



**Economic returns of the Agricultural Research Council's Table Grape Cultivar
Development Programme in South Africa**

By

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DECLARATION

I, Mazwane Sukoluhle, declare that the dissertation, which I hereby submit for the degree of Master of Science at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature:

Date:

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ABSTRACT

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The table grape industry, in line with national policy imperatives such as the National Development Plan (NDP), plays an important role in the South African (SA) economy through employment creation, rural development and foreign currency earnings. The industry has continued to expand over the years. The yields of table grapes have increased considerably in South Africa. For continued growth and sustainability, research and development (R&D) initiatives, among other factors, are important. The Agricultural Research Council's (ARC) Table Grape Cultivar Development Programme (TGCD) is an R&D initiative that supports the industry with breeding of table grape cultivar varieties suitable for SA conditions. It was established in 1952, and has successfully bred 37 table grape cultivar varieties. However, the impact of the programme on yields and contribution to the economy remains unknown. Therefore, the study sought to estimate the economic returns of the ARC'S TGCD to the South African economy.

The impact of the ARC TGCD programme was estimated using a two-stage approach. In the first stage of analysis, the impact on yield of table grapes was estimated using the Just-Pope production function. The first stage of analysis addressed two specific objectives: to determine the yield gains attributable to the ARC's TGCD Programme; and to determine whether attempts to increase yields and quality of table grapes has compromised yield stability. The second stage of analysis employed a benefit-cost analysis to quantify the benefits in monetary terms. Specifically, BCR and MIRR were estimated. Expert advice was used to select seven ARC popular varieties for which data was available in complete form, for the period 2008 to 2017.

The results of the Just-Pope revealed that the adoption of ARC table grape varieties led to average annual yield gains of 0.79% (or 41% for the entire period) for South African table grapes producers from 1965 to 2014. The results of the Just-Pope also revealed that attempts to increase yields or yield quality of table grapes through development of new table grape varieties did not influence yield stability. The average annual economic benefit that accrued to South African table grape farmers as a result of the cultivar development programme was R144 203 964 (in 2010 monetary values) for the same period. This means increased foreign currency earnings through increased and stabilised yields.

With reference to net economic benefits, the Benefit Cost Ratio (BCR) and the Modified Internal Rate of Return (MIRR) were 4.85:1 and 18%, respectively. This meant that every R1 invested in the Programme is associated with about R5 benefits. Therefore, there is a proportion of the yields that is attributable to the ARC's TGCD Programme, over and above improvement in viticultural practices and farmers' experiences over time. With regard to efficiency, the programme is justified (i.e. the benefits derived from the table grape breeding programme are larger than the costs by a multiple of about 5).

The huge and sustainable net economic benefits from the TGCD Programme suggest that an increased injection of public funds should be made to the point, at least, where marginal social benefits are equal to marginal social costs. The restructuring of the TGCD Programme should also consider incorporating the land reform programme. This would mean greater support for the programme through increased smallholder farmer targeting and participation, together with the revitalisation of rural development initiatives for the table grapes industry. These, together with future studies that evaluate the competitiveness of the programme by examining factor and demand conditions, supporting industries; and the programme strategy, structure and rivalry, would generate maximum benefits for the South African economy.

Keywords: Economic returns, Table grapes, ARC, Just-Pope, Benefit Cost Analysis

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LIST OF ABBREVIATIONS

ARC	Agricultural Research Council
BC	Before Christ
CPI	Consumer Price Index
CPPU	Forchlorfenuron
DAFF	Department Agriculture, Forestry and Fisheries
FAO	Food and Agriculture Organization
GA3	Gibberellic Acid
IARCs	International Agricultural Research Centres
IMF	International Monetary Fund
INIA	National Institute for Agricultural Research
MTEF	Medium Term Expenditure Framework
NARS	National Agricultural Research Systems
NDP	National Development Plan
NPC	National Planning Commission
R&D	Research and Development
SATI	South African Table Grape Industry
SAWS	South African Weather Service
TGCD	Table Grape Cultivar Development

CHAPTER 1

INTRODUCTION

2.1 BACKGROUND

South Africa grows grapes for several reasons. Wine production is regarded as the most lucrative business and creative use of grapes. However, grapes are also consumed fresh as table grapes, processed into jams, jellies, juices, or dried as raisins (DAFF, 2012a), and grape seed extract, vinegar and grape seed oil (FAO, 2016). In this regard, grapes that are consumed fresh are referred to as table grapes in contrast to grapes for juice production, wine production or for drying into raisins. Sugar content is the main distinguishing factor between wine grapes and table grapes, with the latter having lower concentration of sugar. Moreover, table grapes are full of flavour, when consumed fresh, as opposed to wine grapes (DAFF, 2012a).

