged research variables are converted to a value marginal product with each coefficient representing the output elasticity of research for that year: see equation 3.11 below:

$$\beta_i = \frac{\partial \ln YIELD_t}{\partial \ln RD_{t-i}} = \frac{\partial YIELD}{\partial RD_{t-i}} \cdot \frac{RD_{t-i}}{YIELD} \quad (3.11)$$

Thus, the marginal physical product of research is the elasticity multiplied by the average physical product, as shown in equation 3.12:

$$MPP_{t-i} = \frac{\partial OUTPUT_t}{\partial RD_t} = \beta_i \frac{OUTPUT_t}{RD_{t-i}} \quad (3.12)$$

Replacing $Yield/RD_{t-i}$ by its geometric mean, and changing from continuous to discrete approximations, gives equation 3.13 below:

$$\frac{\Delta OUTPUT_t}{\Delta RD_{t-i}} = \beta_i \frac{\overline{YIELD}}{\overline{RD_{t-i}}} \quad (3.13)$$

Then, multiplying by the increase in the value of output divided by the change in quantity converts from output quantity to output value. Thus, the value marginal product of research in period $t-i$ can then be written as:

$$VMP_{t-i} = \frac{\Delta VALUE_t}{\Delta RD_{t-i}} = \beta_i \frac{\overline{YIELD}}{\overline{RD_{t-i}}} \cdot \frac{\Delta VALUE_t}{\Delta YIELD_t} \quad (3.14)$$

Where $Yield/RD_{t-i}$ is an average and $\Delta Value_t/\Delta Yield_t$ is calculated as the average of the last five years minus the average for the first five years for both variables. Thus, these are constants, but β_i varies over the lag period, giving a series of marginal returns resulting from a unit change in research expenditure. The value of output, $\Delta Value_t/\Delta Yield_t$ is the geometric mean calculated using the value of output. Similarly, $Yield/RD_{t-i}$ is a constant price-geometric average.

Once the Value of Marginal Product (VMP) has been calculated, the second step involves determining the discount rate (MIRR) which equals the discounted flow of benefits with the discounted research costs. The marginal internal rate of return (MIRR) is calculated as:

$$\sum_{i=1}^n \frac{VMP_{t-i}}{(1+r)^i} - I = 0 \quad (3.15)$$

Where r is the MIRR, and n is equal to the mean lag of the distribution of benefits.

The production function method is the most popular method among the econometric methods used to evaluate returns to agricultural research. This is mainly due to its relative ease of application compared to the more complex and data-intensive methods, such as the profit function. The method uses actual data and not experimental data and the assumption about the elasticities to measure the surplus area is not necessary (Nieuwoudt and Nieuwoudt, 2004). The production function has the advantage of being able to isolate the impact of research investments on output from other factors that also explain changes in agricultural output. In addition, the method also captures the effects of minor improvements in farming practices resulting from research that might be overlooked in analyses looking at major technological changes (Heisey *et al.*, 2010). The method also has the advantage of providing estimates of marginal products of research as well as marginal products of other variables affecting input quality (Lyu, White and Lu, 1984). Lastly, the method offers more rigorous statistical analysis of the impact of research on outputs (Anandajayaseram, Martella and Rukuni, 1996).

On the other hand, the production function method requires detailed time-series data on conventional inputs, labour, infrastructure, chemical applications, machinery and private investments in agricultural research that are, in some cases, difficult to find (Norton and Davis, 1981). This consequently creates possible omission (misspecification) problems in the model. This can, however, be mitigated by the inclusion of a time-trend variable in the model to capture factors that affect output but have not been included in the model as well as by the use of proxy variables (Bervejillo, Alston and Tumber, 2011). There are also other data and econometric problems associated with all statistical analyses. There is also the uncertainty of projecting past rates of return into the future. However, Davis provided evidence that the production coefficient on the research variable in aggregate agricultural production function has remained stable since 1964 (Norton and Davis, 1981). Thus relatively accurate estimates and projections can be made. Lastly, the method can only be applied in ex-post research evaluations while some other analyses require ex-ante evaluations. There are, however, other research evaluation methods that can be applied to ex-ante agricultural research evaluations.

3.4 CONCLUSION

This chapter discussed the two most commonly used methods in evaluating returns to agricultural research. These are the economic surplus method and the production function method. Both of these methods have a long history in agricultural research evaluation studies. The economic surplus method was first used by Schultz (1953) while the production function method was first applied by Griliches (1964). The assumptions made in the economic surplus method have been modified since Schultz's work, with respect to the nature of the shift of the supply curve and the specifications of the supply and demand functions. The economic surplus method is very popular mainly due to its ability to disaggregate benefits among consumers, producers and other market participants as well as disaggregating between countries, regions and agro-ecological zones. The method is also most appropriate when focusing on particular technologies and research programmes. On the other hand, it can be restrictive for aggregate evaluations of agricultural research. This shortcoming of the economic surplus method is addressed by the production function method. The production function method allows for more aggregated evaluations of agricultural research and at the same time focuses on all research programmes, both successful and failed. In addition, the production function allows for a disaggregation of the research and non-research effects on agricultural output, an important feature for this study. From these two ex-post evaluation methods, the production function proves to be the most appropriate method to use in the evaluation of the returns to vegetable research.

CHAPTER 4

PRIVATE AND PUBLIC SECTOR PARTICIPATION IN VEGETABLE BREEDING IN SOUTH AFRICA

4.1 INTRODUCTION

The purpose of this chapter is to evaluate the distribution of issued plant breeders' rights for selected vegetable crops in South Africa from 1980 to 2012. Through this, the chapter will determine the contribution of ARC-VOPI in the breeding of 14 selected commercial vegetable crops relative to the private sector. This is done by evaluating the ownership of registered vegetable cultivars in the South African Plant Variety Journal from 1980 to 2012. The motivation was that these cultivars have generated royalty income for the institute which has been reinvested into vegetable research and thus forms part of the research investment series to be used in estimating the economic rate of return to vegetable research.

Before this is done, however, the first application among the 14 selected vegetable crops as documented in the plant breeders' registry is assessed to give a historical overview of who the breeders of vegetable cultivars were over the years. The chapter also looks at the lag between the time of application and the final grant of plant breeders' rights.

4.2 APPLICATIONS FOR PLANT BREEDERS' RIGHTS: AN OVERVIEW

Table 4.1 shows the number of applications for plant breeders' rights in South Africa for selected vegetable crops in the period 1966 to 2012 (DAFF, 2013b). The table shows the differences in the total number of applications per decade between the different vegetable crops as well as the differences within each vegetable crop per decade. A total of 1 226 applications were lodged for plant breeders' rights in the period.

Table 4.1: Plant Breeders' Rights Applications per Vegetable Crop, 1966-2012

	1966-1979	1980-1989	1990-1999	2000-2009	2010-2012	Total
Onions	0	8	34	40	8	90
Potatoes	0	10	96	94	42	242
Tomatoes	0	20	67	47	16	150
Peppers	0	2	22	20	1	45
Soy Beans	9	28	76	58	35	206
Dry Beans	0	23	63	50	8	144
Beans	0	6	6	10	0	22
Garden Beans	5	14	56	51	6	132
Pumpkin ²	0	5	28	29	13	75
Lettuce	0	1	12	4	5	22
Garden Peas	2	7	23	8	6	46
Sweet Potatoes	0	0	4	12	6	22
Carrots	0	6	5	5	0	16
Cabbage	0	4	4	3	3	14
Total	16	134	496	431	149	1226

Source: Adapted from DAFF, 2013b

Notes: Actual Number of Applications

The first applications for plant breeders' rights among these vegetable crops were made in 1966 for soybean cultivars. Those applications were for three cultivars and they were all locally bred varieties. In 1967, the first application for a garden bean cultivar was made and it was also an application for a locally bred cultivar. All other applications made in the period 1966 to 1979, as shown in Table 4.1, were made from 1971 to 1979. These applications were for six soybean cultivars, four garden bean cultivars and two garden pea cultivars. The applications for the garden bean cultivars were largely from the USA with one from South Africa. The applications for the garden pea cultivars were all from the USA, while the soybean applications were from Zimbabwe and South Africa. These applications were lodged after the first Plant Breeders' Rights Act came into effect in 1964. This Act was, however, repealed and a new Act came into effect in 1976: the Plant Breeders' Rights Act, Act No 15. This act was brought about to comply with the International Union for the Protection of New Varieties of Plants (UPOV) convention.

In the subsequent period, 1980 to 1989, the number of applications increased to 134. This was a significant increase and to some extent reflected the usefulness of the plant breeders' rights system. In that period, applications for plant breeders' rights for other kinds of vegetable crops which had not been applied for previously were lodged, although soybean, garden bean and garden pea cultivar applications were also made. The majority of the applications made in that period were for soybean, dry bean and tomato cultivars and accounted for 21 percent, 17 percent and 15 percent respectively of the total applications. Other notable applications that were made

² Pumpkin includes squash cultivars

in that period were for garden bean, potato and onion cultivars, each accounting for 10 percent, 7 percent and 6 percent of the total applications respectively.

Table 4.1 also shows that the decade 1990 to 1999 had the highest number of plant breeders' rights applications in the period under analysis. There was a 3.7-fold increase in the number of applications from the previous decade. The highest number of applications in the decade 1990 to 1999 was for potato cultivars, followed by soybean applications, tomato applications, dry bean applications and lastly garden bean applications. Although a high number of applications were made for plant breeders' rights in the decade 1990 to 1999, not all of the applicants were granted final plant breeders' rights. In the case of potato cultivar applications, 7 of the applications were withdrawn and others rejected. Similarly, 9 of the soybean cultivar applications and 10 of the tomato cultivar applications were withdrawn and others rejected.

There are a number of reasons why applications for plant breeders' rights are withdrawn and in some cases rejected. Section 11 (1) of the Plant Breeders' Rights Act, Act No 15 of 1976, includes reasons such as: the application not complying with the provisions of the Plant Breeders' Rights Act, the variety in respect of which the application made is not a new variety and does not comply with the provisions of the Act, or that the plant variety does not belong to a kind of plant which the minister has declared subject to the Plant Breeders' Right Act. In addition, when the applicant under the Plant Breeders' Rights Act is not entitled to make the application, or when the application contains a material misrepresentation, the application may be rejected.

In the same decade (1990-1999), the first sweet potato cultivar applications were made. These were made in 1999. All the cultivars were locally bred. There was also a notable increase in the applications made for pepper and lettuce cultivars, from 2 to 22 and from 1 to 12 applications respectively. The applications for the pepper cultivars were mainly from Italy and the Democratic People's Republic of Korea (KP), and a small number from France. About 75 percent of the lettuce applications were from the Netherlands, 17 percent were from South Africa and the remaining 8 percent were from the USA.

There was a slight decrease from the previous period in the total number of applications made in the period 2000 to 2009. The total number of applications declined from 496 to 431. This was roughly a 13 percent decline. The decline was as a result of fewer applications made for tomato, soybean, dry bean, garden peas and lettuce cultivars compared to the previous period.

There was, however, an increase in the number of applications made in 4 out of the total 14 vegetable commodities. These were onions, beans, pumpkin and sweet potatoes. The number of carrot applications remained unchanged between the decades 1990 to 1999 and 2000 to 2009. In other words, the number of carrot cultivars bred was the same in both decades.

Between 2010 and 2012, there were a total of 149 applications made. The majority of the applications were for potatoes, soybeans, tomatoes and pumpkin cultivars. The applications for potato cultivars were mainly from the Netherlands, with a few applications made from South Africa and Israel. The soybean cultivar applications were mainly from South Africa, Argentina and Brazil. The soybean applications from South Africa accounted for about 48.5 percent of the total applications and Argentina and Brazil together accounted for about 37.1 percent. Seventy one percent of the applications for tomato cultivars in this period were from South Africa, about 21.4 percent of the applications were from the USA and the remaining 7.1 percent of the applications were from Israel. In the case of pumpkin, about 85.7 percent of the applications were from South Africa and the remaining 14.2 percent were from Brazil.

4.3 GRANT LAG

The process of granting plant breeders' rights in South Africa requires intensive examination of each application to ensure that both the applicant and the variety meet the requirements of the Plant Breeders' Rights Act.

Section 2 (1) of the Plant Breeders' Rights Act, Act No. 15 of 1976, of South Africa requires that a variety must be new before it can be granted varietal protection. According to the Act, a variety is new when it is distinct, uniform and stable. Ensuring that a variety is new takes time and contributes to the delay in granting final breeders' rights. Because commodities and cultivars differ, the period between a grant application and the final award of plant breeders' rights differs across commodities and within cultivars of the same commodity. According to SAPO, the process of plant breeders' rights and variety listings for fruits takes approximately two years (SAPO, 2013). For some crops, the lag may be longer or shorter.

The lag between application and grant of final plant breeders' rights is a function of the whole system. To a certain extent, it is also a reflection of the efficiency of the processing office. Lesser and Mutschler, (2002) in Pardey, Koo, Drew, Horwich and Nottenburg, (2013), suggested that the delay in processing applications for plant variety protection in the USA might

have been one of the reasons for the decline in plant variety protection applications in the late 1990s (Pardey, *et al.*, 2013).

The Plant Breeders’ Rights Act of South Africa gives applicants up to 12 months to furnish documentation and material required for processing the application. Lags can therefore also be lengthened by delays to furnish the registrar with such necessary documentation and materials. In this section, the lag between applications and granting of final plant breeders’ rights for selected vegetable commodities in South Africa is evaluated to determine the differences that exist among these commodities.

In estimating the lags between the date of application for plant breeders’ rights and the date of the final granting of the right, the number of days between the date of application and the date of the grant for each cultivar was calculated and the average of these was used. Figure 4.1 depicts this. The figure shows the average number of days it took for the cultivars to be granted protection for the period 1990 until the third quarter of 2013.

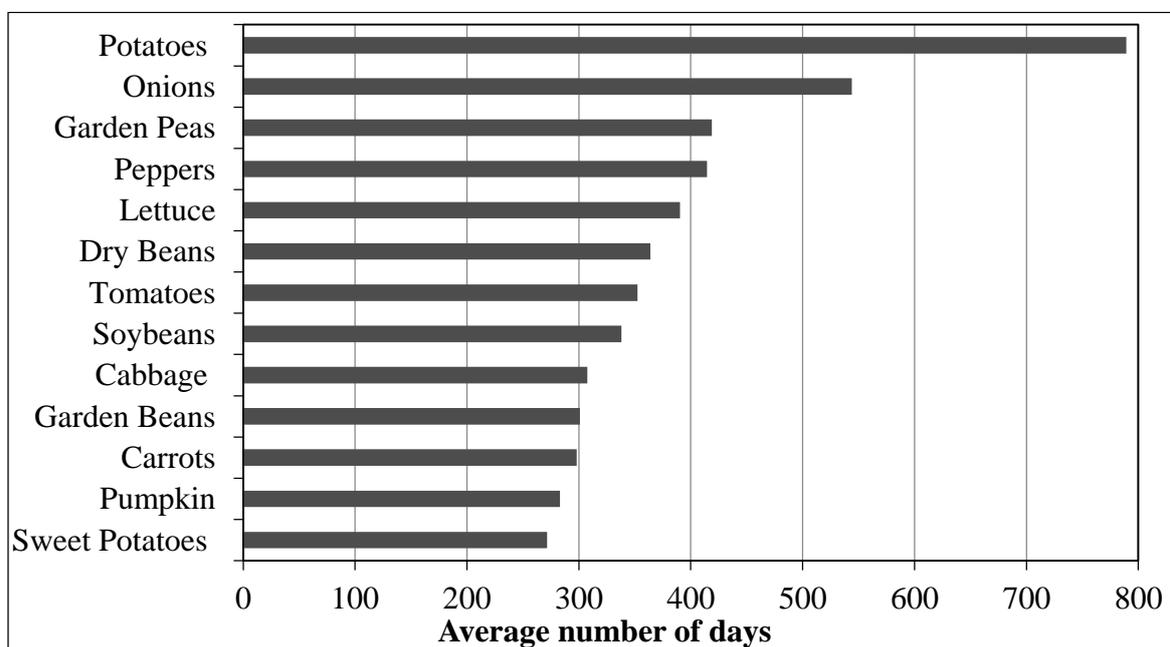


Figure 4.1: Average Grant Lag for Each Vegetable Crop, 1990-2013

Source: Adapted from DAFF, 2013b

As indicated in Figure 4.1, sweet potato, pumpkin, carrot and garden bean cultivars had relatively short grant application lags, less than 300 days or slightly less than a year. Most of the applications for varietal protection within these commodities were by local applicants. The shortest lag occurred within sweet potato cultivars, with an average lag of 272 days between 1999 and 2013.

It took between 300 to 400 days for cabbage, soybean, tomato, dry bean and lettuce cultivar applications to be granted varietal protection. Soybean cultivars specifically had an average lag of 338 days between 1996 and 2013. In the United States of America, soybean plant variety protection applications were found to have longer lag lengths than corn applications (Janis and Kesan, 2002). The maximum issuing duration was found to be 2 359 days (over 6 years) for soybean applications and 1 810 days (just over 4 years) for corn applications. Janis and Kesan, (2002) found that the average time lag had risen since the 1970s but had fallen since 1999 when applications began to decline.

Pardey *et al.*, (2013) found that in the period 1977 to 1987, the average lag for plant variety protection certificates in the United States was 500 days (more than a year) and after 1987 the lag had lengthened to 1 449 days (about four years). During the ten-year period 1989 to 1998, the number of granted plant variety protections declined while the number of applications continued to increase, reflecting the growing administrative delays in granting applications. In China, the average grant lag for plant variety protection applications was found to be about 17 months or about a year and a half from the date of application between April 1999 (when the first application was lodged) and May 2002 (Koo, Pardey, Qian and Zhang, 2003).

Among the selected vegetables in this study, the longest lag was found in the applications for potato cultivars. On average, it took about 789 days or about two years for a potato cultivar to be granted protection between 1992 and 2013. About 56 percent of those applications were from the Netherlands. Between 1996 and 2012, it took an average of 544 days (almost a year and a half) for an onion cultivar to be granted varietal protection. This was followed by garden pea cultivars with an average lag of 419 days over the same time period, 1996 to 2010.

According to the processing office, these lags were a result of the instability in the first season's trials, animal damages to trials and hail damage to trials which resulted in trials being repeated in the following season. Uncertainties that arose while trials were being conducted also resulted in the repetition of trials. Inhibition of seed germination in some cases also contributed to relatively long lags.

4.4 GRANTED PLANT BREEDERS' RIGHTS: AN OVERVIEW

4.4.1 Overall trends

The long-run trend of plant variety grants worldwide has been upwards. According to the World Intellectual Property Organisation (hereafter WIPO), grants worldwide increased from 6 200 in 1995 to 11 100 in 2010. In 2011, however, the number of grants declined to 10 200, a 7.8 percent decrease from the 2010 figure. The decline was attributed mainly to the decline in grants in China and the Ukraine (WIPO, 2012).

The largest number of plant variety grants in 2011 was issued by the Community Plant Variety Office, a European Union agency which manages a system of plant variety rights covering 28 member states, followed by Japan, the United States and the Netherlands. South Africa ranked ninth in the top ten grant offices, with a total of 297 grants in 2011. With regard to grants by origin, however, South Africa ranked 16th with 124 grants issued in 2011. About 120 of those grants were issued to residents of South Africa and the remaining 4 were issued within the region and abroad. At the time, there were about 2 425 plant variety grants in force in South Africa. This positioned the country tenth in the world after the European Union, USA, Japan, Netherlands and the Ukraine which occupied the top five positions (WIPO, 2012).

A granted plant breeders' right in South Africa gives the holder the sole right to the use of the particular variety for eight years, after which the holder is obliged to license the cultivar out. For vegetables, the period of plant breeders' rights is 20 years. This is in line with the International Union for the Protection of New Varieties of Plants convention, which as of December 2012 had been adopted by 71 states.

4.5 COUNTRY COMPOSITION OF SOUTH AFRICAN PLANT BREEDERS' RIGHTS

This section looks at the distribution of ownership of vegetable variety rights in South Africa. The distribution is evaluated for vegetable varieties owned by the domestic and foreign private and public sector organisations.

Figure 4.2 shows the country composition of SA plant breeders' rights as it was at the third quarter of 2013. The figure represents the total number of granted plant breeders' rights per

country. The countries included were those in the top five (after South Africa). A few conclusions are drawn from the figure: Firstly, South Africa was dominating with regard to the number of plant breeders' rights issued within the selected vegetable commodities. This was mainly from the combination of domestic companies, research institutes, ARC-VOPI, ARC-GCI, Cedara Agricultural Research Station and some private individuals. Secondly, the number of plant breeders' rights issued to holders (organisations) originating from the Netherlands was higher than those originating for the United States. This implied that the Netherlands in that period played a relatively more important role in the South African vegetable variety market than the United States. This was slightly different from the worldwide trend in 2011 where the US held relatively more varietal rights than the Netherlands. The Netherlands was also found to have played a very significant role in the South African ornamental plant industry. Thirdly, the number of varietal rights granted to the USA was more than the number granted to Israel, Australia and Argentina combined. This was consistent with WIPO findings that these countries held relatively fewer varietal rights in total worldwide than the USA. Some varietal rights were issued to Japan, Brazil and France; however, the relative share of those countries was low and thus not included in the figure.

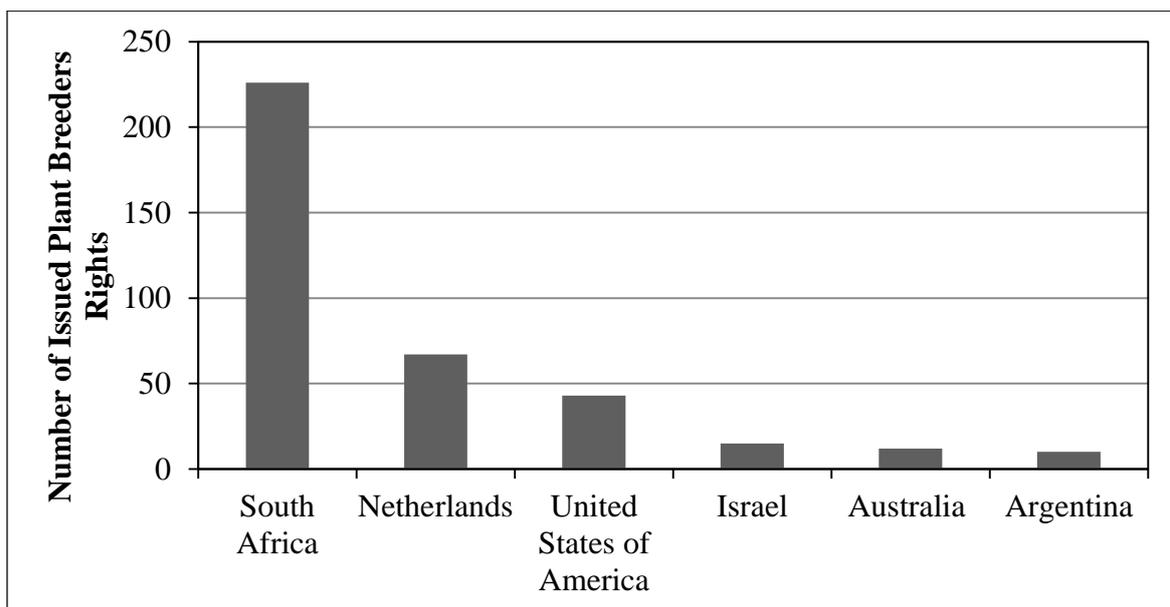


Figure 4.2: Composition of South African Vegetable Varieties by Country

Source: Adapted from DAFF, 2013b

The position of South Africa in the domestic vegetable variety market, as shown in Figure 4.2, gives an impression that the country had been performing very well; however, when further analysis of the underlying data is done, a slightly different picture is formed.

4.6 HOLDERS OF VEGETABLE CULTIVAR RIGHTS IN SOUTH AFRICA

4.6.1 Foreign companies

Figure 4.3 shows that foreign companies dominated the local vegetable variety market with a total share of over 41 percent. This was higher than the total share of local companies which stood at just over 37 percent. Although the difference was not by a large margin, it is a point of concern, especially if the share of foreign companies were to increase, as royalty payments for the use of protected foreign varieties could affect the country's balance of payments (Loyns and Beaton, 1998). The share of foreign companies was greatest among the potato, onion, cabbage, lettuce and garden pea cultivars.

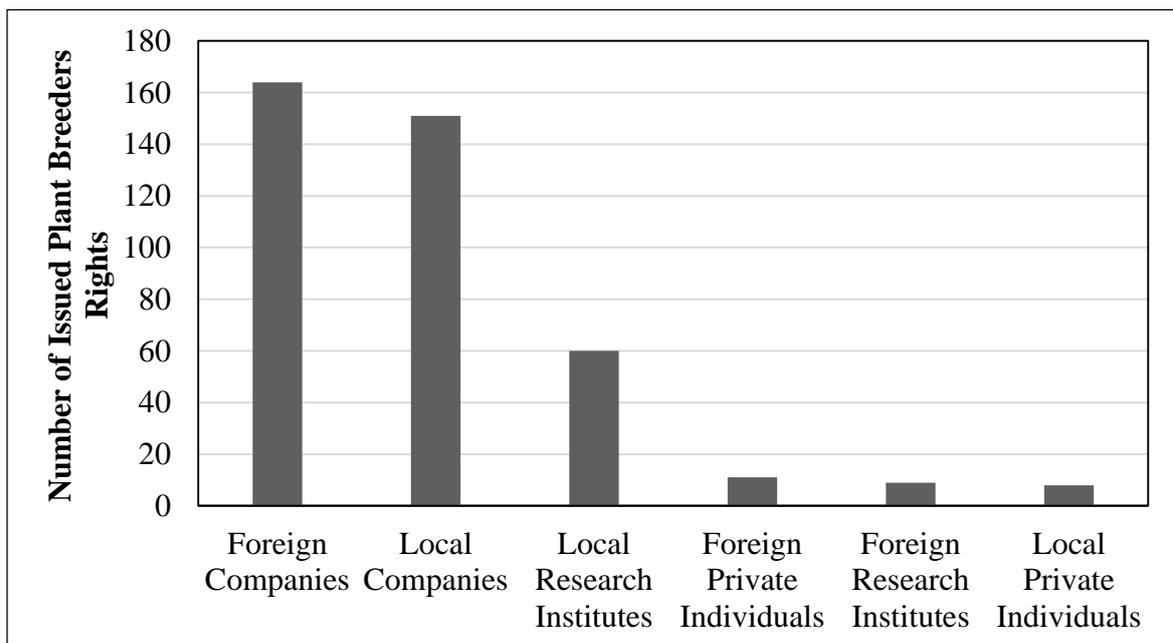


Figure 4.3: Category of Plant Breeders' Rights Holders

Source: Adapted from DAFF, 2013b

Foreign companies accounted for about 65 percent of the total potato cultivar rights issued. Agrico and HZPC Holland BV of the Netherlands each held nine varietal rights of potato cultivars. This was about 31 percent of the total granted breeders' rights to foreign companies. The other prominent role players included Germicopa, a French company, and Hettema, a Netherlands company. These companies had a share of about nine percent or five plant breeders' rights each. Other foreign companies that held the remaining share of granted plant breeders' rights included Netherlands-based companies, Van Rijn-KWS BV and HZPC as well as an Ireland-based company, IPM. Each of these companies had a share of about 6.8 percent.

Frito Lay of the United States of America accounted for a relatively small share, about 3.4 percent. The remaining 35 percent of the potato variety grants were issued to the local research institute, the ARC-VOPI, foreign research institutes and foreign individuals. Within the onion cultivars, foreign companies held about 73 percent of the total rights of protected cultivars. These were from a total of about 35 protected cultivars that were released between 1997 and 2012. Jarit, an Australian company, and Hazera, an Israel company, each held a quarter of the protected varieties. The other important role player was a United States of America company, Monsanto, with a share of about 17 percent. This company was also found to be one of the prominent companies within the lettuce varieties.

All lettuce varieties that were granted protection were bred by foreign companies. The companies originate from the Netherlands, Japan and the United States. Nunhems BV of the Netherlands accounted for the greatest share: over 42 percent. This was followed by Monsanto of the USA with a share of over 28 percent and lastly Takii & CO, a Japanese company with a share of just over 14 percent.

It was also found that all the protected cabbage varieties belonged to foreign companies, one Japanese company and one USA Company. Sakata, the Japanese company, held about 67 percent of these protected cultivars and Alf Christianson, the USA company, held the remaining 33 percent. There was no local participation in these vegetable commodities.

Within the garden pea cultivars foreign companies dominated by a share of 88.9 percent. Of this, Syngenta held over 37 percent of the protected cultivars and Elsoms Seed held about 25 percent. Syngenta is a Netherlands-based company and Elsoms Seed is a United Kingdom-based company. The rest were USA companies: Monsanto, Brother Seed and Crites Moscow Growers, each with a share of 12.5 percent of the garden pea cultivars.

In the following section, the participation of domestic private sector companies is analysed to compare how this category has been performing relative to foreign private companies.

4.6.2 Local companies

In the period 1980 to 2013, local companies were prominent within the soybean, pepper, pumpkin, garden bean, tomatoes and dry bean cultivar sectors. They accounted for the greatest share of the rights granted to both genetically modified (GMO) and conventional soybean

cultivars. The share of local companies was about 47 percent of the granted soybean PBRs. Only two local companies accounted for all the rights issued to soybean GMO cultivars. These were Link Seed and Pannar (Pty) Ltd. Link Seed held about 74 percent of the protected cultivars in the market and the rest of the protected varieties (about 26 percent) were held by Pannar (Pty) Ltd. With the conventional soybean varieties, the picture was slightly different although the same companies also dominated this market: Link Seed and Pannar (Pty) Ltd each held 40 percent of the protected cultivars and Sensako held the remaining 20 percent.

Local companies which were prominent in the pepper, pumpkin, garden bean, tomatoes and dry bean commodities between 1996 and 2013 were Pannar (Pty) Ltd, Hygrotech, Plennegy, Pro-Seed, Seedcor, Sakata, Starke Ayres and Premier. Of these, Pannar accounted for the greatest share of the rights issued and had a share of varietal rights in all of those vegetable commodities. Within the squash cultivars, Pannar (Pty) Ltd held just over 82 percent of the rights granted. This was followed by Plennegy, which accounted for almost nine percent of the squash varieties. Hygrotech and Premier each had a share of about five percent of the squash cultivars. Hygrotech accounted for the greatest share within the garden bean cultivars, about 26.08 percent, while within the carrot cultivars, Hygrotech accounted for about 33 percent. This company also had varietal rights within garden bean cultivars, but these were surrendered in 1992.

In 2013, Sakata accounted for only about 19 percent of the varietal rights issued to tomato cultivars, but between 1975 and 2003, the company had a total of 37 tomato varieties that it had surrendered. This was more than 78 percent of the total tomato variety rights that were granted in that period. Pro-Seed, on the other hand, held the highest number of varietal rights granted to garden bean cultivars. This was higher than the share held by Pannar (Pty) Ltd, the leading role player among all the local companies. Pro-Seed surrendered a total of 14 garden bean cultivars over the years 1980 to 2013. This was about 69 percent of the total soybean cultivars surrendered. Seleкта accounted for about 17 percent of the surrendered soybean cultivars in the same period. Starke Ayres and Alpha Seed accounted for eight percent each and Hygrotech accounted for about four percent.

In the dry bean market, Pannar (Pty) Ltd and Pro-Seed were again the leading local companies with plant breeders' rights. Other participants in the dry bean market were the Dry Bean Producer Organisation and Capstone. Pannar (Pty) Ltd and Pro-Seed accounted for about 72 percent of the dry bean varieties with plant breeders' rights over the period 1980 to 2013 and

the remaining 28 percent were owned by the Dry Bean Producer Organisation, and Capstone. Sensako, Pioneer, Pro-Seed, Selektta and KKSM also played a role in the dry bean variety market; however, these companies had surrendered their plant breeders' rights.

4.6.3 Foreign and local individuals

Figure 4.3 shows that there have been private individuals participating in the development of vegetable crop cultivars, from foreign countries as well as from South Africa. The participation of this category of breeders has, however, on the overall been relatively low. Pardey *et al.*, (2013) attributed the relatively low participation of private individuals in the USA varietal market to possible changes in the structure and costs of research and especially the cost of marketing new seed and crop varieties. Figure 4.3 shows that the share of granted plant breeders' rights to foreign individuals was slightly higher than the share to local individuals. Foreign individuals accounted for about 2.7 percent of the total plant breeders' rights granted, while local individuals accounted for about two percent of the total share. The concentration of foreign individuals was within the soybean, pumpkin and potato cultivars, with a share of about 4.8, 4.5 and 9.1 percent of the granted plant breeders' rights respectively. As was the case with foreign companies, the majority of foreign individuals holding plant breeders' rights were from the Netherlands.

Local private individuals participated only in the breeding of onion and pumpkin cultivars. The participation of local individuals was most prominent among the onion cultivars, with a share of just over 21 percent. Within the pumpkin cultivars, local private individuals accounted for just over nine percent of the granted plant breeders' rights.

This section gave a description of the participation of foreign and local private sector companies as well as individuals in vegetable breeding. The following section evaluates the share of granted plant breeders' rights owned by the public sector among the selected vegetable crops. The evaluation includes foreign and domestic research institutes, governments and universities.

4.6.4 Local and foreign public sector

Figure 4.3 also shows the participation of local and foreign state-owned or public sector research institutes in the breeding of the selected vegetable crops. The public sector accounted for only 17 percent of the total registered vegetable cultivars, of which 14 percent was by local research institutes and three percent was by foreign research institutes. The local research

institutes were two institutes of the ARC, ARC-VOPI and ARC-GCI, as well as Cedara Agricultural Research Station. The ARC's participation was in four of the 14 selected vegetable crops. This was in sweet potatoes, soybean, potatoes and dry bean cultivars. Within sweet potatoes, ARC-VOPI held all of the plant breeders' rights issued as at the third quarter of 2013. These rights were for 21 cultivars and were granted between 2000 and 2013, an average of 1.5 cultivars a year. In that period, only one protected sweet potato cultivar was surrendered, and this was a cultivar that was also developed by ARC-VOPI. No other public or private sector organisation was granted plant breeders' rights for sweet potato cultivars in that period.

The participation of the local public sector was also evident within the conventional soybean varieties. Here, the public sector accounted for just over 34 percent of the protected cultivars. This contribution was made by ARC-GCI and Cedara Agricultural Research Station. The ARC-GCI held about 30 percent of the plant breeders' rights issued for conventional soybean varieties and the remaining four percent of the rights were held by Cedara Agricultural Research Station. These plant breeders' rights were issued between 2000 and 2005. Since then, no other plant breeders' rights were issued for soybean cultivars to the domestic public sector. In the period 1980 to 2013, only one soybean variety that was bred by a local public research institute was surrendered. This was a variety developed by ARC-GCI. The variety was granted protection in 1993 and surrendered in 2002, indicating that this institute has been involved in the development of soybean cultivars for many years.

Within dry beans, 36.8 percent of the plant breeders' rights were issued to the public institute and the remaining 63.2 percent of the rights were granted to domestic private sector companies. In this commodity, all the protected varieties as at the third quarter of 2013 were developed by ARC-GCI. This was a total of 14 dry bean cultivars and the grants were issued between 1998 and 2013, an average of one cultivar a year. There was a total of nine cultivars that ARC-GCI surrendered between 1994 and 2007. One of those cultivars was granted protection in 1988 and the rest at varying times between 1992 and 1999. This indicates the long history of this institute in the breeding of dry bean cultivars over the years as was the case with soybeans.

In contrast to the case of sweet potato, soybean and dry bean breeding, in which the participation of the public sector was only domestic, both domestic and foreign public sector organisations participated in potato breeding. Here the domestic public sector owned just over 19 percent of the plant breeders' rights issued, foreign research institutes owned just over 10 percent and one foreign university held one percent of the plant breeders' rights issued.

The domestic public sector was represented by ARC-VOPI, as all the potato cultivars were developed by the institute. There was a total of 17 potato cultivars for which the institute held plant breeders' rights. These rights were issued between 1995 and 2004, giving an average of 1.7 registered cultivars each year. Foreign research institutes that accounted for the 10 percent of the plant breeders' rights issued were; Caithness Potato Breeders in London and the Centre for Potato Research in Israel. Caithness Potato Breeders owned about 75 percent of the plant breeders' rights granted to foreign research institutes for potato cultivars and the Centre for Potato Research held the remaining 25 percent of the rights. There were about four potato cultivars that were surrendered by foreign research institutes between 2001 and 2013 and all of those were from Caithness Potato breeders.

Participation by other public sector organisations, both domestic and foreign, was minimal. Only one foreign university held plant breeders' rights: Oregon State University. This university held just over one percent of the plant breeders' rights issued for potatoes and these were granted in 2005.

4.7 CONCLUSION

The highest number of applications for plant breeders' rights was found to be for potato cultivars. These applications accounted for almost 20 percent of the total applications made among the 14 selected vegetable crops, thus indicating the relative importance of this crop among vegetables. At the same time, the longest lag between application and granting of plant breeders' rights was also found to be among potato cultivars. On average, it took about 789 days for a breeder of a potato variety to be granted plant breeders' rights. This was to some extent due to the relatively higher number of potato cultivar applications that had to be processed over the years. Different grant lags were found for the other vegetable crops, with the least lag found in sweet potato cultivars. The difference in the lag reflected the difference in the gestation period of the different crops, the relative ease or difficulty of breeding those vegetable crops as well as delays that can occur in the processing of applications for plant breeders' rights.

The highest degree of participation in the breeding of vegetable cultivars in the period under analysis was by the private sector. The main developers of vegetable cultivars in South Africa were foreign companies, with an overall share of over 41 percent in the period 1980 to 2012.

The participation of foreign companies was mainly within potatoes, onions, cabbage, lettuce and garden pea cultivars. The majority of foreign companies were from the Netherlands followed by the United States of America.

Following the relatively high contribution of foreign companies were local companies with an overall share of about 37 percent of the total granted plant breeders' rights. The participation of local companies was in the breeding of soybean, pepper, pumpkin, garden bean, tomatoes and dry bean cultivars. The main contributor was Pannar (Pty) Ltd which had varietal rights in all these vegetable commodities. Other local companies included Link Seed in the conventional soybean cultivars; Plennegy, Hygrotech and Premier in the pumpkin cultivars; Sakata in tomato varieties; and Pro-Seed, Selekt, Starke Ayres and Alpha Seed in the garden bean cultivars.

The participation of the public sector, on the other hand, was relatively low, both in foreign and local participation. The ARC-VOPI, ARC-GCI and Cedara Agricultural Research Station represented the local public sector and had a combined share of only 14 percent of the total plant breeders' rights granted over the period. The share was in 4 out of the 14 vegetable crops selected, i.e. sweet potatoes, soybean, dry bean and potatoes. The ARC-VOPI's contribution was in the breeding of sweet potato and potato cultivars and ARC-GCI in the breeding of soybean and dry bean cultivars. Cedara Agricultural Research Station was only involved in the breeding of dry bean cultivars. Foreign public sector participation was minimal and was only in the breeding of potato cultivars. These were foreign research institutes from London and Israel and one university from the United States of America.

This chapter gave an overview of the distribution of issued plant breeders' rights among the selected vegetable crops in South Africa. The review showed that plant breeding among these vegetable crops is relatively more important and dominant in the private sector than in the public sector. ARC-VOPI, the main public sector institute conducting vegetable research in South Africa, also had a relatively low percentage share of the issued plant breeders' rights among the vegetable crops. This is to some extent an indication that vegetable breeding at the institute is relatively less important than other forms of research.

In the following chapter, the historical evolution of the institute is given and the different forms of research conducted at the institute over the years are evaluated to determine what the research focus of the institute has been over time.

CHAPTER 5

HISTORY OF VEGETABLE RESEARCH AT ARC-VOPI

5.1 INTRODUCTION

ARC-VOPI is one of the current 11 research institutes of the ARC. The institute started as a Horticultural Research Station of the Department of Agriculture in 1949. It has since then developed into a Horticultural Research Institute and has undergone various structural and institutional changes. The institute has progressed to be one of the important horticultural research institutes in the country.

This chapter gives the historical development of this institute to its present state. The chapter also highlights some of the important research that has been conducted at the institute over the years, including the research undertaken for the small-scale agricultural sector.

5.2 INSTITUTIONAL DEVELOPMENT LEADING TO THE DEVELOPMENT OF ARC-VOPI

5.2.1 The horticultural research station

Horticultural research in the former Transvaal³ was initially undertaken by the Division of Horticulture of the Transvaal Department of Agriculture, established after the Anglo Boer War in 1902. This division was one of the ten divisions of the Transvaal Department of Agriculture under the British regime. The first horticultural experimental farms in the Transvaal region were near Potchefstroom, Warmbaths and Ermelo. The research conducted on those farms focused on variety trials, crop production techniques and the provision of planting material to the public.