Table and dried grapes constitute one of the most important deciduous fruits grown in South Africa. The total areas planted to deciduous fruits in South Africa were 80 740 ha and 79 912 ha in 2014/15 and 2016/17, respectively (HORTGRO, 2017). Table grapes together with dried grapes contributed 32% of the total area planted in both 2014/15 and 2016/17 respectively (HORTGRO, 2017). Table grapes, alone, accounted for 55% and 78% of the 32% of the total area planted to table and dried grapes, in 2013/2017 and 2016/2017, respectively. This means that the total area planted to table grapes increased by 23% from 2015 to 2017. The increase in total area planted was accompanied by a rise in production. For example, production volumes increased from 1 680 436 tonnes in the 2010/11 production season to 2 008 819 tonnes in the 2015/16 production season (DAFF, 2017).

Increased table grape production ensures employment creation, foreign currency earnings and the promotion of rural development within the industry, in support of National Development Plan goals and objectives (DAFF, 2016). Foreign currency earnings are important for the country's balance of payments. With reference to job creation, employment in the table grape industry has gained strength over time. Accordingly, a total of 14 796 workers were permanently employed in 2016 compared with a total of 10 628 workers in 2011 (DAFF, 2016). This is no surprise since table grape production is regarded as one of the most labour-intensive industries, with 1.6 labour units required per ha (NPC, 2011).

The South African table grape industry has also gained recognition worldwide. It prides itself on delivering reliable shipments of table grapes to the northern hemisphere, particularly Europe, which it has done for over 100 years. Furthermore, table grapes from South Africa have an advantage because they are available to many northern hemisphere markets during their winter and spring seasons when their vines are dormant. The market for South Africa's table grapes has continued to expand. Table grape exports have increased, reaching 305 512 tonnes in 2016, from 170 379 in 2000 (DAFF, 2017). In 2016, South Africa ranked number six in world exports (FAO, 2016). This is because South Africa exports about 80% of its table grapes (DAFF, 2012a; FAO, 2016). The increase in table grape acreages, together with production volumes over time, explains much of the rise in exports. Favourable market conditions also play a role. For example, the 2016 amendment of rules regarding shipment of table grapes from South Africa to China resulted in an increased opportunity for market expansion. South Africa currently ships table grapes at higher temperatures. This allows an extra revenue generation of R2.5 billion. This is because the below-freezing shipments had a negative impact on the quality of table grapes upon arrival in the Far East. (SATI, 2017).

The numerous and diverse success stories of the table grape industry have nevertheless been coupled with various challenges. With reference to the agribusiness environment under which the table grape industry operates, Symington (2008) notes deregulation and globalisation of trade, revision of labour policy (which includes the minimum wage levels), and land reform policy as being the main issues which the industry then had to subdue. He employed Porter's determinants (factor demands, market demands, supporting industry factors, government factors, firm structure, strategy and rivalry) to point out the several dynamics at play which had contributed to the industry's then current competitiveness. The industry supporting factors include the Table Grape Cultivar Development Programme (TGCD) of the Agricultural Research Council (ARC). In light of this, the success of the industry is somewhat attributed to the TGCD of the ARC.

The ARC was established under the Agricultural Research Act, 1990 (Act No. 86 of 1990, as amended by Act 27 of 2001). It is the main agricultural research institution in South Africa. Accordingly, the ARC strives to achieve the following objectives in order to develop the agricultural sector: carry out research, drive research and development, and drive technology development and transfer (ARC, 2016). The ARC achieves its aims through various institutes that conduct research on grain crops, livestock, vegetables, ornamental plants, fruits etc.