At the outbreak of the Second World War in 1939, the importation of vegetable seeds was restricted. This caused a shortage of vegetable seeds in the country and this shortage led to the establishment of the local seed industry. The Division of Horticulture became responsible for evaluating the performance of the local seeds to limit exploitation by local companies and to prevent the production of poor quality seeds.

³ Transvaal region comprised Gauteng, Mpumalanga and Limpopo provinces

Between 1943 and 1944, performance testing of the local seeds was conducted at Rietvlei at the Pasture Research Station near Pretoria. The size and number of the experimental plots used for testing were very limited and therefore created challenges with experiments in the area. As a result, the performance tests were shifted to Onderstepoort, at the Veterinary Science Laboratories. There, four hectares of land were made available for field experiments and the first carrot and onion breeding programmes took place. The purpose of the breeding programmes was to improve the adaptation of carrot and onion cultivars. The Cape Market carrot, the De Wildt onion and the Early Texas Grano onion cultivars in particular had bolting problems. Through the breeding programmes, improved carrot and onion cultivars were developed and later released (ARC-VOPI, 2013c).

Following the Second World War, the country experienced a growing need for horticultural research and a decision was taken to establish a horticultural institute for deciduous fruit, vegetables, cut flowers and ornamental plants. A committee was tasked with finding a suitable site for the institute in Pretoria within a 30 km radius of Church Square. The property owned by Mr F. van der Veen was purchased (ARC-VOPI, 2013c). This property was located 30 km North-East of Pretoria and was part of the original Roodeplaat farm⁴. The property that was purchased was about 295 morgen (about 253 hectares) in size and comprised the present central part of the institute. Another 30 morgen (about 26 hectares) was also bought on the same day. The property was purchased on 1 April 1949, the day on which the Horticultural Research Institute was officially founded. The first director of the Institute was Dr P. W. Vorster who led the institute from its inauguration in 1949 until 1950 (ARC-VOPI, 2013c).

Various pieces of the farm were bought between 1953 and 1959, with the last 310 hectares of land acquired in 1964. These 310 hectares of land were bought for the arable soil that formed part of the land used by the Department of Agriculture for variety control. The Transvaal Region was allocated 193 hectares of this land for use as pasture (ARC-VOPI, 2013c). The institute was then known as the Horticultural Research Station, Pretoria. Only five hectares of the land was cultivated at the time. The rest of the land was veld that had to be cleared of bush and levelled. Vegetable research and the evaluation of seed samples, which were the responsibility of the Division of Horticulture and thus the responsibility of the research station, were continued on the five hectares of land (ARC-VOPI, 2013c).

⁴ The original Roodeplaat farm belonged to Phillip Carel Minnaar who obtained the title deed of the farm from the Zuid-Afrikaanse Republiek on 19 July 1859

There was little fixed and movable capital on the farm at the time. The only capital available comprised an old house, prefabricated military barracks erected by the personnel, and a pickup vehicle (Studebaker). The barracks served as offices, stores and farm buildings, while the vehicle was used for transportation on the farm as well as for the transportation of personnel to and from Pretoria. Irrigation water was obtained from the communal irrigation furrow, shared with six other farmers in the vicinity (ARC-VOPI, 2013c).

5.2.2 The development of the research station into a research institute

With the development and expansion of the research activities undertaken at the research station, the farm area became too small and necessitated the purchase of more land from surrounding farmers. At the time, the research station had established itself and was well known for the essential service it rendered to the agricultural industry. In 1962, under the leadership of Dr van der Merwe, a new building complex was built and the research station was renamed the Horticultural Research Institute. With the extension of the research station came further developments in the research that the station conducted. The newly-named institute was then made responsible for all vegetable and flower research in the Transvaal as well as all research on deciduous fruit and grapes in the summer rainfall areas. In 1964, Dr Strydom succeeded Dr van der Merwe as the director of the institute. Dr Strydom served as the director until 1970, after which Mr Strydom took over.

In the early 1970s, the research scope of the Horticulture Research Institute in Pretoria was further extended. The institute was given the national responsibility of conducting all vegetable and flower research in the Republic. At the time, an ornamental research programme was initiated in the Western Cape. This was at a time when the production of proteas and other fynbos plants as an industry developed and a demand developed for research into these indigenous plants. The early research on ornamental plants was done at Oude Bosch Forest Station on the Palmiet River near Kleinmond by Dr Vogts. The collection of protea and fynbos species was later moved to Tygerhoek Experimental Farm near Riviersonderend, and in the late 1980s it was again moved, this time to Elsenburg where it currently resides (Blomerus, 2014).

In the 1980s, the gradual process of establishing national commodity research institutes began. This was initiated by the amalgamation of the three departments involved in agriculture at the time into one department, which was called the Department of Agriculture and Fisheries (DAF)⁵

⁵ The three department were; the Department of Technical Services (DATS), the Department of Agricultural Economics and Marketing (DAEM) and the Department of Agricultural Credit and Lands (DACL)

(Roseboom, Pardey, Von Bach, Van Zyl, 1995). Research responsibilities were reorganised between the institutes. During 1981, the responsibility of potato research was transferred from the regional Agricultural Development Institute to the Horticultural Research Institute in Pretoria. The responsibility for research on deciduous fruits was transferred from the Horticulture Research Institute in Pretoria to the Fruit and Fruit Technology Research Institute in Stellenbosch, and the research on grapes was also transferred from the Horticulture Research Institute in Pretoria to the Viticulture and Oenological Research Institute (Nietvoorbij). These institutes, together with seven (and later eight) others were overseen by the Directorate of Agricultural Research (DAR) under the Department of Agricultural Technical Services⁶. At the time, the Horticulture Research Institute in Pretoria was under the leadership of Dr Heyns.

5.2.3 The establishment of the ARC

The 1980s were characterised by various political and economic instabilities in South Africa which led to various policy interventions and changes. The Agricultural sector was also affected. The structural imbalances between white commercial and black subsistence agriculture became even more apparent. At the same time there was great pressure to deregulate the sector; the process which, according to Vink, (1993) had begun in the 1970s in the financial sector. According to Kassier and Groenewald, (1992), by the start of the 1980s, distortionary influences on prices, together with a range of farm-specific policies, had created an agricultural sector that desperately needed to be reformed.

In 1984, the structure of the Department of Agriculture was reorganised. Two departments of agriculture were formed: the Department of Agricultural Development (DAD) and the Department of Agriculture (DOA). The reason was to segregate the services of the department for white and non-white agriculture (Roseboom *et al.*, 1995). This reorganisation left all public agricultural R&D agencies residing in a white own affairs department (Department of Agricultural Development, DAD) with no mandate to assist in the homeland areas. The Department of Agricultural Development (DAD) took over all the research activities of its predecessor department including the 11 institutes, the seven regional institutes, and all eight directorates (Roseboom *et al.*, 1995). The Horticulture Research Institute was then renamed to the Vegetable and Ornamental Plant Institute to prevent confusion with the Chief Directorate of Horticulture. The institute was under the leadership of Dr Meynhardt, who came into office in 1984.

⁶This was whilst DAF existed as a full government department, before the merger into one department DAF.

In 1987, two research centres were added to the 11 research institutes operating under the Department of Agricultural Development (DAD), namely the Grassland Research Centre and the Plant Biotechnology Research Centre, thereby increasing the number of research entities to 13 (Roseboom *et al.*, 1995). In the following year, however, the Botanical Research Institute was transferred to the Department of Environmental Affairs, thereby reducing the number of research entities administered by the Department of Agricultural Development (DAD) to 12 (Roseboom *et al.*, 1995).

A notable feature of the public R&D system at the time was a high degree of ineffectiveness of the regional institutes and the extension services. There were great efforts to privatise government services which until then were publicly provided services within the Department of Agricultural Development (DAD). These, according to Liebenberg (2013), provided the necessary impetus to establish the ARC.

The ARC was to be responsible for all agricultural research functions of the national government, including the mandate to serve farmers in the homeland areas. Most of the agricultural research activities of the Department of Agricultural Development (DAD), including those of the 12 institutes, except the regional institutes, were to be transferred to the ARC.

In 1990, legislation to establish the ARC titled the Agricultural Research Act, (Act 86 of 1990, hereafter referred to as the Act) came into effect. The main function of the ARC was to undertake and promote research, development and technology transfer⁷.

The administration of the Act was entrusted to the Minister of Agriculture. The first chairman of the council and first president of the ARC were appointed in December 1990 and the rest of the council members were appointed in April 1991. Section 8 (1) of the Act states that the ARC was to be managed by a council, which would, subject to the provisions of the Act, determine the policy and objectives of the ARC and exercise general control over the performance of its functions, the exercise of its powers and the execution of its duties. The council would, thus, direct and influence the various research activities to be undertaken by the ARC institutes. To prevent duplication of functions of the ARC with those of other organisations, however, Section

⁷ See the Agricultural Research Act 86 of 1990 for other functions of the ARC Agricultural Research Council

8 (2) of the Act states that decisions taken by the council would from time-to-time be reserved for the consent of the Minister of Agriculture.

In February 1991, offices were rented in Schoeman Street, Pretoria, and occupied, signalling the start of the functioning of the ARC as a visible entity at policy level. At the operational level, the Department of Agricultural Development (DAD) carried out the functions of the ARC on an agency basis until 31 March 1992. This preparatory work done until 31 March 1992 eventually led to the transfer of the 12 research institutes of the Department of Agricultural Development (DAD) to the ARC (ARC-VOPI, 2013c).

At the time of transfer, some of the institutes underwent a name change and one of the institutes was closed: the Grassland Research Centre became the Roodeplaat Grassland Institute, the Directorate of Biometric and Datametric Services became the Agrimetrics Institute and the Plant Biotechnology Research was closed (Roseboom *et al.*, 1995).

The ARC initially operated under a policy of “Framework Autonomy” introduced in 1986 and funded on the basis of a baseline formula, and reported directly to parliament (Liebenberg, 2013). This gave the ARC a large degree of freedom in its operations under the guidance of institute-specific advisory panels which included industry-specific representation. In 1997, however, the funding mechanisms were reconfigured and consisted of a parliamentary grant for core funding and a competitively bid Innovation Fund, designed to direct research towards identified national imperatives (Liebenberg, 2013). All non-core income generated through contract research for government departments, industry and the private sector was considered external income and projects funded by this means were charged on a “full cost” basis. The organisation became exposed to severe budgetary cuts under the new competitive parliamentary grant system (Liebenberg, 2013). This greatly influenced the operations of the ARC. This new, business-like management style of the ARC was to be introduced into the institutes (Roseboom *et al.*, 1995).

During its development under the Department of Agriculture, the Vegetable and Ornamental Plant institute was fully funded by the government. However, after the institute was transferred to the ARC in 1992, it had to raise part of its budget from external sources. The target for external funding for the first four years was 30 percent. In 1997, however, this was adjusted such that 50 percent of the budget was to be sourced outside the parliamentary grant. The

financial constraints forced the institute to focus its research on the needs of the clients who make substantial contributions towards the research cost (ARC-VOPI, 2013c).

5.3 RESEARCH AND DEVELOPMENT

ARC-Roodeplaat as a research station and later as the horticulture institute conducted much research and established itself as one of the important research institutes in the country. It has focused on five key research areas over the years: i.e., Plant Breeding, Crop Science, Genetic Resource Conservation, Plant Protection and Biotechnology research. The following section discusses these key vegetable research focus areas of the institute over the years.

5.3.1 Vegetable breeding

The institute conducted various breeding programmes for a number of vegetable crops. The cultivars developed improved yields, were of better quality and resistant to various economically important diseases, among other traits. Some of the cultivars were registered for plant breeders' rights to earn royalties for the ARC. The vegetable crops bred were tomatoes, onions, sweet potatoes, cabbage, broccoli, cauliflower, green beans, green peas, dry peas, pumpkin, squash, bitter cucumbers, carrots, beetroot, chicory and potatoes. Table 5.1 shows the different years in which the breeding programmes of the various vegetable crops were initiated and terminated at the institute.

Table 5.1: Vegetable Breeding Programmes ARC-VOPI, 1949-2012

Research Area: Plant Breeding Programmes				
Vegetable Crops	1949-1969	1970-1979	1980-1991	1992-2012
ROOT CROPS				
Onion Breeding	Initiated			Ongoing
Sweet Potato Breeding	Initiated			Ongoing
Potato Breeding			Transferred to institute	Ongoing
Beetroot Breeding	Initiated		Terminated	
Carrot Breeding	Initiated		Terminated	
STEAM LEAF-CROPS				
Cabbage Breeding	Initiated		Terminated	
Broccoli Breeding	Initiated	Terminated		
Chicory Breeding			Initiated & Terminated	
FLOWER FRUIT-SEED CROPS				
Tomato Breeding	Initiated			Terminated
Dry Peas Breeding		Initiated	Terminated	
Pumpkin Breeding	Initiated		Terminated	
Green Peas Breeding	Initiated		Terminated	
Green Beans Breeding	Initiated		Terminated	
Cauliflower Breeding	Initiated		Terminated	
Squash Breeding			Initiated & Terminated	
Bitter Cucumber Breeding	Initiated	Terminated		

Source: Adapted from ARC-VOPI, 2013c

Root Crop Vegetable Breeding

Table 5.1 shows that all the root crop breeding programmes were initiated in the years 1949 to 1969 at the institute with the exception of the potato breeding programme. The potato breeding programme was transferred to the institute only in 1981 after it had been the responsibility of regional agricultural development institutes (ARC-VOPI, 2013c). Onion, sweet potato and carrot breeding were among the first breeding programmes to be initiated at the institute. The onion breeding programme was brought about to develop improved open pollinated short-day cultivars for the Transvaal region. However, crosses with intermediate-day onions were also made to incorporate other characteristics such as firmness, quality-retention and the ability to withstand handling (ARC-VOPI, 2013c).

The sweet potato breeding programme was mainly aimed at supplying producers in the industry with new plant material. Among the root crop breeding programmes that were conducted at the institute, beetroot and carrot breeding programmes have been terminated. Both breeding

programmes were terminated by the end of the 1980s. Onion breeding continued at the institute with test hybrids released to seed producing companies for evaluation in the early 2000s (ARC, 2013a). Sweet potato and potato breeding are also still ongoing at the institute.

Stem and Leafy Vegetable Crop Breeding

The breeding of stem and leafy vegetable crops was initiated in different years at the institute. Cabbage and broccoli breeding were initiated in the period 1949 to 1969, while the breeding of chicory was only introduced at the beginning of the 1980s. The aim of all three of the breeding programmes was to produce good quality yields. In the case of cabbage breeding, the aim was also to breed fine quality round heads (ARC-VOPI, 2013c).

All the stem and leafy crop breeding programmes have been terminated at the institute. Broccoli and chicory breeding programmes were among the shortest breeding programmes. Broccoli breeding was terminated in the early 1970s, a decade after it had been initiated. Chicory breeding was also undertaken for a short period, from the beginning of the 1980s until the end of the 1980s. Cabbage breeding was also terminated at the end of the 1980s.

Flower-Fruit-Seed Vegetable Crop Breeding

Most of the vegetable breeding at the institute was on flower, fruit and seed crops. These were tomatoes, dry peas, pumpkin, green peas, green beans, cauliflower, squash and bitter cucumber. The breeding programmes were aimed at developing cultivars with higher yields, improved quality and resistance against diseases (ARC-VOPI, 2013c).

More than 60 percent of those breeding programmes were initiated in the years 1949 to 1969, while dry peas and squash breeding were only introduced in the early 1970s and early 1980s respectively (ARC-VOPI, 2013c). In the late 1970s, the breeding of bitter cucumber was terminated and by the end of the 1980s, all the flower-fruit-seed vegetable crop breeding programmes, with the exception of tomato breeding, were terminated. Among these, only tomato breeding continued at the institute after the institute became part of the ARC (ARC) in 1992, although in recent years tomato breeding has also ceased.

5.3.2 Crop science research

Crop science research on vegetables at the institute has a long history and has coincided with plant breeding research since the inception of the institute in the late 1940s. Crop science research at the institute included cultivar evaluation, fertilisation, irrigation, chemical weed

control and plant production research as well as other physiological research on herbs and spices (ARC-VOPI, 2013c). Research has been conducted on various aspects of vegetable production since the foundation of the institute. Initially research was mainly confined to cultivar evaluation with some research on irrigation and spacing of specific vegetables (ARC-VOPI, 2013c). Over time, the research expanded and activities were intensified to cover all aspects of crop production. Crop science research was conducted on tomatoes, onions, potatoes, cauliflower, lettuce, sweet potatoes, pumpkin, green beans, cabbage, paprika and watermelon (ARC-VOPI, 2013c).

Cultivar evaluation received the most attention and results obtained from those evaluations were used to identify cultivars and breeding lines with the best yield, quality and disease resistance. Post-harvest research was also conducted at the institute, although this area of research was not a major focus (ARC-VOPI, 2013c). Research in this area was only done on carrots, sweet potatoes, chillies and melons. Researchers used the acquired knowledge and experience to advice farmers and other clients on the choice of cultivars with regard to climatic region and purpose of production (ARC-VOPI, 2013c).

With the incorporation of the institute into the ARC in the early 1990s, much of the research, including crop science research that covered a wide spectrum of vegetable crops, ceased. This was mainly caused by financial constraints which resulted from changes in the funding policy. This, among other challenges, led to a decrease in the research capacity at the institute from the 1990s into the 2000s. By 2012, crop science research was focused on the following commercial vegetables: potatoes, sweet potatoes, tomatoes, peppers, lettuce, onions, beetroot and cucumbers with recent additions including mustard spinach and Swiss chard (ARC-VOPI, 2014b).

5.3.3 Genetic resource conservation research

Another important research area in which the institute has been involved for a number of years has been genetic resource conservation. Vegetable plant material conservation began in the 1950s at the institute. The purpose was to conserve genetic resources and advanced lines for the various breeding programmes (ARC-VOPI, 2013c). The institute maintained cultivars to regularly supply breeder's seed for the production of certified seed by the vegetable seed industry.

The vegetable crop material conserved as seed include cultivars bred in South Africa, cultivars that have been adapted through local seed production over the years and landrace cultivars. Some of these landrace cultivars were introduced in the country by settlers centuries earlier, such as the Cape Market carrots and Caledon Globe onions (ARC-VOPI, 2013c). The plant material conserved also includes open pollinated cultivars listed in the South African plant variety journal. The potato germplasm also includes the National Cultivar Collection. These collections are kept *in vitro* to ensure that the plant supplied to laboratories for the production of planting material for the industries are disease-free and true to type (ARC-VOPI, 2013c).

The collection of the national assets of vegetables has continued to grow over the years with the addition of new plant material, such that by 2010 there were about 3 209 accessions maintained. In 2013 the commercial vegetable gene-bank held 54 accessions consisting of breeders' seed of 10 vegetable genera as well as seed from various tomato, onion and other vegetable breeding lines. In addition, the sweet potato gene-bank contained 560 accessions maintained in glasshouses (ARC-VOPI, 2014a). These consisted of 26 ARC sweet potato cultivars, breeding lines, imported cultivars and local varieties. The potato gene-bank, on the other hand, consisted of 2 300 accessions maintained *in vitro and in vivo*. This was made up of a combination of contract cultivars, sub-licensed cultivars, open cultivars, virus-free lines, breeding lines and public good material (ARC-VOPI, 2014a).

5.3.4 Plant protection research

Plant protection research also has a long history at the institute. Plant protection research consisted of plant pathology, entomology and virology. Plant pathology research began in 1951 and was conducted on crops such as tomatoes, cucumbers, onions, chicory and potatoes. In its early years, plant pathology research was concentrated on tomato diseases and only later in the 1970s did research expand to include other crops such as cucumbers. In the early 1980s, research expanded further and included onion, chicory and potato diseases (ARC-VOPI, 2013c).

Entomology research was initiated soon after plant pathology research, in 1956, and the focus was given to insects affecting fruits. Attention was also given to insects affecting tomatoes and potatoes. The focus on these vegetable crops was due to the occurrence of pests and diseases that affected these specific crops at the time. In 1963, virology research was initiated at the institute. Virology research was conducted on a number of vegetable crops including sweet

potatoes, tomatoes, cucurbit crops, onions, pepper, garlic, cassava and potatoes. The aim of virology research was to prevent diseases caused by viruses among these vegetable crops (ARC-VOPI, 2013c).

Plant protection research has since continued at the institute and is still undertaken. However, similar to crop science research, the scope of plant protection research has narrowed. The research is now focused on fungal diseases, insects, nematodes and viral diseases affecting potatoes and tomatoes. The plant protection division also conducts biotechnology research, but this kind of research is currently limited to a few crops (ARC-VOPI, 2014b).

5.3.5 Biotechnology research

Biotechnology research was initiated in the 1970s in the Transvaal region as a result of the need for rapid multiplication of vegetative material to supply virus-free material to industries (ARC-VOPI, 2013c). The forms of biotechnology research conducted were molecular biology, molecular marker and stress physiology. The growth of biotechnology research led to the establishment of the Plant Biotechnology Research Centre (PBRC) in 1987 which later, in 1992, was incorporated into the institute (ARC-VOPI, 2013c). By 1999, biotechnology research was conducted on various root and tuber crops such as cassava, potatoes, onions, sweet potatoes as well as other crops such as tomatoes, garlic, soybeans, cowpeas, tobacco and some ornamental plants (ARC-VOPI, 2013c). The scope of the research has narrowed in recent years and currently only covers potatoes and flowers (ARC-VOPI, 2014b).

5.4 RESOURCE-POOR AGRICULTURE

With the transfer of the institute to the ARC in 1992 came the mandate to service small-scale agriculture. Therefore, resource-poor agriculture was added to the institute's responsibilities. The institute allocated about 20 percent of its parliamentary grant towards this sector alone (ARC-VOPI, 2013c). This was apart from the general plant breeding and plant protection research which benefited the agricultural sector as a whole. The institute conducts research on indigenous and traditional vegetables, sweet potatoes and indigenous medicinal plants for this sector.

5.4.1 Indigenous vegetable research

The research conducted on indigenous plants at the institute focused on seed and leafy vegetables, cowpeas, Bambara groundnuts, pigeon peas as well as root and tuber vegetables. These indigenous vegetables were chosen because they are high in nutrients such as calcium, protein and provitamin A (ARC-VOPI, 2013c). The leafy vegetable crops include *Amaranthus spp* and *Cleome gynandra*. The tuber vegetables include *Plectranthus esculentus* (Livingstone potato) and *Solenostemon rotundifolius* (Hausa potato). Since very little was known about indigenous vegetables, the institute carried out research to understand their agronomic requirements, as many of these indigenous vegetables were consumed in rural communities. The varieties were collected locally and others were collected from Tanzania and Zimbabwe (ARC-VOPI, 2013c). By 1999, about 30 varieties of Amaranth were evaluated for taste and texture. From those, the best varieties were retained for agronomic evaluation and development at the institute. In addition, the institute carried out research into the cultivation methods suitable for use by resource-poor farmers as well as research that would increase yields and improve the quality of these vegetables. The research on *Amaranthus spp* and *Cleome gynandra* resulted in improved yields and quality of the harvestable crop of these plants to commercial and small-scale farmers (ARC-VOPI, 2013c).

The indigenous and traditional vegetable materials are also kept in the indigenous crop gene-bank at the institute. Cassava was among the crops added to the gene-bank as it had the potential of becoming an industrial crop and an important food crop. The institute kept approximately 300 accessions of this crop, including some resistant to the African Cassava Mosaic Virus (ACMV). The institute has sought to expand the gene-bank collection with important traditional and indigenous crops planted and consumed by local farmers. In 2013, the indigenous and traditional vegetable gene-bank consisted of 566 accessions of 63 indigenous and traditional vegetable genera. These were mostly leafy vegetables. About 353 of those accessions were maintained as seed, 178 accessions of three indigenous and traditional root crop genera were maintained *ex situ* in a glasshouse and 13 *Amaranthus spp* (Moringa) accessions were maintained as plants (ARC-VOPI, 2014a).

5.4.2 Sweet potato research

Much research on orange-fleshed sweet potatoes has been conducted at the institute for small-scale farmers since the institute became part of the ARC in the early 1990s. The institute's

research on orange-fleshed sweet potatoes was, however, initiated before then, in the 1980s, but it was mainly aimed at the frozen-food industry (ARC-VOPI, 2013c). The cultivars that were used generally had a low dry-matter content and poor stability. Research was thus focused on improving the dry-matter content and the stability of the cultivars. In 1996, the institute became part of the Southern African Root Crops Research Network (SARRNET), which focused on cassava and sweet potato research (ARC-VOPI, 2013c). As a result, in that year research on orange-fleshed sweet potatoes expanded at the institute. The research began with examining breeding lines that were used in the 1980s and choosing lines which had a high dry-matter content and acceptable shape for further evaluation. Other plant material was imported in subsequent years.

The cultivars that were selected were those that showed improved yields and quality and still had an acceptable taste. The cultivars had a sweet and dry taste which was preferred by the local African communities, and were rich in vitamin A, thus potentially alleviating vitamin A deficiencies (ARC-VOPI, 2013c).

Between 2000 and 2001, orange-fleshed sweet potato cultivars were distributed to primary nursery sites for the first time. The purpose of distributing to the primary nursery sites was to allow for easier access by farmers through wide distributions. Farmers were also offered training in cultivation and multiplication techniques at the sites. The research on orange-fleshed sweet potatoes has expanded with demonstration trials with new varieties conducted in community gardens and on farms. Community-based nurseries have also been established to supply cuttings for the expansion of production. Since 2000, the orange-fleshed sweet potato programme has expanded to distribute material to other countries in Southern Africa, such as Botswana, Lesotho, Namibia, Swaziland and Zimbabwe (ARC, 2013a).

5.4.3 Indigenous medicinal plants

Another important research area that the institute identified for small-scale agriculture is indigenous medicinal plants. Research on indigenous medicinal plants was initiated in the 1990s at the institute after it was found that about 70 percent of the local population still used indigenous medicinal plants. Conservation of indigenous medicinal plants was mainly carried out in Kwazulu-Natal but later similar research was conducted in Gauteng (ARC-VOPI, 2013c).

The institute, in collaboration with the Traditional Healers Association of Soshanguve, identified and collected 30 species of medicinal plants. The collection grew to 80 species and by 1999, 500 accessions of species with medicinal value were maintained (ARC-VOPI, 2013c). The institute could supply planting material of these medicinal plants to communities that cultivate them for traditional healers.

The research continued to grow at the institute in subsequent years. Different accessions of medicinal plants have been sourced from various areas in the country, including Kwazulu-Natal (KZN) and the Free State (FS). In 2009, 20 more accessions of medicinal plants were added to the medicinal gene-bank and in the period between 2009 and 2010, a medicinal plant nursery was established (ARC, 2013b). The nursery was to serve as a production model for communities to conserve scarce medicinal plants through propagation and cultivation. By 2010, the national assets of medicinal plants totalled 110 accessions (ARC-VOPI, 2014a).

5.5 CONCLUSION

The ARC-VOPI has undergone various changes since its establishment as a research station and later as a research institute. The scope of the research conducted at the institute has expanded over time as the institute developed. The mandate of the institute covers all vegetable crops in the country. This was evident when in the early years of its establishment the institute conducted breeding programmes on about 16 vegetable crops. However, by the end of the 1980s and into the early 1990s, 12 of the 16 vegetable breeding programmes were shut down. Similarly, crop science and plant pathology research also narrowed down to a few vegetable crops by the beginning of the 1990s.

Further changes in the research conducted at the institute took place when the institute became part of the ARC. These changes were brought about by changes in funding policies. Furthermore, the mandate given to the institute to service small-scale agriculture resulted in 20 percent of the parliamentary grant being dedicated to servicing that sector.

Currently, the research conducted at the institute comprises breeding programmes for potatoes, sweet potatoes and onions as well as crop science research on potatoes, sweet potatoes, tomatoes, peppers, lettuce, onions, beetroot, cucumbers, mustard spinach and Swiss chard. Plant protection research, on the other hand, is focused on fungal diseases, insects, nematodes

and viral diseases affecting potatoes and tomatoes. The institute also conducts research on indigenous and traditional vegetable crops, sweet potatoes and indigenous medicinal plants for the small-scale agricultural sector.

Research conducted for the small-scale agricultural sector has continued to grow since it was initiated at the institute, while research on commercial vegetables has declined. The addition of research on indigenous and traditional vegetables has provided the institute with an opportunity to pioneer research that had not been conducted previously in the country. Yet at the same time, the decline in research conducted on commercial vegetables is a concern since it is the institute's mandate to conduct research on commercial vegetable crops in the country. This shift in research-focus by the institute is creating a gap in commercial vegetable research that may not be filled.

CHAPTER 6

RESEARCH INVESTMENT HISTORY: ARC-VOPI

6.1 INTRODUCTION

In the previous chapter, the establishment and evolution of the Horticultural Research Institute (later to become ARC-VOPI) was described. It was explained how the institutional changes were accompanied by changes in the focus and scope of the research conducted at the institute. The mandate of the institute changed from focusing on all vegetables and flower research in the former Transvaal region, inclusive of deciduous fruit and grapes in the summer rainfall areas in 1962, to the national responsibility for vegetable and flower research alone in 1972. A decade later in 1981, the responsibility to conduct potato research was included in the mandate of the institute, and the responsibility for research on deciduous fruits and grapes was transferred to other research institutes. Further changes took place during the 1990s. These changes meant that the institute was to focus solely on vegetable and ornamental plant research.

In this chapter, expenditure at the institute by cost category and investments made at project levels between 1980 and 2012 are highlighted, including the trend in scientist capacity and educational attainment. The chapter also looks at the distribution of researchers across various research disciplines at the institute over the years. Information on this will serve as input data in the estimate of the rate of return to vegetable research in the following chapter.

6.2 EXPENDITURE BY COST CATEGORY

The financial database of the institute (ARC-VOPI, 2013d) over the period 1993 to 2012 showed that expenditure at the institute was grouped into three categories, namely operating, personnel and capital expenses. The main cost component over the years was expenditure on personnel. Personnel expenses included salaries, ARC medical fund contributions, vehicle allowance and pension fund contributions among others; the greatest portion of these being salaries. In 1993, personnel costs amounted to about R65 million in inflation-adjusted 2010 values, which was about 68 percent of the total expenditure in the three categories. About 69 percent of the personnel expenses was on salaries. The salary component excluded salaries paid to contract and temporary workers. After 1994, personnel expenses declined at the institute,

together with operating and capital expenses. However, the proportion of personnel expenses out of the total expenses increased. By 1997, about 73 percent of total expenses in the three cost categories was on personnel. This was about R45 million in 2010 inflation-adjusted terms. Operating expenses by then accounted for about 24 percent and the remaining three percent was capital expenses. This was about R14 million and R2 million on operating and capital expenses respectively. Operating expenses included costs that pertain to the day-to-day functioning of the institute, such as water and electricity, transport costs and other administration expenses.

Since 1997, personnel expenditure continued to decline such that by 2000, personnel expenses amounted to about R34 million, which was about 69 percent of the total spent. The salary component still accounted for the greatest percentage of personnel expenses, about 64 percent or R21 million in inflation-adjusted 2010 values.

Expenditure on temporary workers as a percentage of total personnel expenses increased over the period, from about 3 percent or R1.3 million in 1997 to about 4.5 percent or R1.5 million in 2000. This component of personnel expenses continued to grow to reach about 9.5 percent or R2.8 million in 2008. This was far greater than spending on contract workers, which accounted for only 1.2 percent or about R0.36 million of total personnel spending expenses in 2008.

In 2011, expenditure on temporary workers had declined to about 7.8 percent or R2.1 million of personnel expenditure, while expenditure on contract workers had increased to about 3.44 percent or R0.95 million. A year later, expenditure on temporary workers had increased to reach its highest level at 12.7 percent or about R3.9 million of personnel expenditure. Contract workers, on the other hand, accounted for about 4.5 percent or R1.3 million of total personnel expenditure. Overall, expenditure on personnel declined to about 62 percent in 2012, while operating expenses accounted for about 35 percent of the total spent at the institute. This was about R31 million and R17 million in inflation-adjusted 2010 values on personnel and operating expenses respectively in that year.

Given that the institute acquired most of its capital items while it was still operating under the Department of Agriculture and Technical Services, capital expenses were relatively small at the institute over the period under analysis. In addition, leasing of vehicles and equipment were treated as an operational expense which also explained the low spending on capital. At most,

capital expenses at the institute accounted for about 7 percent of the total spent in the three cost categories and this took place in 1994. This was equivalent to about R7.3 million in inflation-adjusted 2010 values. Since then, capital expenses fluctuated between 2 percent and 5 percent of total expenses over the period 1995 to 2012. This was a fluctuation of between R1.0 million and R3.5 million in inflation-adjusted 2010 values over that period. Capital expenses were mainly on the write-off (depreciation) of capital items, impairment of fixed assets and losses and gains made on the sale of property and other capital items.

6.3 EXPENDITURE TRENDS AT THE PROJECT LEVEL

The previous section gave an overview of expenditure at the broad institute level in terms of personnel, operating and capital cost categories. This section takes this a step further and looks at expenditure at the project levels at the institute.

6.3.1 Overview of expenditure trends at the project level

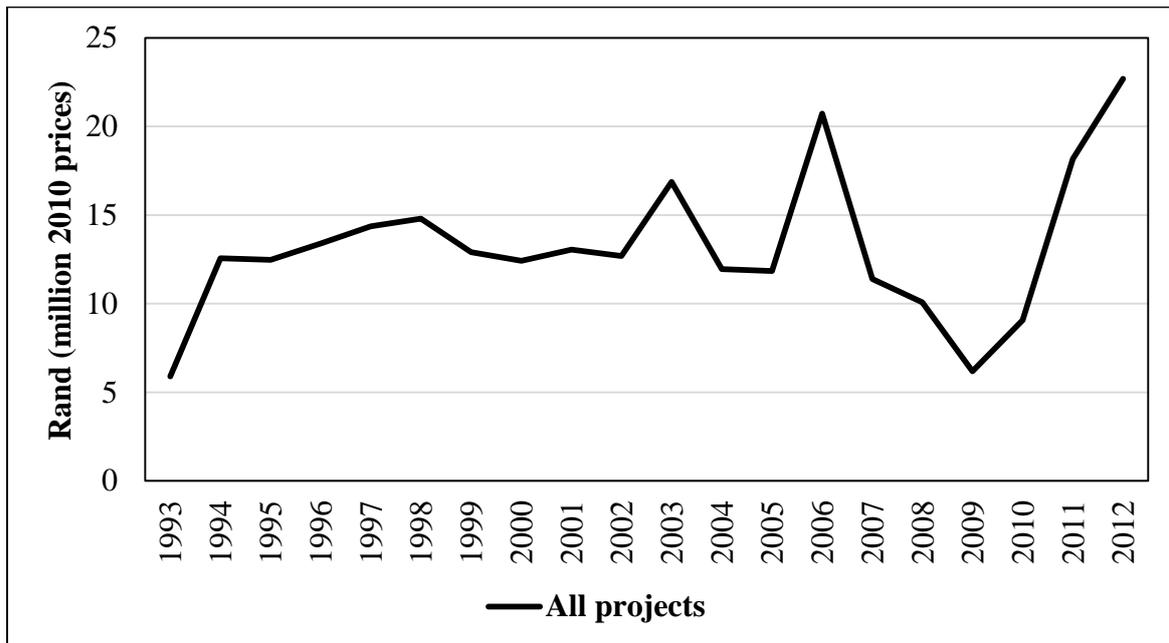
The institute invested a little over R36 million in inflation-adjusted 2010 values in potato, vegetable and ornamental plant projects in the 1980s. This was about 0.25 percent of the gross value of production of the potato, vegetable and ornamental plant industries (ARC-VOPI, 2013b). At that time, about 63 percent of all the projects were vegetable research projects and the 33 percent of the projects were ornamental plant research projects. The majority of the projects conducted at the institute in the 1980s were research projects with a few extension and training projects. Extension and training at the institute were conducted through advisory services to various industries, technical publications and press information days.

The investment at the institute in vegetable and ornamental plant projects (research, extension and training) decreased substantially at the beginning of the 1990s. Expenditure on all vegetable and ornamental plant projects amounted to just about R6 million in 1993, in constant 2010 prices. The decline in investment in the early 1990s related to the structural and institutional changes that took place in the Department of Agriculture and at the institute at the time. Until 1992, the institute was fully funded by the Department of Agriculture. However, with the transfer of the institute to the ARC in 1992, the institute had to raise part of its budget from external sources which made it difficult for the institute to maintain the investment levels of the 1980s (ARC-VOPI, 2013a).

The share of expenditure on vegetable and ornamental plant projects was affected by this change. In 1993, about 78 percent of expenditure on all research, training and extension projects at the institute was on vegetables and only 13 percent was on ornamental plant projects (ARC-VOPI, 2013d). The remaining 9 percent was on various indigenous crops and traditional medicinal plant projects. When the institute became part of the ARC, it was given the mandate to service resource-poor agriculture and the institute consequently allocated part of its budget to research into indigenous crops and traditional medicinal plants that were important to this sector.

Figure 6.1 (PANEL A) shows the institute's expenditure on all vegetable, ornamental plant, indigenous, traditional and medicinal crop projects. This is expenditure in inflation-adjusted terms on all research, extension and training projects at the institute from 1993 to 2012. PANEL B on the other hand, shows the percentage of the expenditure shown in PANEL A among vegetable, ornamental plant, indigenous, traditional and medicinal crop projects.

PANEL A: Real Expenditure on all Projects



PANEL B: Proportion of real expenditure on projects

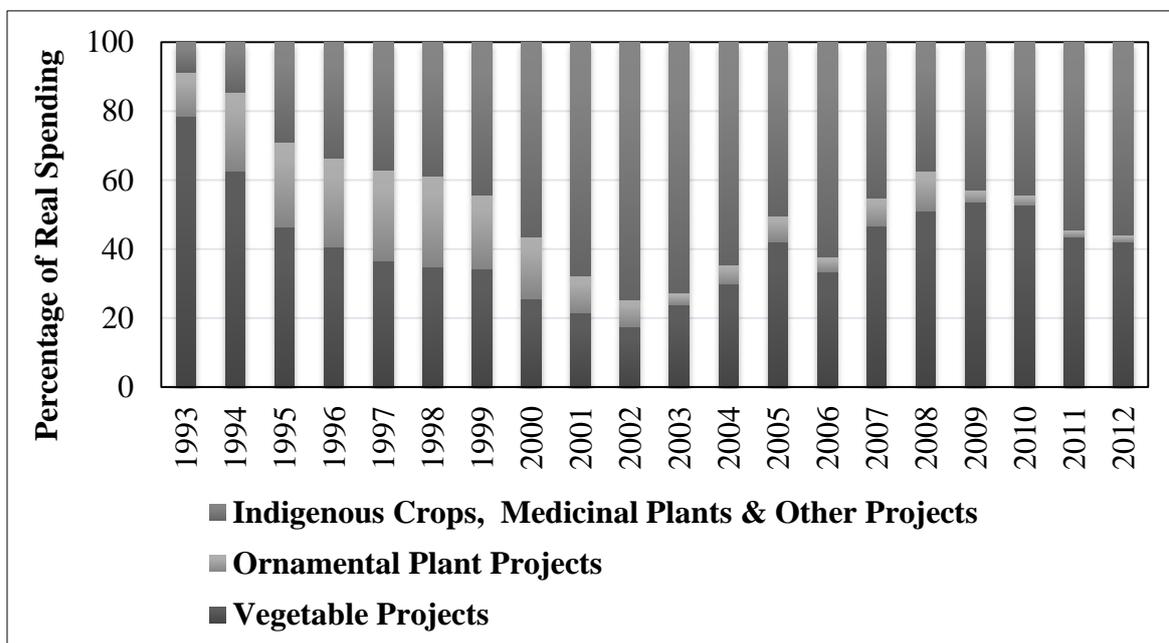


Figure 6.1: Total Expenditure on all Projects: 1993 to 2012

Source: Adapted from ARC-VOPI, 2013d

Real expenditure on all projects at the institute increased from around R6 million in 1993 to just over R12 million in 1999. Over that period, the share of expenditure on vegetable projects declined while expenditure on ornamental plant projects increased (ARC-VOPI, 2013d). The greatest increase in expenditure over that period was on indigenous crops and medicinal plant projects. Expenditure in this category of crops increased from 9 percent in 1993 to about 44 percent by the end of 1999. This was an almost five-fold increase in spending in this category

of crops in less than a decade. Expenditure on vegetable and ornamental plant projects decreased 2.3 and 1.6-fold respectively. This change in the proportion of expenditure across the different categories of crops reflected the fact that the institute was focusing on projects whose clients were willing to identify their needs and make substantial contributions towards the research cost (ARC-VOPI, 2013c).

The total spent on all projects increased from just over R12 million in 1999 to R16 million in 2003 and increased further to R20 million in 2006. About 73 percent of that increased expenditure in 2003 was on indigenous and traditional crop projects, 24 percent was on vegetable projects and the remaining 3 percent was on ornamental plant projects (ARC-VOPI, 2013d). By 2006, however, the proportion of money spent on indigenous and traditional crop projects had decreased to about 62 percent and the proportion spent on vegetable projects had increased to about 33 percent. The increase in expenditure on vegetable projects was in potato, sweet potato and onion projects.