Among the ARC crop sciences cluster is the ARC Infruitec-Nietvoorbij Institute, situated in Stellenbosch in the Western Cape. The institute is responsible for conducting research and development, as well as transfer of breeding technology, cultivation, protection and post-harvest technology of deciduous fruits, grape vines, alternative crops and indigenous herbal teas.

The Viticulture Division of the ARC Infruitec-Nietvoorbij Institute breeds new red, white and black seeded or seedless table grape cultivar varieties. The ARC assesses cultivar productivity, susceptibility to field cracking, grape quality, the intensity of inputs required, and storage ability in different table-grape growing regions (SATI, 2017). The table-grape growing regions in South Africa are Orange River, Hex River, Olifants River, Berg River, Northern Provinces. Northern provinces refer to a group of provinces from the north that are involved in table grape production. This group includes Limpopo and Northern Cape Provinces. Before any cultivar can be released, viticultural evaluation takes place to allow for the development of production guidelines. These include pruning systems and manual bunch preparation actions, as well as plant bio-regulator applications, including gibberellic acid (GA3), forchlorfenuron (CPPU) and ethephon. Since the establishment of the ARC table grape-breeding programme in 1952, the institute has released 37 cultivars (Burger *et al.*, 2010). Nevertheless, the contribution of cultivar Research and Development (R&D) to the South African economy in rand amounts, except for that of wine grapes, has not been estimated. This makes research evaluation necessary to ascertain the benefits.

The recognition of the importance of research evaluation (particularly ex-post evaluation) is not a recent occurrence, as it dates back to many years ago (Anandajayasekeram & Martella, 1999). However, this aspect of research has recently received considerable attention. As such, efforts to account for the value of money in science through the evaluation of the rates of return for various agricultural research investments by scholars such as Townsend and van Zyl (1998), Schimmelpfennig *et al.* (2000), and Dlamini *et al.* (2017) are not coincidental. There are several reasons that have culminated in this dimension of research receiving considerable attention from scholars. The continuous reduction in research financial resources is the most obvious impetus (Anandajayasekeram & Martella, 1999). Townsend and van Zyl (1998) attribute the continuous reduction in research funding to increased competition. Research funding, and the lack thereof, is always a challenge (SATI, 2017).

Literature reveals low and stagnating public investment in agricultural research and development (Dey & Deb, 1990; Vink, 2000; Naseem *et al.*, 2010). The consequences of this are widespread and point to a hindrance in innovations related to the development of novel technologies. Climate change impacts, such as an increase in the spread of diseases and their frequencies, exacerbate the impacts of declining public funding. Despite the stagnant growth in investments related to R&D in agriculture, global trends suggest that these investments have to increase to keep up with the growing demand for food (FAO, 2009). Investments in R&D are important and have the following impacts, particularly in the table grape industry: yield growth and improvement of other grapes qualities such as disease resistance which stabilises yields, crack resistance and end-use quality, such as even berry size and excellent flavour.

2.2 RESEARCH PROBLEM

Various factors play a role in achieving the perceived higher yields in table grapes. Improved viticultural management practices, climatic factors, and farmers' experiences are all important contributors. While improved management practices show gains associated with improvements in efficiency concerning the use of modern inputs such as fertiliser, pesticides, irrigation, plant bio-regulator applications, and pruning systems, the climatic factors show effects of the quantity and quality of rainfall, relative humidity, temperature and incident radiation. However, these factors do not reveal genetic gains in the vines, which are associated with improvements in the breeding of new cultivar varieties (Dlamini *et al.*, 2017). Cultivar development allows for the impacts of genetic improvements on yields to be quantified and separated from other yield-enhancing factors.