The years following 2006 saw a significant decrease in expenditure on all projects at the institute: from about R20 million in 2006 to about R9 million in 2010. This, however, changed significantly after 2010. Expenditure on all projects at the institute increased to reach R18 million in 2011 and R22 million in 2012 (ARC-VOPI, 2013d). This increase in expenditure on all projects was stimulated by an increase in the parliamentary grants issued. Specifically in 2012, the ARC received funding from the National Treasury for economic competitiveness and support packages; and, in addition, other contracts were signed with the Department of Rural Development and Land Affairs which contributed to the ARC's increased parliamentary grant and external income (ARC, 2013c). This in turn led to a higher parliamentary grant to the institutes of the ARC.

The expenditure pattern among all the projects remained the same with indigenous and traditional crops accounting for the highest share, although the relative proportion had decreased slightly after 2006. By 2012, expenditure on indigenous crops and medicinal plants projects accounted for about 56 percent of the total spent at the institute, vegetable projects accounted for about 42 percent and ornamental plant projects accounted for only 2 percent.

6.3.2 Expenditure on vegetable and ornamental plant research

The previous section highlighted expenditure on all vegetable, ornamental plant, indigenous and traditional crop projects at the institute. These were a combination of research, training and extension projects at the institute. In this section, the share of vegetable and ornamental plant research projects are discussed to determine what the trend was in this category of projects at the institute.

The institute invested about R15 million in vegetable research in the early 1980s. This was for research into various root, stem and leafy vegetables as well as flower-fruit-seed vegetable crops (ARC-VOPI, 2013a). The research included breeding, crop science, plant protection and genetic resource conservation. By the mid-1980s, the investment in vegetable research had increased to about R26 million in inflation-adjusted 2010 values. This was due to the increase in the number of vegetable research projects undertaken at the institute in the mid-1980s and the late 1980s (ARC-VOPI, 2013b). However, this changed in the 1990s.

From the total expenditure on all projects at the institute, the proportion spent on vegetable and ornamental plant research declined considerably between 1993 and 2012. Figure 6.2 shows the percentage share of expenditure on vegetable (including potato) and ornamental plant research to expenditure on all projects at the institute from 1993 to 2012. In 1993, the combined share of expenditure on vegetable and ornamental plant research was about 87 percent of the total spent on all projects at the institute. This was about R5 million of the R6 million spent on all projects in that year (ARC-VOPI, 2013d). About R4 million was spent on vegetable research and the remaining R1 million was spent on ornamental plant research.

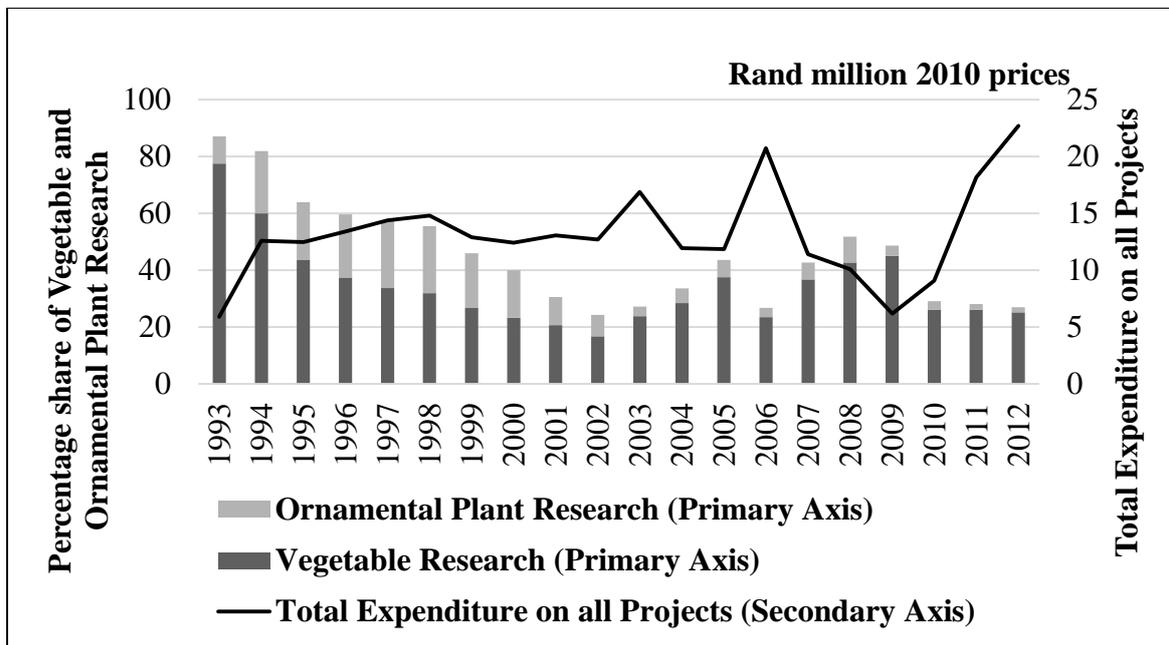


Figure 6.2: Percentage Share of Vegetable and Ornamental Plant Research of the Total Spent on all Projects, 1993-2012

Source: Adapted from ARC-VOPI, 2013d

The total spent on all projects increased slightly to R8 million by 1997 but decreased to about R6 million in 1999. The percentage share of expenditure on vegetable and ornamental plant research decreased over that period. Investment in vegetable research declined from about R4.8 million in 1997 to about R3.4 million in 1999 and ornamental plant research declined from about R3.4 million in 1997 to about R2.4 million in 1999 (ARC-VOPI, 2013d). By that time, the combined percentage share of expenditure on vegetable and ornamental plant research had decreased to 46 percent, i.e. 27 percent and 19 percent for vegetable and ornamental plant research respectively. This was a decrease on average of about 2.4 percent per year for the six-year period of 1993 to 1999. The remaining 54 percent spent in 1999 was on research into indigenous crops and medicinal plants as well as on extension and training activities on sweet potato, indigenous and traditional medicinal crops (ARC-VOPI, 2013d).

There were slight sporadic increases in the proportion of expenditure on research, particularly vegetable research, between 2000 and 2010, although the amount invested declined as Figure 6.2 shows. In 2005, for example, expenditure on vegetable research accounted for about 37 percent or about R4.4 million of the total spent; in 2008 it accounted for about 43 percent but in Rand value it had declined to about R4.2 million (ARC-VOPI, 2013d). By 2009, investment in vegetable research had increased slightly to about 45 percent but had declined in Rand value

to about R2.7 million, indicating that the total amount invested in projects at the institute was declining over that period.

The share of ornamental plant research, on the other hand, continued to decrease even in the period of 2000 to 2010. Its share reached a low of 3 percent in 2006 or about R0.68 million, after which it improved slightly in 2008 to account for 9 percent or about R0.92 million of the total spent (ARC-VOPI, 2013d). By 2012, the combined share of vegetable and ornamental plant research had decreased to about 27 percent. However, the amount spent on vegetable research had actually increased to about 25 percent or R5.7 million in inflation-adjusted 2010 values. This left about 2 percent or R0.41 million for ornamental plant research out of the total spent on all projects (ARC-VOPI, 2013d).

6.4 SOURCES OF INCOME

Under the Department of Agriculture and Technical Service, the institute was almost fully funded by the department. Other sources of funding came from the various industries, such as the potato board, the vegetable industry, flower industry as well as various other marketing boards. The funds from these non-government sources were mostly driven by specific needs or demands of the industries at a particular time. For example, in the 1980s funding was made available to the institute by the vegetable industry to undertake research when hormonal herbicides allegedly damaged vegetable crops in the Thala Valley and elsewhere (ARC-VOPI, 2013b).

With the establishment of the ARC in 1992, however, efforts to diversify the funding base of all the institutes began (Roseboom *et al.*, 1995). The Council embarked upon a more aggressive cost recovery program by introducing a “user pay principle”. This was to induce a stronger client orientation than was hitherto the case (Roseboom *et al.*, 1995). This meant that the institute had to raise part of its budget from external sources. The target for external funding for the first four years, (1992-1995) was 30 percent (ARC-VOPI, 2013c).

Figure 6.3 shows the sources of income at the institute for the period 1993 to 2012. From the figure, the declining share of the parliamentary grant and the subsequent increase in the share of external income as a result of the efforts to diversify the funding base of the institute can be seen. The share of the parliamentary grant as a source of income decreased from about 93

percent in 1993 to about 76 percent in 1997. In the following years, the proportion of the parliamentary grant decreased further and by 1999 accounted for about 68 percent of the total income at the institute.

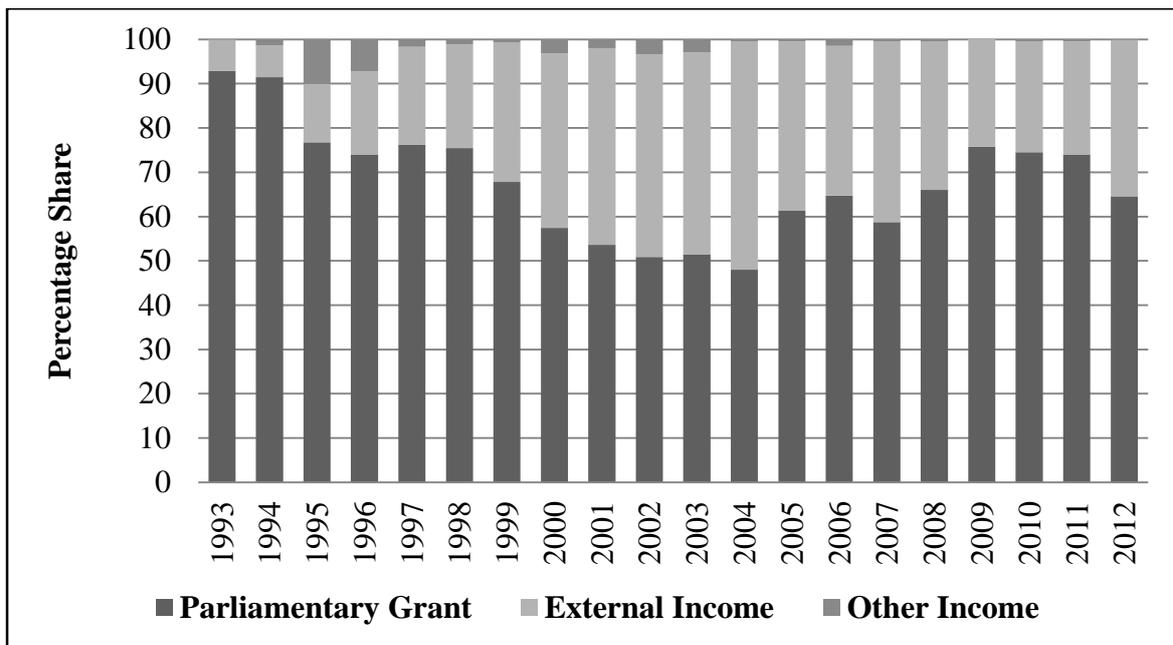


Figure 6.3: Sources of Income: 1993-2012

Source: Adapted from ARC-VOPI, 2013d

In 1997/98, competitive bidding with other science councils for parliamentary grants was introduced (Liebenberg, Beintema & Kirsten, 2004). This meant that the ARC had to compete with other science councils for government funding. Liebenberg (2013) stated that severe criticisms of the ARC exposed the organisation to budgetary cuts under the new competitive parliamentary grant system. These cuts were also experienced at the institute after 1998. Figure 6.3 shows that the percentage of the parliamentary grant as a source of income declined from about 75 percent in 1998 to about 57 percent in 2000 and further down to about 48 percent in 2004. According to Liebenberg (2013) prior to the formation of the ARC, a goal was established to reduce the target of government funding to 70 percent by 2000. The institute had exceeded this target by 13 percent in 2000.

In the years following 2004, the parliamentary grant increased, from a share of about 61 percent in 2005, to about 76 percent of the total income in 2009 (ARC-VOPI, 2013d). This increase in the share of the parliamentary grant was due to the relative decline in the share of external income and not as a result of an increase in the amount of the parliamentary grant issued to the institute. By 2012, the share of the grant had declined to about 65 percent of the total income

as a result of the relative increase in the external income generated by the institute (ARC-VOPI, 2013d).

6.4.1 Non-government funding

External income at the institute was generated through rendering advisory services, diagnostic services, support services, personnel service and research services to the industry over the years as well as through the sale of farm products and research products. External income as a source of income at the institute remained relatively small given that the institute was primarily funded by the state: Figure 6.3 shows this.

With the establishment of the ARC, specific targets for external funding as a source of income were set. The target for external funding for the first four years was 30 percent. In 1993, the share of external income was about 7 percent of the total funding. There was a slight improvement in the share of external income generated in the following years and by 1995 external income accounted for about 13 percent of the total income (ARC-VOPI, 2013d).

In 1993, about 75 percent of the external income was from personnel services such as telecommunication, rent received, municipal services, and personnel transport, followed by income from research services which accounted for about 16 percent. In 1995, the share of research services as a source of income accounted for about 69 percent, advice services accounted for about 13 percent, while the sale of research material accounted for about 11 percent of the total external income. The remaining share of the income was generated through personnel services (ARC-VOPI, 2013d). By 2000, the share of income generated through various research services had decreased to about 59 percent. The share of income generated through the sale of research material increased to about 26 percent by 2000, with the remaining share of the income generated from advisory services, personnel services and diagnostic services.

The share of income generated through various research services increased after the year 2000 to account for about 80 percent of the total external income in 2005 (ARC-VOPI, 2013d). The sale of research material in that year contributed about 9 percent of the total external income and personnel services and advisory services each accounted for about 5 percent of the total external income. The contribution of advisory services to external income increased to reach about 18 percent in 2011 and about 33 percent in 2012. Personnel services as a source of income also increased and reached about 11 percent in 2011, but then decreased a year later to about 9

percent. Research services still accounted for the highest share of external income in 2012, although its share had decreased to about 54 percent of the total income (ARC-VOPI, 2013d).

6.5 SCIENTIST TRENDS

The competence of a research institute to conduct research is influenced by two main factors i.e. the availability of funds and the availability of scientists to conduct the research. Any constraint in the availability of either one of these results in research output that is lower than what could be potentially achieved by the institute. In this section, an evaluation of the trend in the researchers at ARC-VOPI from 1980 to 2012 is presented. This is done by looking at the educational attainment of the researchers and the spread of researchers across the various research disciplines at the institute.

6.5.1 Scientists trend and qualifications⁸

The Horticulture Research Institute was given the national responsibility for vegetable and flower research in 1972. At the time, the institute employed a total of 30 researchers with PhD, MSc and BSc qualifications (Liebenberg, 2013). The highest proportion of researchers had MSc qualifications, (45 percent) followed by 33 percent qualified with BSc and about 22 percent with PhD qualifications. There was a slight increase in the number of researchers with a BSc qualification in the 1970s and by the end of the decade, the total number of researchers at the institute had increased to only 32 (Liebenberg, 2013). This changed in the 1980s, when there was a 25 percent increase in the total number of researchers employed at the institute. This followed from the transfer of potato research from the Transvaal region (the regional institute) to the Horticulture Research Institute as well as the reorganisation of the other horticultural institutes that took place at the time, such as the transfer of the responsibility of research on deciduous fruits and grapes from the Horticulture Research Institute to the Fruit and Fruit Technology Research Institute and the Viticulture and Oenological Research Institute respectively (Roseboom *et al.*, 1995).

At the beginning of the 1980s, there was a significant increase in BSc-qualified researchers. By mid-1980 the number of BSc-qualified researchers had almost doubled the 1979 figure (from 12.5 in 1979 to 24 in mid-1980s), while the number of MSc and PhD qualified researchers both

⁸ This section only focuses on BSc, MSc and PhD qualifications

decreased from 13.5 to 12 and from 6 to 5 researchers respectively. By the end of the decade, however, the number of BSc-qualified researchers had declined and was almost equal to the 1980 number: see Figure 6.4. The MSc- and PhD-qualified researchers, on the other hand, had both increased such that the number of researchers at the end of the 1980s totalled 40 and was higher than the number of researchers at the end of the previous decade (which had stood at 32).

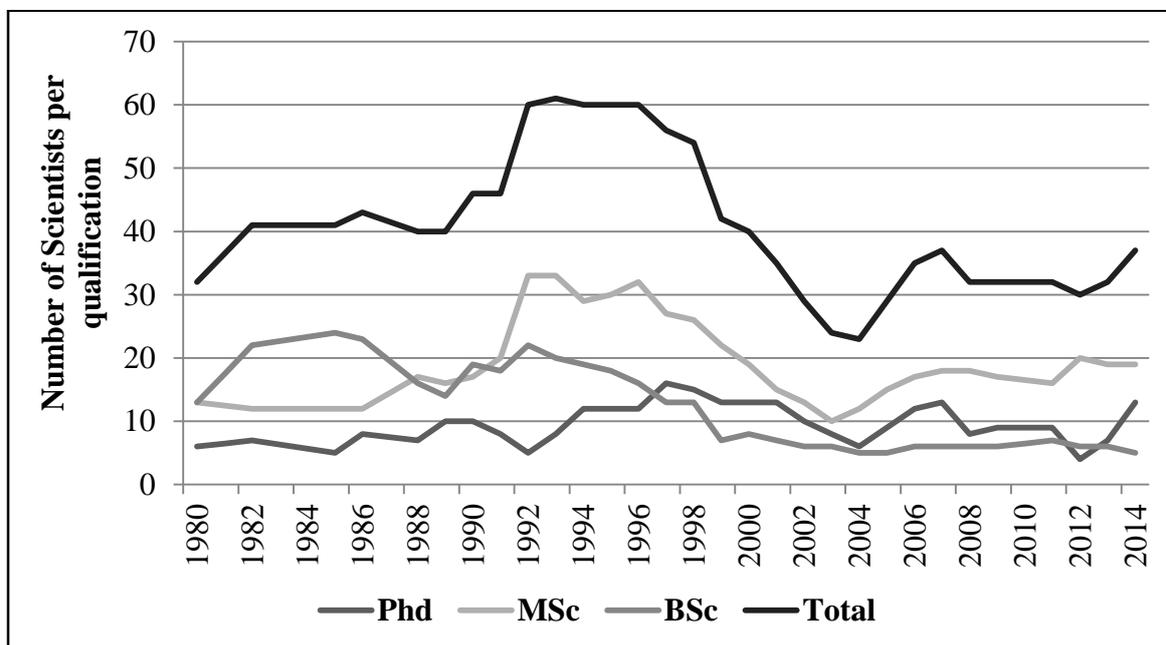


Figure 6.4: ARC-VOPI Scientists Trend and Qualifications, 1980-2013

Source: Liebenberg (2013)

Therefore, the research capacity of the institute at the beginning of the 1990s was much higher than it had been in the previous two decades (1970s and 1980s). From Figure 6.4, it is seen that the trend in the total number of researchers increased in the 1980s to reach a peak in the 1990s and then decreased again until around 2004.

The increase in the number of researchers from the late 1980s until the mid-1990s was highest within the MSc-qualified staff and only showed a slight increase within the PhD-qualified staff. The number of researchers with BSc qualifications initially increased in the early 1990s (1992/1993), but decreased half way into the decade. The decline became more rapid and continued until the end of the 1990s. This coincided with the declining trend in scientist capacity in the whole of the ARC after 1996. Liebenberg (2013) attributes this decline to the response by researchers to voluntary retrenchment initiatives that were introduced to reduce the size of government. Similar to the rest of the ARC, the decline in researchers at the institute was higher among those with BSc qualifications than those with MSc and PhD qualifications.

The decrease in research capacity continued into the early 2000s. The total number of researchers in the year 2000 was 40 compared to 56 in 1997. About 19 of the 40 researchers held MSc qualifications, 13 held PhD qualifications and only 6 held BSc qualifications. By 2005, the number of researchers at the institute totalled 29. This changed, however, from 2006 such that by 2012 the total number of researchers had improved and stood at 35. This improvement was caused by an increase in the number of researchers qualified with MSc degrees. This group of researchers increased from 15 in 2005 to 20 in 2012. There was also a slight increase in BSc-qualified researchers that contributed to the total increase in 2012.

6.5.2 Research capacity by discipline

Chapter five highlighted the five key research areas which the institute focused on over the years. These were plant breeding, crop science, plant protection, biotechnology and genetic resource conservation research⁹. This section evaluates the research personnel who conducted research in those key research disciplines from 1992 to 2012.