Literature abounds with studies that evaluate the impact of breeding programmes on genetic gains of grain crops, particularly breeding impacts on yield increases (Nalley *et al.*, Barkley & Featherstone, 2010; Dlamini *et al.*, 2017; Coale, 2017). Nevertheless, literature is devoid of studies that assess genetic gains in yields of horticultural crops that are associated with breeding programmes. Specifically, the ARC's Table Grape Cultivar Development (TGCD) programme has been in existence for several decades, but no studies have been conducted to estimate its impact on yield and economic contribution. Townsend and van Zyl (1998) evaluated the economic contribution of wine grape research in South Africa. While their study focused on quantifying returns associated with wine grape research, there have been no previous studies designed to quantify the economic contribution, in monetary terms, of table grape research. It

is, however, imperative to quantify such gains to justify and influence the flow of more amounts of public funds into agricultural R&D, at aggregate as well as at crop level (Townsend & van Zyl, 1998). Increased competition for funds further motivates the need to demonstrate the economic returns.

The following research questions inform this study:

- What is the economic contribution of the ARC's TGCD programme in South Africa?
- What proportion of yield gains is attributable to the ARC's TGCD Programme?
- Do attempts to increase the quality and yields of table grapes through the ARC's TGCD Programme compromise yield stability?
- What are the resulting net economic benefits for South African table grapes producers?

2.3 OBJECTIVES OF THE STUDY

2.3.1 Overall objective:

The overall objective is to estimate and evaluate the rate of returns to the ARC's TGCD Programme.

2.3.2 Specific objectives:

The overall objective will be addressed through pursuing the following specific objectives:

- To determine the proportion of the yield gains that can be attributed to the TGCD Programme of the ARC for the period 1965 to 2014.
- To determine whether ARC table grape varieties had an impact on yield variability within the same time period. In the case of table grapes, yield variance also considers quality improvement, as yield is adjusted for quality.
- To quantify the net economic benefits of the TGCD Programme for South African producers from 2008 to 2017.

2.4 STATEMENT OF HYPOTHESES

The study conjectures a positive rate of return to the ARC's TGCD Programme. This hypothesis is based on the findings of past studies that have presented positive returns for breeding programmes.

The following hypotheses were formulated in line with the above specific objectives:

- A proportion of yield gains in table grapes yields varietal releases by the ARC is attributable to the genetic improvements facilitated by the ARC, over and above improvements in viticultural practices, managerial experience etc. (Nalley *et al.*, 2010; Coale, 2017; Dlamini *et al.*, 2017).
- It is expected that yield variances of the ARC varieties increase over time. This hypothesis finds support in general findings of previous studies to the effect that the higher yields of modern varieties are associated with higher variability, as compared with yields of traditional varieties in low-income countries (Nalley *et al.*, 2010).
- It is hypothesised that the benefits of the table grape breeding programme are greater than costs are. Previous studies have found the benefits of breeding programmes to be greater than the costs of the programmes are (Nalley *et al.*, 2010; Dlamini *et al.*, 2017; Coale, 2017).

2.5 METHODOLOGY

The study used secondary data to test the hypotheses. The stages involved in testing the hypotheses of the study were: Firstly, secondary data were requested from SAWS, CULDEVCO, SATI and ARC Infruitec-Nietvoorbij. The obtained data comprised those relating to average annual rainfall for the five table grape growing regions, total area planted to table grapes in South Africa, average yield of each cultivar variety released by ARC, type of cultivar variety, release years, adoption rates, and annual costs of running the programme. Other secondary data, such as those relating to interest rates on savings and table grape prices, were sourced from various websites such as IMF and other government publications such as Abstract of Agricultural Statistics (DAFF, 2017). Secondly, a two-stage approach (Just-Pope and benefit-cost analysis) was used to analyse the data.

2.6 ORGANISATION OF THE STUDY

The study is structured such that it first gives an overview of the South African table grape industry and how it influences the objectives of the Cultivar Development Programme. It then deals with how the effects of TGCD Programme of the ARC are modelled to gauge its effectiveness.

Therefore, the six chapters of this study unfold as follows:

Chapter 2 sets the stage for the study by tracing the origins of table grapes, describing the industry's structure in terms of production, market trends, etc., and providing a link between the industry and the TGCD Programme of the ARC. Chapter 3 draws upon the literature on productivity analysis and research evaluation: the concept of agricultural research, modelling of agricultural research, and rates of return arrived at different levels of aggregation to unpack general modelling methods. Chapter 4 reviews common modelling techniques, the economic surplus and production function approach in particular, and related contemporary issues to discover the most relevant method for estimating rates of return to breeding research, and provides a detailed discourse on the Just-Pope production function. Moreover, it describes the data and manipulation of data for the empirical estimation of the yield gains attributable to the ARC's TGCD Programme. Chapter 5 presents, interprets and discusses the results. Chapter 6 concludes and proposes interventions by the government, breeders and areas for future research.