Figure 6.5 shows the total number of researchers involved in the various research disciplines at the institute from 1992 to 2012. In 1992, there were about 100¹⁰ researchers conducting plant breeding, crop science, plant protection and biotechnology research at the institute (ARC-VOPI, 2012). The highest number of researchers among these (about 29 percent) was involved in plant biotechnology research. This was due to the incorporation of the Plant Biotechnology Research Centre (PBRC) in the institute in 1992, which resulted in the transfer of research personnel from the centre to the institute (ARC-VOPI, 2013c). This was followed by researchers conducting plant breeding research. The total number of researchers conducting plant breeding research in 1992 was 27 and this comprised vegetable breeding and ornamental plant breeding. Of these, 23 of the researchers conducted vegetable breeding (including potato breeding) and the remaining four researchers were involved in ornamental plant breeding (ARC-VOPI, 2012). Crop science and plant protection research had 21 and 23 researchers respectively in 1992. This was the research personnel that formed part of the institute previously and were simply transferred with the institute to form part of the ARC. The spread of the researchers in 1992 indicated that in its early years, as part the ARC, the institute had an almost even distribution in the number of researchers across all the research disciplines.

⁹ Genetic resource conservation is carried out by the plant breeding division, therefore the researchers conducting plant breeding research are also involved in genetic resource conservation

¹⁰ The number also includes researchers without a BSc, MSc or PhD qualification

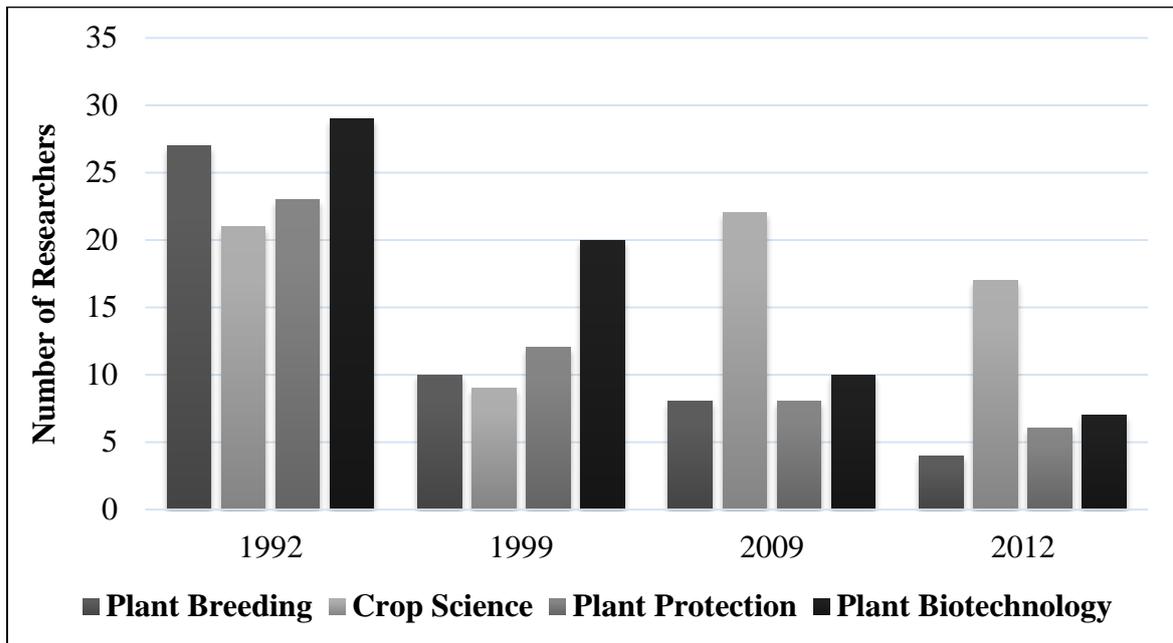


Figure 6.5: ARC-VOPI Research Capacity per Discipline, 1992-2012

Source: ARC-VOPI, 2012; ARC-VOPI, 2013c; ARC-VOPI 2014c

Notes: Number of researcher in head count

By 1999, almost a decade later, there had been a significant decrease in the number of researchers at the institute. The total number of researchers decreased from 100 in 1992 to about 51 in 1999. This was a decrease of almost 50 percent of the research capacity of the institute. The total number of researchers conducting plant breeding research decreased from 27 in 1992 to 10 in 1999, while the number of researchers conducting crop science research decreased from 21 in 1992 to 9 in 1999. Similarly, the number of researchers conducting plant protection research halved from about 23 in 1992 to about 12 in 1999. This decrease in research capacity at the institute and in the ARC as a whole was caused in part by a number of extraneous factors, as was the case with other Sub-Saharan countries, including the aging pool of researchers taking retirement and researchers being prompted to pursue better opportunities in universities and other private sector organisations (Beintema and Stads, 2011). Researchers conducting biotechnology research in 1999 were still greater in number than researchers conducting all other forms of research, although the number had also decreased.

There was only a slight decrease in the total number of researchers from 1999 to 2009: from 51 to 48. The number of researchers conducting crop science research, however, increased in that period, from 9 to 22, while the number of researchers conducting other forms of research continued to decrease. This reflected the relative importance of crop science as a research

discipline at the institute at the time compared to the other research disciplines. In 2012, the picture remained more or less the same, with more researchers conducting crop science research compared to other forms of research. The institute, however, lost about 14 researchers between 2009 and 2012, a period of about three years. This comprised five crop scientists, four plant breeders, three plant biotechnologists and two plant protectionists. By 2012, the total number of researchers at the institute had decreased almost 3-fold compared to 1992.

6.6 SUMMARY

The incorporation of the institute into the ARC brought about major changes at the institute. Firstly, the changes related to the investments made at the institute. The institute went from investing about R36 million on all its projects in the 1980s to about R6 million in 1993 and then doubled to about 12 million in 1999. It furthermore saw a significant increase to about R20 million in 2006 and finally up to R22 million in 2012. The increases in funding from the mid-2000 until 2012 were sporadic and resulted from additional funding to the whole ARC from government departments such as the National Treasury and the Department of Rural Development and Land Affairs which increased the organisation's parliamentary grant and external income.

The second change involved the distribution of funds across the various categories of crops being researched at the institute. The institute invested about 63 percent of its funds in vegetable projects, which included research, training and extension, and the remaining 33 percent on ornamental plant projects in the 1980s. In 1993, about 78 percent of expenditure was on vegetable projects, 13 percent was on ornamental plant projects and the remaining 9 percent was on indigenous and traditional plants. The inclusion of indigenous and traditional plants came about when the institute became part of the ARC in 1992 and was given the mandate to service small-scale agriculture. The share of expenditure in this category of crops increased at the institute while the share of vegetable and ornamental plant projects continued to decrease. These changes were such that by the year 2000 about 73 percent of expenditure on all projects at the institute was on indigenous and traditional crops, 24 percent was on vegetable projects and the remaining 3 percent was on ornamental plant projects. The proportion of expenditure among these three categories of crops changed slightly by 2012, although the share of indigenous and traditional crops remained higher (about 56 percent) than the share of vegetable and ornamental plant projects.

The third notable change at the institute since 1992 has been the source of income. Before the incorporation of the institute into the ARC in 1992, the institute was almost fully funded through the parliamentary grant from the state. After 1992, the institute had to generate part of its funding from external sources. The target for external funding for the first four years was 30 percent and by 1999 the target had increased to 50 percent. At that time, however, the institute generated only about 30 percent of its funding from external sources. The institute reached the target by 2004 and generated about 51 percent of its income from external sources, which were mainly through research services and the sale of research materials. The share of external funding decreased by 2012, however, such that external income accounted for about 35 percent of total income of the institute.

Lastly, the research capacity at the institute also changed. The institute went from employing about 100 scientists in the early 1990s to 48 in 2009 and 34 in 2012. This was a decrease of about 66 percent of the research capacity of the institute over those years. In addition, the spread of scientists across the various disciplines also changed: from an almost even distribution of scientists across the four disciplines in 1992 to more scientists conducting crop science research in 2012. This indicated the growth in the relative importance of crop science research at the institute compared to all other forms of research. This relative importance of crop science research at the institute was also seen in the previous chapter when the research focus of the institute shifted from less plant breeding and biotechnological research to more crop science research.

These changes that have taken place at the institute have had a significant impact on the performance of the institute and in particular on the type of projects that it undertakes. More specifically, variations in the extent of available funding and the source of income in recent years have forced the institute to focus on research projects that are in part privately funded by the institute's clients that have included relatively more indigenous and traditional plant projects and relatively less vegetable and ornamental plant projects to meet their client's research needs.

CHAPTER 7

ECONOMIC RATE OF RETURN TO VEGETABLE RESEARCH: 1980-2012

7.1 INTRODUCTION

For a number of years, ARC-VOPI has conducted vegetable research and has supplied various vegetable industries with research output, this has contributed to the growth of the vegetable industry. Much investment has been made over the years in the development of this research output. The benefits derived from the research have, however, not yet been quantified.

The previous chapter evaluated the investments that have been made in vegetable research and in other projects at the institute over the years. Through this, a series of vegetable research investment data over the period 1980 to 2012 was compiled which will be used in this chapter. The purpose of this chapter is to quantify the returns to vegetable research by estimating the Marginal Internal Rate of Return (MIRR) to public vegetable research investments for the years 1980 to 2012.

Using the series of vegetable research investment data, the rate of return to vegetable research is estimated by means of a production function approach with a second order polynomial lag structure. Before this is done, the data compilation and manipulation procedures are first discussed. This is followed by the analysis of the data and then the estimation of the marginal internal rate of return. The chapter ends with a discussion of the results and the conclusion.

7.2 DATA MANIPULATION

The study attempted to estimate the marginal internal rate of return to vegetable research conducted by the ARC-VOPI. The period covered in the study is from 1980 to 2012. The study only focuses on vegetable research conducted at the institute and does not include in private investments in vegetables research due to the challenge of obtaining data on private investments in vegetable research. By extension, the exclusion of private investments in vegetable research in the model would lead to an overestimate of the benefits accruing to ARC-VOPI investments.

Given the scope of commodities covered by the research projects at the institute for the period of 1992 to 2012, the study limits the vegetables included in the rate of return estimation to potatoes, onions, tomatoes and sweet potatoes. The motivation was that these were the only commercial vegetables in which the institute still conducted research. The other vegetables on which research is conducted at the institute are indigenous vegetables, the commercial production and statistics of which are unknown as they are not monitored in official statistics.

As mentioned previously, the institute formed part of the Department of Agriculture and Technical Services and was almost solely funded by the department until 1992 when it was transferred to the ARC. Research expenditures of the institute were recorded by the department, but little detail is available beyond the institute aggregate. As a result, the vegetable research expenditure was estimated using 2 methods for the pre-and-post 1992 period.

For the period 1980 to 1991, the research expenditure on vegetables was estimated as a proportion of total expenditure based on the number of vegetable projects conducted at the institute. This information was obtained from the institute's annual reports that were published in 1986 and 1988. The vegetable research series for the years 1992 to 2012 was calculated from the project-specific financial statements of ARC-VOPI available from its finance division. These financial statements were for all the projects conducted at the institute from 1992 to 2012. The project's financial statements included all the operational expenses incurred during the research period, the salaries of the personnel involved in the research projects as well as all expenditure on capital items that were required for the various projects such as laboratory equipment and apparatus. Once the vegetable research expenditure data were compiled, the series was converted to real 2010 values by using the Gross Domestic Product (GDP) deflator. This was the seasonally--adjusted GDP deflator for the period 1980 to 2012, obtained from the Organisation of Economic Co-operation and Development (OECD, 2014).

The area planted data was obtained from the commercial census of agriculture for the years 1980, 1993, 2002 and 2007 published by Stats SA (Central Statistical Services, 1980-2007). This source was used as it is the only source of data on the area planted to vegetables in the country. Other publications including the Abstract of Agricultural Statistics that is published by DAFF, do not capture the area planted to vegetables data. The inter census nodes were estimated by trend extrapolation. The Commercial Census of Agriculture for 2012, had not yet been published, therefore the series for 2012 was estimated based on the 2007 Census. The

estimate was obtained by assuming a 5 percent increase of the area planted to vegetables between 2007 and 2012. This was based on the 2002 and 2007 Census of Commercial Agriculture reports, which showed that there was a combined total of about a 5 percent annual increase in the production of potatoes, tomatoes, onions and sweet potatoes between the years 2002 and 2007. In addition, the census reports showed that there was a combined increase of about 8 percent in the area planted to these 4 vegetable crops between 2002 and 2007. Therefore, a 5 percent increase was assumed as it was fairly close to the previous period's growth in production and area planted.

Weather data was obtained from the South African Weather Service (South African Weather Service, 2013). The series is based on annual rainfall from 1980 to 2012 in the districts and towns in all the provinces where potatoes, onions, tomatoes and sweet potatoes are produced. The monthly rainfall data was used to compile the annual average rainfall for each district and town per province. The annual averages of the districts and towns were then used to compile the provincial average rainfall. These were in turn used to compile the national weather index for each year from 1980 to 2012. The national index was compiled by selecting a base year– 2010– and setting the weather variable in that year at 100. The indices for the other years– 1980 to 2012– were then obtained by measuring each year's deviation from the base year rainfall.

The vegetable production data was obtained from the Abstract of Agricultural Statistics, published annually by the Department of Agriculture, Forestry and Fisheries (DAFF, 1980-2012). This is data on the national annual production of potatoes, sweet potatoes, onions and tomatoes. The Abstract of Agricultural Statistics, published in 1998, was used to obtain vegetable production data for the years 1980 to 1996. For the years 1997 to 2003, the vegetable production data was obtained from the 2005 publication of the Abstract of Agricultural Statistics and the production data for the remaining years– 2004 to 2012– was obtained from the 2013 publication of the Abstract of Agricultural Statistics (DAFF, 1998, 2005 and 2013).

The vegetable price data obtained from the Abstract of Agricultural Statistics (1980-2012) used the average prices of the vegetables sold on 15 and later 17 major fresh produce markets in South Africa. The vegetable price data was adjusted to 2010 real prices using the GDP deflator as used in other studies, e.g. Liebenberg, (2013).

As mentioned previously, the study only focuses on public investments in vegetable research over the period 1980 to 2012 and does not include private investments in vegetable research

due to their confidential nature and hence the challenge of obtaining such data. However, given the important role that the private sector plays in vegetable research, a proxy for private investments in vegetable research for the period 1980 to 2013 was estimated. Following the study by Bervejillo, Alston and Tumber (2011), the number of private cultivars of potatoes, sweet potatoes, onions and tomatoes that were included each year in the South African Plant Variety Journal from 1980 to 2012 were used as a proxy for the stock of knowledge in year (t) from private sector vegetable research (PR_t). The approach used by Bervejillo *et al.*, (2011) in the wine industry in Uruguay was followed because it was found that the study attempted to account for the stock of knowledge generated through private research investments as those investments also contributed to productivity growth in the wine industry, whereas other studies did not account for private research investments, for instance as conducted by Townsend and Van Zyl, (1998).

7.3 DATA ANALYSIS AND RESULTS

The analysis of the study follows the commonly used Cobb-Douglas production function using ordinary least squares (OLS). Specifically, the variation in production is explained using the institute's vegetable research expenditure, the weather variable and the area planted to vegetables. In the initial model, a proxy for private investment in vegetable research was included following Bervejillo *et al.*, (2011). The private investment proxy was estimated as the number of private cultivars of potatoes, sweet potatoes, onions and tomatoes that were included each year in the South African Plant Variety Journal from 1980 to 2012. The proxy for private research investments gave results that were consistent with economic theory, but the variable was somehow found to be statistically insignificant in the model. Hence, the proxy for private investment in vegetable research was dropped from the final regression. Due to data limitations, conventional inputs were not included in the function.

7.3.1 The lag structure

The function that was used to determine the suitable lag structure and length was:

$$\ln Output_t = \ln \alpha_0 + \ln \alpha_1 AreaPlanted_t + \sum_{i=1}^n \beta_i \ln RD_{t-i} + \alpha_3 Weather_t + u_t \quad (7.1)$$

Where:

$\ln Output$ is the total production of potatoes, tomatoes, onions and sweet potatoes in tons

$\ln AreaPlanted$ is the total area planted to potatoes, tomatoes, onions and sweet potatoes

$\ln RD_{t-1}$ is real expenditure in public vegetable research

$Weather$ is the weather index; rainfall in millimetres in all the potato, tomato, onion and sweet potato producing areas in South Africa.

u_t is the error term in the model that captures all the variables that affect potato, tomato, onion and sweet potato production not included in the model

$\alpha_0 \dots \alpha_3$ are the coefficients to be estimated

β is the coefficients of the research variable at various lag lengths, and

n is the maximum lag of research that affects output.

The Almon polynomial lag structure was used to determine the appropriate lag length for the model. Various polynomial orders were tested; from the second order polynomial to the fourth order polynomial using various lags of the vegetable research variable. The lag lengths varied from 5 to 20 years. However longer lags (18 years and more) resulted in a model that was not statistically reliable.

Initially, the polynomial lag structure was estimated with no restrictions (near end, far end and both ends), but the coefficients of this unrestricted model changed signs frequently. This could not be justified with economic theory and therefore, restrictions had to be imposed on the model. Following Bischoff (1967), zero restrictions were then imposed on the function. Firstly, the lag structure was restricted at the near end as it was expected that the impact of vegetable research on vegetable production would have a lagged effect and not be experienced in the first year that the research investment was made. Still, the model gave results that were not economically reliable as the model indicated alternating positive and negative impacts of investment in vegetable research on vegetable production in successive years. Similar results were obtained when the model was restricted at the far end. Lastly, the model was restricted at both ends; the form that was initially proposed by Shirley Almon (Hall, 1967) and also used by Townsend and Van Zyl, (1998).

The restrictions were applied to various polynomial orders, beginning with a low polynomial of the second order with 5, 10-, 12- and 15-year lags. The polynomial was then increased to the third and fourth order with 5-, 10-, 12- and 15-year lags to compare with the second order polynomial. The second order polynomial model with a 15-year lag proved to be more reliable than the other models due to the t , F , Durbin-Watson and the adjusted R^2 values.

7.3.2 Diagnostic tests

The model generally resulted in statistically significant variables at a 5 and 10 percent level of significance. Other diagnostic tests were conducted to verify the reliability and consistency of the model. The unit root test was conducted and it was found that all the variables, with the exception of the weather and the proxy for private investment in vegetable research variables, were non-stationary, indicating that the mean, variance and covariance of the data change over time and the model suggested relationships that were spurious. This was addressed by differencing the vegetable production, public investment in vegetable research and the area planted to vegetables data taken in logarithm form.

The residuals of the model were tested for normality using the Jarque-Bera normality test. It was found that the residuals were normally distributed. Heteroscedasticity was also tested for, using the Autoregressive Conditional Heteroscedasticity (ARCH) test at first and second order lags. No Autoregressive Conditional Heteroscedasticity at first and second lag was detected in the model. This was expected given that the analysis of the study is about 33 years – a relatively long period.

Serial correlation was tested using the Breusch-Godfrey Serial Correlation LM test at second lag. Serial correlation was not detected in the model. Lastly, model specification was tested using the Ramsey Reset test. From this test, it was found that there was no model misspecification.

7.3.4 Interpretation of results

Table 7.1 shows the results of the function regressed. The table shows that all the variables included in the model were statistically significant. More specifically, the area planted to vegetables variable and the weather variable were found to be statistically significant at 5 percent level while the public investment in vegetable research variable and its lagged variables from the first year until the fifteenth year were found to be significant at 10 percent level. This indicated that the variables included in the model are important in explaining variations in vegetable production.

Table 7.1: Fifteen-year Vegetable Research Lag Model

Variable	Coefficient	S.e	t-stat
C	-0.075287	0.047383	-1.588924
LnArea	1.043497**	0.264458	3.94570
LnRD	0.00652*	0.00300	2.16991
LnRD(-1)	0.01222*	0.00563	2.16991
LnRD(-2)	0.01711*	0.00788	2.16991
LnRD(-3)	0.02118*	0.00976	2.16991
LnRD(-4)	0.02444*	0.01126	2.16991
LnRD(-5)	0.02689*	0.01239	2.16991
LnRD(-6)	0.02852*	0.01314	2.16991
LnRD(-7)	0.02933*	0.01352	2.16991
LnRD(-8)	0.02933*	0.01352	2.16991
LnRD(-9)	0.02852*	0.01314	2.16991
LnRD(-10)	0.02689*	0.01239	2.16991
LnRD(-11)	0.02444*	0.01126	2.16991
LnRD(-12)	0.02118*	0.00976	2.16991
LnRD(-13)	0.01711*	0.00788	2.16991
LnRD(-14)	0.01222*	0.00563	2.16991
LnRD(-15)	0.00652*	0.00300	2.16991
W	0.002663**	0.001018	2.616519
R-squared	0.561350		
Adjusted R-squared	0.460123		
Prob (F-statistic)	0.011280		
S.E. of regression	0.029925		
Sum squared residuals	0.011642		
Durbin Watson stat	1.881412		

Source: EViews output

Notes: *Statistically significant at a 10% level

**Statistically significant at a 5% level

Table 7.1 also shows that the t-statistics of the lagged public research variable were found to be the same. This was expected given that the study used a restricted lag structure to model public vegetable research investments. This was also found in the study by Townsend and Van Zyl, (1998) in the wine grape industry using a restricted lag distribution model.

The R-squared value suggests that about 56 percent of the variation in vegetable production can be explained by the variation in the area planted, the weather and the lagged public investment in vegetable research. Private investment in vegetable research expenditures and conventional inputs are important factors that affect vegetable production. These variables were not included in the model due to data limitations and given their importance to total vegetable production: their exclusion from the model would result in a relatively low R-squared value compared to what was found in other similar studies (Carter, 1999; Townsend and Van Zyl, 1998; Nieuwoudt and Nieuwoudt, 2004).

The probability of the F-statistic measures the joint significance of the variables included in the model in explaining vegetable production. Table 7.1 shows that the probability of the F-statistic is 0.011280 and significant as it is smaller than 0.05. This suggests that the null hypothesis of the F-test that the independent variables included in this model do not jointly influence vegetable production does not hold. Therefore, the weather variable, public investment in vegetable research and its lagged variables as well as the area planted to vegetables variable jointly affect vegetable production.

The signs of the coefficients of the independent variables were positive and thus indicated a positive relationship between the independent variables and the dependent variable, i.e. between the area planted and vegetable production, between the weather and vegetable production and between public investment in vegetable research and vegetable production. These signs of the coefficients of the independent variables were as expected and consistent with economic theory.

The positive relationship between the independent variables and the dependent variable suggests that increasing (decreasing) the area planted to vegetables by 1 percent, *ceteris paribus* would result in a 1.04 percent increase (decrease) in vegetable production. The change in the area planted affects vegetable production in the same year. The positive relationship also suggests that favourable weather has a positive impact on vegetable production and adverse weather has a negative impact on vegetable production, *ceteris paribus*. The changes in the weather affect vegetable production in the same year when the weather changes.

The effects of public investment in vegetable research on vegetable production are spread over a period of 15 years. Investment in vegetable research affects vegetable production positively in the current year with the maximum impact felt 7 and 8 years after the research investment was made. The immediate effect of vegetable research on vegetable production reflects the value of the direct impact of improving the quality of vegetable crops, as the institute is also involved in quality improvement research. The immediate impact of research on output was also found in the wine grape industry by Townsend and Van Zyl, (1998) also using a production function approach.

The coefficients of the lagged public vegetable research variable indicate the distribution of the benefits of vegetable research in the industry from year 0 (the year in which the research investment is made and the initial benefits of research are derived) until year 15 (the year in

which the research output becomes obsolete). The distribution of the lagged coefficients suggests that research generates increasing benefits to the industry until eight years after the research investment. After the eighth year, the benefits of vegetable research, although still positive, diminish until the fifteenth year after the research investment was made; where after the research output becomes obsolete and substituted by other better research outputs. This is shown in Figure 7.1.

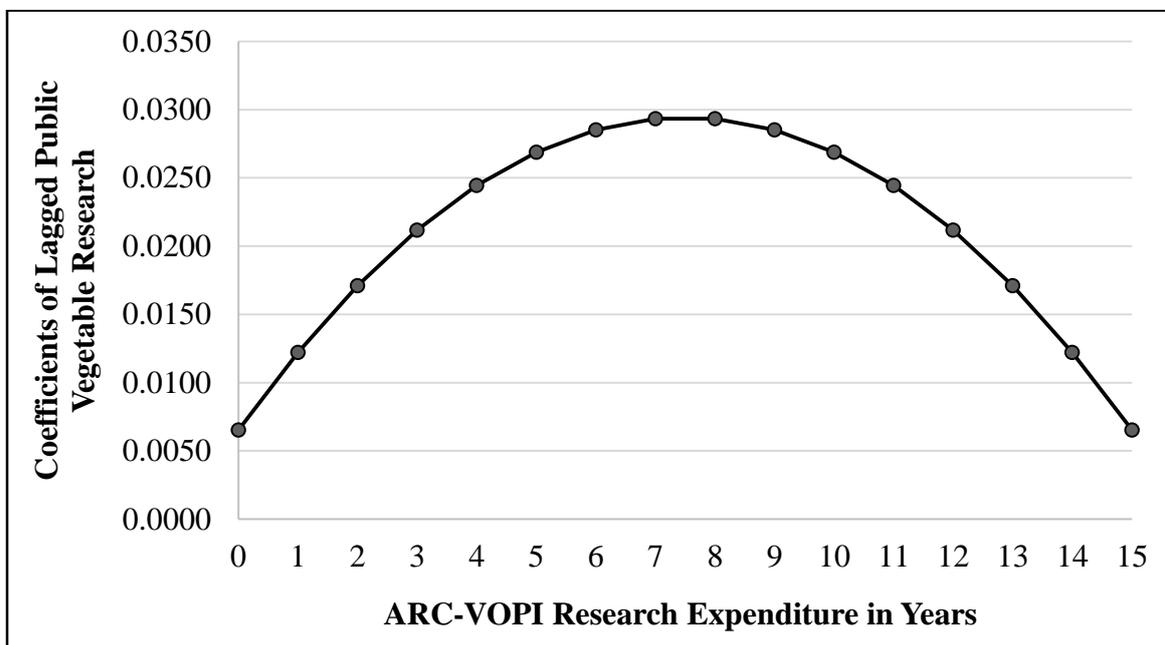


Figure 7.1: Lag Structure of Public Vegetable Research

Source: Own Calculation

The decline from the ninth year relates only to the research investment made in year 0. The research investment made in year 1 will have the same lag structure and so will peak in year 7 to 8 in Figure 7.1. This will maintain the research effect on output at a peak as the effects of the expenditure in year 0 are superseded by the research expenditure in year 1 (Townsend and Van Zyl, 1998).

7.4 ESTIMATING THE MARGINAL INTERNAL RATE OF RETURN

The first stage in estimating the rate of return to vegetable research investment using the production function approach involved estimating the coefficients of the lagged public research investment variables. This was done in section 7.3. The second stage entails estimating the Marginal Internal Rate of Return (MIRR) from the coefficients estimated in section 7.3.

The lag structure in the polynomial model identified the effect of changes in vegetable research investments on industry output *ceteris paribus*. The coefficients of the public vegetable research variable and its lagged variables are thus elasticities and are used to estimate the marginal internal rate of return to vegetable research as equation 7.2 shows:

$$\beta_i = \frac{\partial \ln YIELD_t}{\partial \ln RD_{t-i}} = \frac{\partial YIELD}{\partial RD_{t-i}} \cdot \frac{RD_{t-i}}{YIELD} \quad (7.2)$$

The rate of return to vegetable research was estimated in a 2-stage procedure following Thirtle and Bottomley (1988). The procedure involved firstly calculating the Value of Marginal Product (VMP) and then estimating the Marginal Internal Rate of Return (MIRR).

In estimating the value of marginal product, the geometric mean of vegetable production for the period 1980 to 2012 was calculated. In a similar manner, the geometric mean of vegetable research expenditure for the period 1980 to 2012 was calculated. These were calculated following equation 7.3 below:

$$\frac{\Delta OUTPUT_t}{\Delta RD_{t-i}} = \beta_i \frac{\overline{YIELD}}{\overline{RD_{t-i}}} \quad (7.3)$$

The next step in calculating the value of marginal product involved estimating the value of vegetable production for the period 1980 to 2012. This was done by taking the average prices of potatoes, tomatoes, sweet potatoes and onions over the period 1980 to 2012. These were real average prices of these vegetables sold on the fresh produce markets. These were in turn multiplied with vegetable production data to calculate the value of vegetable production for each year since 1980 to 2012.

Furthermore, the change in the value of vegetable production and the change in vegetable output had to be estimated. The change in the value of vegetable production was estimated by taking the difference between the average of the first five years (1980 to 1984) and the average of the last five years (2008 to 2012). The change in vegetable yield was calculated following a similar approach of taking the difference between the average vegetable production in the first five years (1980-1984) and the average vegetable yields in the last five years (2008-2012).

The mean vegetable production, the change in the value of vegetable production and the change in vegetable production were then multiplied with the elasticities of each of the lagged research

investment variables to calculate the value of marginal product for each of the 15 years of the research lag distribution following equation 7.4.

$$VMP_{t-i} = \frac{\Delta VALUE_t}{\Delta RD_{t-i}} = \beta_i \frac{\overline{YIELD}}{RD_{t-i}} \cdot \frac{\Delta VALUE_t}{\Delta YIELD} \quad (7.4)$$

Once estimated, the value of marginal product was used to estimate the rate of return to vegetable research. This was done by firstly calculating the discount rate (i). The discount rate was calculated based on the number of years of the lagged research variable, i.e. 15 years. This discount rate (i) was taken as the reciprocal of the lag length of the vegetable research variable, ($1/15$).

Equation 7.5 was then solved by making r the subject of the formula and thereby estimating the marginal internal rate of return to vegetable research.

$$\sum_{i=1}^n \frac{VMP_{t-i}}{(1+r)^i} - I = 0 \quad (7.5)$$

The results are shown in Table 7.2. The table shows the marginal internal rate of return to vegetable research for the period 1980 to 2012. The table also shows the aggregate rate of return found for horticultural research in South Africa for the period 1947 to 1991 as well as the rate of return found for sweet potato research at the crop level for the period 1952 to 1995.

Table 7.2: Rate of Return Studies in the Horticultural Sector of South Africa

Study Period	Method	Lag Model	Lag length (Years)	Rate of Return
Enterprise Level: Horticulture				
1947-1991	Profit Function	Perpetual Inventory Method Capital Stock	5 years	100 percent
Institute Level: Nietvoorbij (Wine Grapes)				
1987-1996	Production Function (Yield Model)	2 nd Degree Polynomial	7 years	40-60 percent
Institute Level: ARC-VOPI (Vegetables)*				
1980-2012	Production Function	2 nd Almon Degree Polynomial	15 years	39.68 percent
Crop Level: Sweet Potatoes				
1952-1995	Supply Response	2 nd Degree Polynomial	22 years with 3 year lead time	21 percent

Source: Thirtle *et al.*, (1998) and this study*

From Table 7.2, the marginal internal rate of return to vegetable research using the second order Almon Polynomial Distribution Lag structure was estimated at 39.68 percent. This is a positive and relatively high rate of return. The result suggests that for every R100 increase in vegetable research investment, the marginal returns to the vegetable industry is about R39. Studies evaluating the returns to vegetable research in other countries are scarce and as such comparisons of the findings in this study to international estimates are a challenge. Nonetheless, in the context of the local horticulture industry, the findings of this study compare well to other studies.

Table 7.2 shows that at the enterprise level, the rate of return was estimated to be about 100 percent for horticulture, which is much higher than the rate of return of 39.68 percent estimated in this study. The horticultural industry comprises both vegetables and fruits and therefore a relatively higher rate of return for horticultural research compared to the rate of return to vegetable research would be expected. At the institute level, however, the returns to vegetable research were in line with the returns estimated at Nietvoorbij for wine grapes. The rate of return to wine grapes was estimated to be between 40 and 60 percent. Table 7.2 also shows the returns to sweet potato research at the crop level. The returns were estimated to be about 21 percent which is relatively lower than the returns found in this study of about 39.68 percent. This was due to a number of factors, including the difference in the methods used to estimate the rates of returns and the difference in the level of aggregation in both analyses.

7.5 SUMMARY

Given the nature of the study and the available data, an ex-post production function approach was used to estimate the marginal internal rate of return to vegetable research at the institute level. After comparing various polynomial orders and lag structures, the study made use of a second order polynomial distribution with a lag of 15 years. The marginal internal rate of return to vegetable research was found to be about 39.68 percent, indicating that investment in vegetable research yields positive returns.

The benefits of vegetable research to the industry were found to reach a maximum at years 7 and 8, after which the benefits become less and less until after the 15th year when they are no longer felt. These research benefits however only relate to a single year's research investment. Research investments made in successive years also have the same distribution of research benefits which will keep the benefits of vegetable research high until such time when investments in vegetable research cease.

The rate of return of about 39.68 percent found in this study is high and, given that it is a marginal rate, indicates that there are still more potential benefits that could be derived by investing in vegetable research. This rate of return was found to be smaller than the returns estimated for horticulture at the enterprise level, but at the same time higher than the returns estimated for sweet potatoes at the crop level. Given that the crop level analysis included only one crop and the enterprise level analysis spanned all horticultural crops, the institute level analysis of vegetable research would be expected to yield returns that are between the crop level returns and the enterprise level returns as found in this study. At the institute level, the rate of return to vegetable research was found to be on par with Nietvoorbij returns in the wine grape industry of between 40 and 60 percent.

The findings of this study suggest that within the vegetable industry, the returns to research are relatively more at a higher level of aggregation than at a single crop level, such as sweet potatoes for instance. Therefore investments in vegetable research should be increased at the aggregate level for maximum returns to be attained from vegetable research in the industry.

CHAPTER 8

CONCLUSIONS

8.1 INTRODUCTION

The main objective of this study was to conduct an economic analysis of public vegetable research in South Africa for the period 1980 to 2012. The study specifically focused on vegetable research conducted by the country's vegetable and ornamental plant institute, ARC-VOPI. The institute has a long history in vegetable research since its establishment in 1949, focusing on 5 key research areas: plant breeding, crop science, plant protection, genetic resource conservation and biotechnology. The specific vegetable commodities which the institute has conducted research on over the years are potatoes, tomatoes, onions, sweet potatoes, cabbage, cauliflower, broccoli, green peas, dry peas, pumpkin, bitter cucurbits, muskmelon, carrots, beetroot and chicory.

The breeding and selection programmes were initiated in the early 1950s. The aim was to improve the adaptation and deficiencies of cultivars to supply the Directorate of Plant and Quality Control of the National Department of Agriculture with improved strains of breeder seed for the seed certification scheme. The strains were selected from old open pollinated cultivars. At the same time, crop science research focused on cultivar evaluation and some aspects of vegetable spacing and irrigation, but later expanded to cover all aspects of crop production.

Research on genetic resource conservation, initiated in 1950, focused on vegetable cultivars bred in South Africa, cultivars that were adapted through local seed production, and landrace cultivars which originated through natural selection and crossing between varieties introduced by settlers. The collections conserved vegetable material and furthermore supplied the breeding programmes. Plant protection research was initiated a year later, in 1951, and included entomology and virology. Plant protection research complemented plant breeding and genetic resource conservation research as it focused on introducing resistance against economically important diseases in the various vegetable crops.

Biotechnology research was the last form of research to be introduced at the institute. This was in 1992, although biotechnology research had begun in the 1970s in the region. Biotechnology

research came about as a result of the need for more rapid multiplication of vegetative material of newly bred cultivars together with the need of virologists to supply virus free material to various industries. This led to the development of the meristem culture at the institute, which after refinements resulted in the transition to tissue culture for all relevant crops. In 1987, molecular biology, molecular marker and stress physiology research were introduced and this marked the establishment of the Plant Biotechnology Research Centre (PBRC). The centre was later incorporated into ARC-VOPI in 1992 when the institute became part of the ARC.

Although ARC-VOPI conducted research on a wide range of vegetable commodities, at the beginning of 1990s, much of the research, particularly breeding research on commodities such as cabbage, broccoli, cauliflower, green beans, green peas, dry peas, bitter cucurbit, muskmelon, carrots, beetroot, chicory and tomatoes was terminated. The only commercial vegetable commodities on which breeding research has continued at the institute are potatoes, onions and sweet potatoes.

When the ARC was established in 1992, the institute was integrated into the organisation and was mandated to service small-scale agriculture. Therefore, in addition to the four commercial vegetables, the institute included research on seed and leafy indigenous vegetables such as *Amaranthus spp*, *Cleome gynandra*, *Plectranthus esculentus* (Livingstone potato), *Solenostemon rotundifolius* (Hausa potato) and cassava for small-scale agriculture because of their potential importance as food crops.

8.2 SUMMARY OF RESULTS

The study had three objectives in conducting an economic analysis of public vegetable research. These were to determine the contribution of ARC-VOPI to the breeding of vegetable cultivars over the period 1980 to 2012, to evaluate the trend in public investments in vegetable research at the institute over the period 1980 to 2012 and to estimate the economic rate of return to those vegetable research investments.

In determining the contribution of ARC-VOPI to the breeding of vegetable cultivars over the period 1980 to 2012, an analysis of plant breeders' rights of 14 vegetable crops was done. The vegetables were onions, potatoes, tomatoes, pepper, soy beans, dry beans, beans, garden beans, pumpkin, lettuce, garden peas, sweet potatoes carrots and cabbage. The analysis involved

determining the composition of the holders of plant breeders' rights for these vegetable crops. This was done by firstly looking at the country composition of holders of vegetable varieties in South Africa and then categorising those holders into private and public sector participants.

At the country level, it was found that the highest number of holders of plant breeders' rights for vegetable cultivars in South Africa were of South African origin. This was followed by holders from the Netherlands, the United States, Israel, Australia and Argentina. This indicated that overall, South Africa had been performing well and breeding the greatest number of vegetable cultivars registered for plant breeders' rights in the country. The analysis also indicated that globally (excluding South Africa), the Netherlands has contributed more vegetable cultivars registered for plant breeders' rights in South Africa than any other country.

At the sector level, it was found that the private sector (both domestic and foreign) bred more vegetable cultivars registered in South Africa than the public sector (both domestic and foreign). Specifically, within the private sector, foreign companies accounted for 41 percent of the vegetable varieties registered, while the domestic private sector accounted for 37 percent. The share of foreign companies was highest among potato, onion, cabbage, lettuce and garden pea cultivars and these were mainly Netherlands-- and USA--based companies. The share of local companies was highest in soybean, pepper, pumpkin, garden bean, tomato and dry bean cultivars. The share of local companies was especially high in both genetically modified (GMO) and conventional soybean cultivars. These local companies were Link Seed, Pannar (Pty) Ltd, Hygrotech, Plennegy, Pro-Seed, Seedcor, Sakata, Starke Ayres and Premier.

The contribution of the public sector was relatively low. Overall, public entities accounted for 17 percent of all the registered vegetable cultivars. This included both domestic and foreign public research organisations. The domestic public sector was represented by ARC-VOPI, ARC-GCI and Cedara Agricultural Research Station.

The ARC was involved in the breeding of four of the 14 selected vegetable crops. These were in sweet potato, conventional soybean, dry bean and potato cultivars. Within potatoes and sweet potatoes, the ARC was represented by ARC-VOPI and within soybeans and dry beans, the ARC was represented by ARC-GCI.

ARC-GCI accounted for 30 percent of the conventional soybean varieties and 37 percent of the dry bean cultivars. This 37 percent share in dry bean cultivars represented the total contribution

of the public sector to dry bean cultivars; whereas in soybean cultivars, Cedara Agricultural Research Station also contributed. Cedara Agricultural Research Station accounted for 4 percent of the total conventional soybean varieties.

ARC-VOPI, on the other hand, held all of the varietal right issued for sweet potatoes. There was no other organisation (public or private) which registered sweet potato cultivars. This could be because the industry is relatively small and has also generally remained small compared to other vegetable industries.

With potato cultivars, both domestic and foreign public research institutes played a role. ARC-VOPI accounted for 19 percent of the varietal rights issued, while foreign research institutes accounted for 10 percent. These were Caithness Potato Breeders in London and the Centre for Potato Research in Israel. There was only one foreign university that was involved in the breeding of potatoes and it accounted for just 1 percent of the potato cultivars registered.

The plant breeders' rights analysis revealed that the breeding of vegetable cultivars by the public sector was relatively low compared to breeding by the private sector. Specifically, ARC-VOPI only contributed to the breeding of potato and sweet potato cultivars over the years 1980 to 2012. From the analysis of the history of the institute, it was found that by the end of the 1980, the institute only focused on 4 commercial vegetable commodities i.e. sweet potatoes, potatoes, onions and tomatoes. The plant breeders' rights analysis further revealed that for onions and tomatoes, the institute has not been conducting breeding research, but rather other forms of crop science and plant protection research.

ARC-VOPI played a significant role in the breeding of vegetable cultivars in the early years of its establishment. This was important as those cultivars served as the backbone of the vegetable industry. The participation of the private sector in vegetable research, particularly vegetable breeding in South Africa, has increased over the years, which has assisted in bridging the gap in vegetable breeding given the termination of several of the breeding programmes at the institute. This increased participation by the private sector was nevertheless aided by the long-term research foundations laid by the institute.