CHAPTER 2

AN OVERVIEW OF THE SOUTH AFRICAN TABLE GRAPE INDUSTRY AND THE TGCD PROGRAMME OF THE ARC

3.1 INTRODUCTION

This chapter seeks to put the study in context by discussing the origins of the South African table grape industry in terms of table grape production, and market structure and trends. To contextualise the study further, the chapter looks into the interactions of the table grape industry, the TGCD Programme of the ARC, and funding process thereof.

3.2 ORIGINS OF GRAPES AND HISTORY OF THE SOUTH AFRICAN TABLE GRAPE INDUSTRY

It is difficult to trace the exact origins of grapes. However, there is a consensus that grapes originated from Asia. Grapes then spread throughout East Asia, the Middle East, Europe and North America. Varieties of grapes were carried to Greece, Rome and France before 600 BC. Furthermore, the Romans distributed grapes all over Europe. Traders from Persia and India carried them to the Far East. Then, Spanish missionaries took them to United States of America in the 1700s (DAFF, 2012b).

In South Africa, the first grape vine was planted in 1659. The South African table grape industry remained regulated until 1997 (Reynolds, 2009). The deregulation of the industry has had several consequences. On the one hand, information fragmentation has occurred and some information on certain aspects of the table grape business have been completely lost (Symington, 2008; Reynolds, 2009). Table grape producers and exporters worked independently until a low production season led to establishment of the producer-exporter association (SATI) in 2004. Today, it is the duty of SATI to provide table grape production-related information to the industry.

On the other hand, deregulation has meant a heavy reliance regarding table grape prices on the forces of supply and demand. South African table grape producers took advantage of the opportunity. They began to search and sell their products in lucrative international markets. Consequently, South Africa has become one of the major table grape exporters in the world. Moreover, the numbers of table grape producers in South Africa have mushroomed over time.

3.3 MAJOR TABLE GRAPE PRODUCING REGIONS IN SOUTH AFRICA

Production areas for table grapes in South Africa are Hex River, Orange River, Northern Provinces, Berg River and Olifants River (Figure 2.1 below). In 2015, the Hex River was the largest growing region, followed by the Orange River and the Berg River (SATI, 2018). The Northern Province was the fourth-largest growing region, with Olifants River allocating the fewest hectares towards the production of table grapes. This trend remained for the period from 2008 to 2018, except only in 2011 when the Orange River dethroned the Hex River (Figure 2.1 below). This suggests that the Western Cape is the biggest producer of table grapes in South Africa. The table grapes grow best in hot and dry conditions with low humidity and rainfall. Thus, such conditions give the Western Cape a relative advantage. Moreover, the Western Cape Province is better positioned in terms of shipping table grapes abroad, since the port is situated in Cape Town.