Given the constant need for vegetable crops to adapt to changing environmental and climatic conditions, constant long term breeding for better and more suitable cultivars is necessary. This more long-term and basic research would have to be conducted by the public sector, particularly

the ARC-VOPI, given that it has the national mandate to conduct vegetable research and also because the private sector would not conduct such research, as the private sector is generally driven by short- to medium-term returns on investment.

In the evaluation of the trend in vegetable research investment at ARC-VOPI in the years 1980 to 2012, it was found that investment in vegetable research increased from R15 million in 1980 to R26 million by the mid-1980s. From there, investment in vegetable research declined to reach R19 million in 1990. The decline was caused by a shift in resources at the institute to focus on a priority project that was initiated by the vegetable industry. From 1992, after the institute was integrated into the ARC, investment in vegetable research at the institute declined rapidly: from R12 million in 1993 to R2 million in 2002. This was caused by changes in funding policies which required the institute to source part of its funding from external sources. These financial constraints forced the institute to focus on the needs of clients who were willing to identify their research needs and make a contribution towards the research costs.

In addition, increased efforts by the national government to support small-scale agriculture required the institute to allocate part of its parliamentary grant to research that would benefit the small-scale agricultural sector, thus reducing investment allocated to other forms of research. There was a slight improvement, however, from 2002, when investment in vegetable research increased to reach R5 million in 2012. This increase in investment was, however, still relatively low compared to the investments made in indigenous and traditional crop projects.

The general decline in the investment in commercial vegetable research at the institute over the years raises concerns given that the institute has the mandate to conduct vegetable research, which covers all vegetable crops. Should the current trend in commercial vegetable research investment continue at the institute, the consequence in future would be that the institute would not be able to fulfil its functions and this would create a gap in vegetable research that the private sector may not be able to fill.

In estimating the economic rate of return to public vegetable research, the study focused on only four commercial vegetables: potatoes, tomatoes, onions and sweet potatoes, given that these were the only commercial vegetables in which the institute has continued to conduct research and records were available. The other vegetables on which research is currently conducted at ARC-VOPI are indigenous vegetables. The commercial production of these

vegetables is unknown as it is not monitored in official statistics; therefore indigenous vegetables were not included in the study.

The study used time series data from 1980 to 2012. The results showed that the benefits of research in the vegetable industry are spread over a period of 15 years, with the maximum benefits occurring between year 7 and year 8 after the investment in vegetable research was made. The results also indicated that some benefits of research are experienced in the same year as the investment in research, reflecting the value of other forms of research such as quality improvement research which has an almost immediate effect on vegetable production.

The marginal internal rate of return was estimated at 39.68 percent. This rate of return is significant, indicating that vegetable research conducted at the institute over the years has generated benefits to the vegetable industry. This rate of return also indicates an underinvestment in vegetable research because the marginal return is positive. This justifies increasing investments in vegetable research. The rate of return to vegetable research found in this study also compares well with findings in other horticulture industries, such as the wine grape industry, with an estimated rate of return of between 40 and 60 percent.

8.3 LIMITATIONS AND RECOMMENDATIONS

The study found that the returns to public investment in vegetable research are positive and large, warranting an increase in public vegetable research investment. However it was found that investment in vegetable research has been declining at ARC-VOPI over the years and that the institute has been active in only four commercial vegetable crops. It was also found that research conducted at the institute has become more focused on crop science, with plant breeding only undertaken in two of the four commercial vegetable crops, i.e. sweet potatoes and potatoes.

Based on these findings, it is recommended that investment in commercial vegetable research be increased at the institute in order to allow the institute to undertake the necessary long-term basic research which is needed in the vegetable industry. Increasing investment in vegetable research would allow ARC-VOPI to broaden its research focus to include other commercial vegetables, and conduct a variety of research thus, providing the vegetable industry with

research output that will support the growth of the industry. This would also help reposition the institute as the research backbone of the vegetable industry as it was in its early years of establishment.

The analysis in this study required historic time series data on vegetable research investments. In its early years, the research conducted at ARC-VOPI was fully funded by the Department of Agriculture. As such, investment records for expenditure on vegetable research were kept by the department. With the structural and policy changes that took place over the years in the Department of Agriculture, those records were lost. Therefore, in developing the vegetable research investment series for the period 1980 to 1992, estimates had to be made based on 1980s reports of the institute. This limitation could be addressed by using a more synchronised and systematic approach to record keeping at the department and at the institute. This could be done by setting up an electronic research database in which all research costs, including operational cost, salaries, personnel and overhead costs are recorded per project. This would assist in providing data for future studies and allow for more comprehensive analyses to be made in future.

The vegetable industry differs from other horticultural industries such as the fruit industry in South Africa in that there is no single body overseeing the industry. This has always been the case; even before the deregulation of the agricultural sector in the 1990s, there was no vegetable board overarching the industry. The exception to this was the potato board, which only regulated the potato industry. This creates a challenge in conducting any form of study or analysis in the vegetable industry, because there is a lack of coordination in the industry with organisations and farmers each focusing on their own activities. This makes it difficult to know what is happening in the industry with regard to private investments in vegetable research, as companies such as Syngenta, Hygrotech Pro-Seed, Seedcor, Sakata, Starke Ayres Premier and Potato SA, as well as large-scale farmers, such as ZZ2 in the tomato industry and Vito Rugani in the carrot industry, undertake their own research and even invest in imported vegetable seeds. Because of this, private investments in vegetable research were not included in the analysis.

To overcome this, mutually beneficial collaborations between the private and the public sector are required as they will ensure more coordinated and sustainable research investment decisions in the vegetable industry. This would result in the long-term sustained growth of the vegetable industry. These public and private sector collaborations will also help in pooling resources for vegetable research, given that there is great competition for public funds.

REFERENCES

- Agricultural Research Council. 2012. Web-pages [Online] Available from: <http://www.arc.agric.za/> [Accessed: 2012-05-18]
- Akino, M. and Hayami, Y. 1975. Efficiency and Equity in Public Research: Rice Breeding in Japan's Economic Development. *American Journal of Agricultural Economics*, Volume 57: 1-10.
- Alston, J.M., Norton, G.W. & Pardey, P.G. 1998. *Science Under Scarcity: Principles and Practice of Agricultural Research Evaluation and Priority Setting*. 2nd ed. CAB International: United Kingdom.
- Alston, J.M., Chan-Kang, C., Marra, M.C., Pardey, P.G., and Wyatt, T.J. 2000. *A Meta-Analysis of Rates of Return to Agricultural R&D Ex Pede Herculem?* Research Report No 113. IFPRI, Washington, DC.
- Anandajayaseram, P., Martella, D.R. and Rukuni, M. 1996. *A Training Manual on R&D Evaluation and Impact Assessment of Investments in Agricultural and Natural Resources Research*. SACCAR: Gaborone
- ARC (Agricultural Research Council). 2013a. *Annual Report 2000-2001*. Pretoria: Agricultural Research Council, Pretoria.
- ARC (Agricultural Research Council). 2013b. *Annual Report 2008-2009*. Pretoria: Agricultural Research Council, Pretoria.
- ARC (Agricultural Research Council). 2013c. *Annual Report 2012-2013*. Pretoria: Agricultural Research Council, Pretoria.
- ARC-VOPI (Agricultural Research Council-Vegetable and Ornamental Plant Research Institute). 2012. *Biennial Research Report 1992/93*. Pretoria: Agricultural Research Council, Pretoria.
- ARC-VOPI (Agricultural Research Council-Vegetable and Ornamental Plant Research Institute). 2013a. *Annual Report 1986-1987*. Pretoria: Agricultural Research Council, Pretoria.
- ARC-VOPI (Agricultural Research Council-Vegetable and Ornamental Plant Research Institute). 2013b. *Annual Report 1988-1989*. Pretoria: Agricultural Research Council, Pretoria.
- ARC-VOPI (Agricultural Research Council-Vegetable and Ornamental Plant Research Institute). 2013c. *Research Report 1949-1999*. Pretoria: Agricultural Research Council, Pretoria.

- ARC-VOPI (Agricultural Research Council-Vegetable and Ornamental Plant Research Institute). 2013d. Finance Database. Pretoria: Agricultural Research Council. [Accessed March 2013]
- ARC-VOPI (Agricultural Research Council-Vegetable and Ornamental Plant Research Institute). 2014a. *Genebank Report 2013/2014*. Pretoria: Agricultural Research Council, Pretoria.
- ARC-VOPI (Agricultural Research Council-Vegetable and Ornamental Plant Research Institute). 2014b. Web-pages [Online] Available from: <http://www.arc.agric.za/arc-vopi/> [Accessed: 2014-03-31]
- ARC-VOPI (Agricultural Research Council-Vegetable and Ornamental Plant Research Institute). 2014c. Human Resource Database. Pretoria: Agricultural Research Council. [Accessed June 2013]
- Beintema, N.M., Stads, G., Fugile, K. & Heisey, P. 2012. *Global Assessment of Agricultural R&D Spending: developing countries accelerate investment*. International Food Policy Research Institute, Washington DC.
- Beintema, N.M. & Stads, G. 2010. *Public Agricultural R&D Investments and Capacities in Developing Countries: recent evidence for 2000 and beyond*. Paper for the Global Conference on Agricultural Research for Development, Montpellier, March 2010
- Beintema, N.M. and Stads, G. 2004. Sub-Saharan African agricultural research: Recent investment trends. *Outlook on agriculture* Volume 33 (4) 239–246
- Blomerus, L. 2014. Agricultural Research Council-Infruitec. E-mail communication, 11 August.
- Carter, J. 1999. *Estimating the Economic Rate of Return to Research in the South African Deciduous Fruit Industry*. Unpublished master's thesis. Stellenbosch: University of Stellenbosch
- Chembezi, D. (1991). Acreage response to price and risk: The case of tobacco in Malawi. *European Review of Agricultural Economics* 18 (1) 85-102.
- CSS (Central Statistical Services). 1980. *Report No: 06-01-16. Census of Agricultural and Pastoral Production, 1980*. Pretoria: South African Government Printer.
- CSS (Central Statistical Services). 1993. *Report No: 11-02-01. Census of agriculture, 1993: Financial and Production Statistics*. Pretoria: South African Government Printer.
- CSS (Central Statistical Services). 2002. *Report No: 11-02-01. Census of agriculture, 2002: Financial and Production Statistics*. Pretoria: South African Government Printer.

- CSS (Central Statistical Services). 2007. *Report No: 11-02-01. Census of agriculture, 2007: Financial and Production Statistics*. Pretoria: South African Government Printer.
- DAFF (Department of Agriculture, Forestry and Fisheries). 1998. *Abstract of Agricultural Statistics*; 1998 [Online] Available from: <http://www.nda.agric.za/docs/statsinfo/Ab2012.pdf> [Accessed: 2012-05-18].
- DAFF (Department of Agriculture, Forestry and Fisheries). 2005. *Abstract of Agricultural Statistics*; 2005 [Online] Available from: <http://www.nda.agric.za/docs/statsinfo/Ab2012.pdf> [Accessed: 2012-05-18].
- DAFF (Department of Agriculture, Forestry and Fisheries). 2013a. *Abstract of Agricultural Statistics*; 2003 [Online] Available from: <http://www.nda.agric.za/docs/statsinfo/Ab2012.pdf> [Accessed: 2012-05-18].
- DAFF (Department of Agriculture, Forestry and Fisheries). 2013b. Plant Breeders' Registry. *South African Plant Variety Journal*; 1966 to 2013. Pretoria: Government Printer.
- FAO (Food and Agriculture Organization of the United Nations). 2011. *The State of the World's Land and Water Resources for Food and Agriculture: managing systems at risk*. Earthscan: London.
- Gallagher, P. 1978. The effectiveness of price support policies – some evidence for US corn acreage response. *Agricultural Economics Research*, Volume 30 (4):8-12.
- Griliches, Z. 1958. Research costs and social returns: hybrid corn and related innovations. *Journal of Political Economy* Volume 66 (5) 419-431.
- Heisey, P.W., King, J.L., Rubenstein, K.D., Bucks, D.A., & Welsh, R. 2010. *Assessing the Benefits of Public Research within an Economic Framework: the case of USDA's agricultural research service*. United States Department of Agriculture: USA. Available at <http://books.google.co.za> [Accessed: 2014-08-30]
- Hertford, R. & Schmitz, A. 1977. Measuring Economic Returns to Agricultural Research. In: Arndt, T. M., Dalrymple, D. G. and Ruttan, V. W. (eds.). *Resource Allocation and Productivity in National and International Agricultural Research*. University of Minnesota Press, Minneapolis.
- IFPRI (International Food Policy Research Institute). 2011. *2011 Global Food Policy Report*. International Food Policy Research Institute, Washington DC.
- James, C. 1996. *Agricultural Research and Development: The Need for Public-Private Sector Partnership Issues in Agriculture*, No. 9. CGIAR, Washington, DC.
- Janis, M.D. & Kesan, J.P. 2002. *U.S. plant variety protection: sound and fury?* Faculty Publications. Paper 430, Maurer School of Law: Indiana University
- Kassier, W.E. & Groenewald, J.A. 1992. Report of the Committee of Inquiry into the Marketing Act. Department of Agriculture, Pretoria.

- Khatri, Y., Thirtle, C. & Van Zyl, J. 1996. Public research and development as a Source of Productivity Change in South African Agriculture. *South African Journal of Science* Volume 92 (3):143-50.
- Koo, B., Pardey, P.G., Qian, K., & Zhang, Y. 2003. An option perspective on generating and maintaining plant variety rights in China. *Department of Applied Economics Staff Paper No P03-8*, College of Agricultural, Food and Environmental Sciences: University of Minnesota.
- Liebenberg, F., Beintema, N.M & Kirsten, J.F. 2004. *South Africa: Agricultural Science and Technology Indicators Country Brief No. 14*. Washington D. C., The Hague and Pretoria: International Food Policy Research Institute, International Service for National Agricultural Research and Agricultural Research Council.
- Liebenberg, F. 2013. *South African agricultural production, productivity & research performance in the 20th century*. Unpublished doctoral thesis. Pretoria: University of Pretoria
- Lyu, S.L., White, F. C., & Lu, Y., 1984. Estimating effects of agricultural research and extension expenditures on productivity: A translog production function approach. *Southern Journal of Agricultural Economics*. Volume 16 (2) 1-8
- Loyns R.M.A. & Beaton, N.J. 1988. *Implications of plant breeders' rights: A Canadian perspective. Faculty Paper No 12*. Department of Agribusiness & Agricultural Economics: University of Manitoba.
- Marasas, C., Anandajayasekeram, P., Tolmay, V., Martella, D., Purchase, J. & Prinsloo, G. 1997. *Socio-economic impact of the Russian wheat aphid control research program*. SACCAR: Gabarone, Botswana.
- Mokoena, M.R., Townsend, R.F. & Kirsten, J.F. 1999. Cattle improvement schemes in South Africa: measuring the returns to research. *Agrekon*, Volume 38 (1) 1-12
- Morgan, J. 1999. *Evaluating the returns to research on a project level: cover crops in the South African wine industry*. Unpublished master's thesis. Stellenbosch: University of Stellenbosch
- Morris, M.L., Dubin, H.J., & Pokhrel, T. 1992. *Returns to Wheat Research in Nepal*. Economics Working Paper No. 92-04. Mexico: CIMMYT
- Niederwieser, J.G., Anandajayasekeram, P., Coetzee, M., Martella, D., Pieterse, B. & Marasas, C. 1997. *Socio-economic impact of the Lachenalia research program*. SACCAR: Gabarone, Botswana.
- Norton, G.W & Davis, J.S. 1981. Evaluating returns to agricultural research: a review. *American Journal of Agricultural Economics* Volume 63 (4) 685-699.
- Norton, G.W., Ganoza, V.G. & Pomareda, C. 1987. Potential benefits of agricultural research and extension in Peru. *American Journal of Agricultural Economics* Volume 69 (2) 247-257.

- Nieuwoudt W.L. & Nieuwoudt T.W. 2004. The rate of return on R&D in the South African sugar industry, 1925–2001. *Agrekon* Volume 43 (3) 265-275.
- Ntombela, S. 2012. *South African Fruit Trade Flow, Issue No 6*. National Agricultural Marketing Council: Pretoria
- OECD (Organization for Economic Co-operation and Development). 2014. *Main Economic Indicators: GDP Implicit Price Deflator in South Africa*. OECD: France.
- Pardey, P., Koo, B., Drew, J., Horwich, J., & Nottenburg, C. 2013. The evolving landscape of plant varietal rights in the United States, 1930–2008. *Nature Biotechnology* Volume 31 (1). 25–29
- Republic of South Africa. 2013. Agricultural Research Act. No 86 of 1990. [Accessed: 2013-10-30]
- Roseboom, J., Pardey, P.G., Von Bach, H.S. & Van Zyl, J. 1995. *Statistical Brief on the National Agricultural Research System of South Africa*. ISNAR Indicator series project: Phase II. Statistical Brief No. 23. The Hague: International Service for National Agricultural Research.
- Ryan, J.J. 1977. Supply response to risk: The case of US pinto beans. *Western Journal of Agricultural Economics* Volume 2: 35-43.
- Schuh, G.E. & Tollini, H. 1979. *Costs and benefits of Agricultural Research: the state of the arts*. Staff Work Paper No. 360. World Bank: Washington, D.C.
- Schultz, T.W. 1953. The Economic Organisation of Agriculture. As cited by Arndt, T.M., Dalrymple, D.G. and Ruttan, V.W. (eds.). *Resource Allocation and Productivity in National and International Agricultural Research*. University of Minnesota Press: Minneapolis.
- SAPO (South African Plant Improvement Organisation). 2013. *Variety Listing and Plant Breeders' Rights* [Online] Available at: <http://www.saplant.co.za/product-development> [Accessed: 2013-10-30].
- Swaminathan, M.S. 1995. Population, Environment and Food Security. *Issues in Agriculture*, No. 7. CGIAR, Washington, DC.
- Thirtle, C. & Bottomley, P. 1988. Is publicly funded agricultural research excessive? *Journal of Agricultural Economics* Volume 39 (1): 99-111.
- Thirtle, C., Sartorius Von Bach, H.J. & Van Zyl, J. 1993. Total factor productivity in South African agriculture, 1947-1991. *Development Southern Africa* Volume 10 (3):301-18.
- Thirtle, C., Townsend, R.F., Amandi, J., Lusigi, A. & Van Zyl, J. 1998. The rate of return on expenditures of the South African Agricultural Research Council (ARC). *Agrekon*, Volume 37 (4): 612-622.
- Thirtle, C., Van Zyl, J. & Vink, N. (eds.) 2000. *South African agriculture at the crossroads: An analysis of productivity and efficiency issues*. Routledge: London.

- Townsend, R.F., Van Zyl, J. & Thirtle, C. 1997. Assessing the benefits of research expenditures on maize production in South Africa. *Agrekon* Volume 36 (4) 585.
- Townsend, R. & Thirtle, C. 1998. *Is livestock research unproductive?* Paper for the IAAE inter-conference symposium on challenges facing agriculture in Southern Africa, Badplaas, August, 1998.
- Townsend, R.F. & Van Zyl, J. 1998. Estimation of the rate of return to wine grape research and technology development in South Africa. *Agrekon* Volume 37 (2) 189-210.
- Tripp, R., Louwaars, N., & Eaton, D. 2007. Plant variety protection in developing countries: A report from the field. *Food Policy* Volume 32 (3): 354–371
- United Nations. 2012. *World population projected to reach 9.6 billion by 2050 with most growth in developing regions, especially Africa*. New York. United Nations 2012. Available at: http://esa.un.org/wpp/documentation/pdf/wpp2012_press_release.pdf. [Accessed: 2013-10-30]
- Van Zyl, J. 1996. *Returns to research on crops, horticulture and livestock in South Africa*. Agricultural Research Council: Pretoria.
- Vink, N. 1993. Entrepreneurs and the political economy of reform in South African agriculture. *Agrekon* Volume 32 (4): 153-166.
- Wessels, J., Anandajayasekaram, P., Littlejohn, G. Martella, D., Marasas, C. & Coetzee, C. 1997. *Socio-economic impact of the proteaceae development and transfer program*. SACCAR, Gabarone, Botswana.
- World Bank. 2014. Web-pages [Online] Available from: <http://databank.worldbank.org> [Accessed: 2014-10-10]
- WIPO (World Intellectual Property Organization). 2012. *World Intellectual Property Indicators*. Geneva, Switzerland. Available at: <http://www.wipo.int/portal/en/> [Accessed: 2014-05-30]