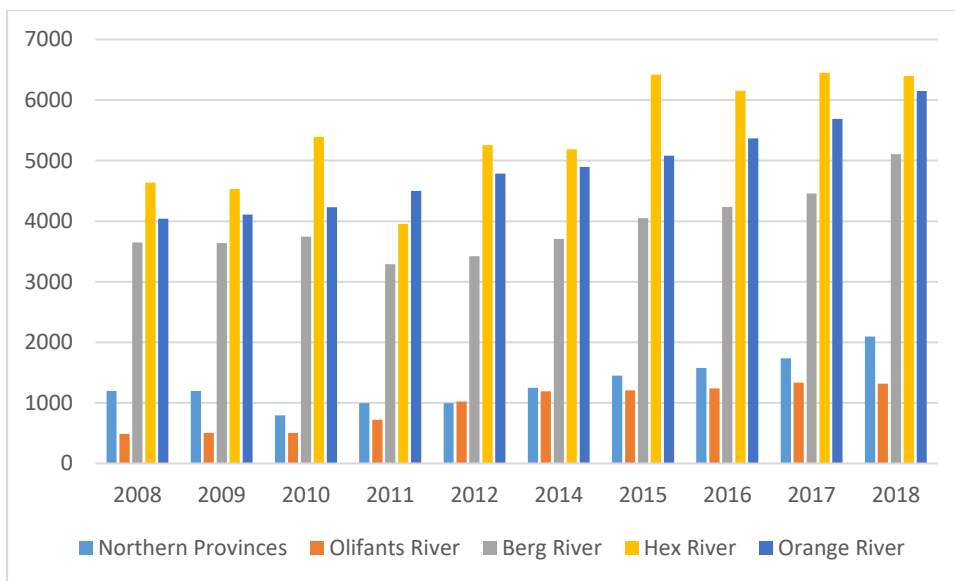


Figure 3.1: Number of hectares allocated to table grapes in each growing region in South Africa for the period 2008 to 2018

Source: SATI (2018)

Nevertheless, the same hot and dry conditions which grant the Western Cape region a relative advantage threatens the future production of table grapes. This is because of negative impacts of climate change, such as prolonged droughts that can quickly deplete water in the dams and negatively affect the production of table grapes in the region. For example, the persistent droughts observed in the Western Cape region during the period 2012 to 2017 depleted water in the Olifants canal. This had a negative effect on table grape production, particularly production of Red Globe, and was exacerbated by water restrictions of about 40% (SATI,

2018). This means that the ARC’s TGCD Programme is becoming increasingly relevant. It could help to curb the adverse consequences of climate change through the breeding of drought-tolerant cultivar varieties.

The area planted to table grapes in South Africa has been growing. Figure 2.2 below shows the different growth rates that were recorded among the various table grape producing regions in South Africa for a 10-years period (2008–2018).

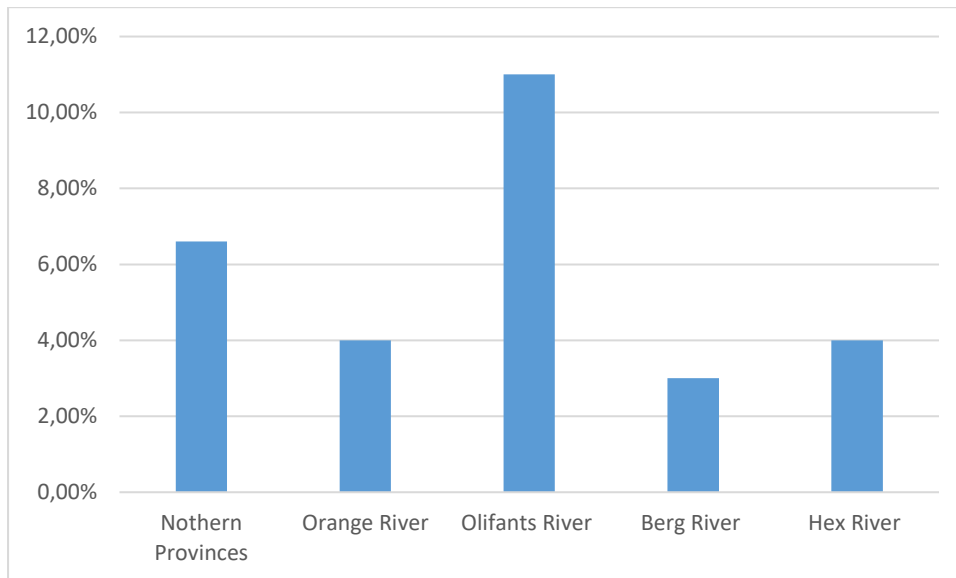


Figure 3.2: Average growth rates in area planted for different table grapes growing regions for the period 2008 to 2018

Source: Constructed from the data obtained from 2018 SATI statistical booklet

The Olifants River, followed by the Northern Provinces, has registered the highest average growth rate in the area planted, despite being the smallest production region over the time period under consideration. The Hex and Orange River growing regions had equal growth rates of about 4% for the period 2008 to 2018 (Figure 2.2 above). The Berg River recorded the smallest growth rate of about 3.5%. The lower growth rates in areas planted in the Hex, Orange and Berg River could be an illustration of the fact that they are the largest table grapes growing regions, and therefore they are close to their maximum potential. The opposite can be stated for the Olifants and Northern Provinces. Since they registered the largest growth rates, this implies that they are far from reaching their full potential. The adoption rates of the ARC’s table grape varieties could increase considerably, if the ARC were to target more numbers of producers in these two growing regions.

3.4 TRENDS IN TABLE GRAPE MARKETS

The production of table grapes in South Africa is primarily aimed at export markets. South Africa exports approximately more than two-thirds of its table grape harvests, with the remaining amounts of harvests being sold locally. The amounts of table grapes targeted for the local and international markets solely depend on the production volumes of a particular season. Therefore, the following subsections discuss the trends in table grape markets, both locally and abroad.

3.4.1 Table grapes domestic market trends

Important trends have been seen in table grape volumes and prices in the local markets. Figures 2.3 and 2.4 below show table grape volumes and real prices, respectively, in both domestic and export markets over a period of 9 years. Figure 2.3 shows that volumes of table grapes sold locally declined during the 9-year period (2008/09 to 2016/17). A possible explanation for this is the fact that South Africa’s table grape industry is export oriented. For example, only 20 713 tonnes of table grapes were sold locally in the 2016/17 marketing season. Although the trend depicts a fairly steep decline, this value was approximately 13% lower than that of the 2008/09 marketing season (DAFF, 2017).

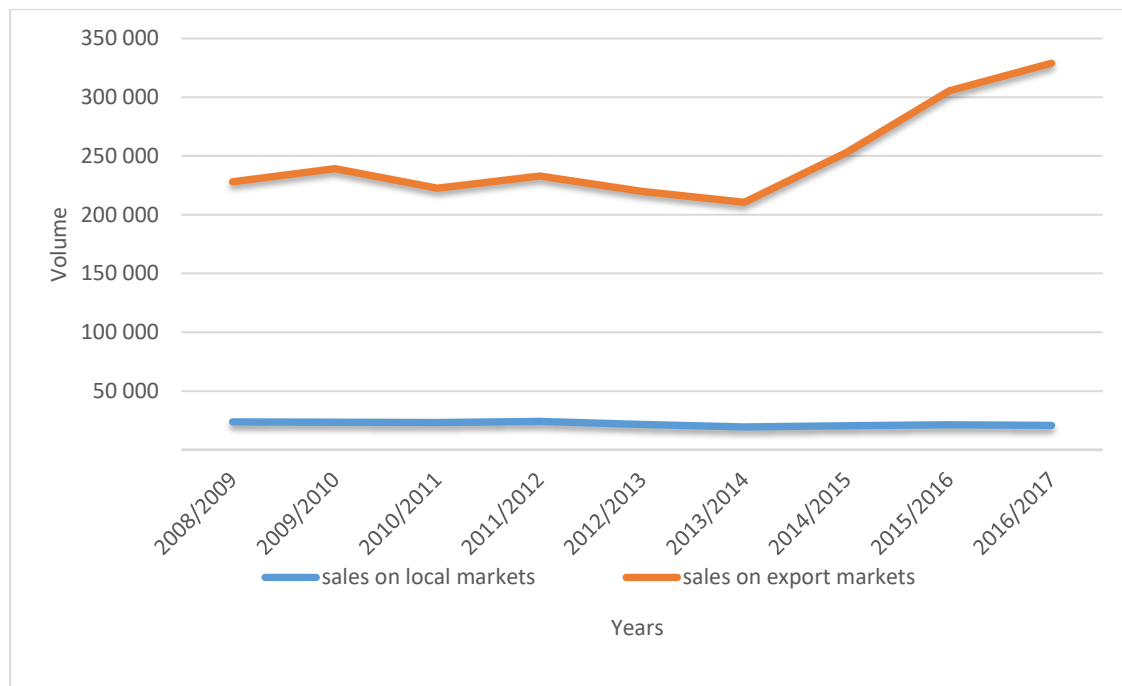


Figure 3.3: Volumes of table grapes sold both in local and export markets for 9-year period
Source: Constructed from data obtained from DAFF

With reference to the market price of grapes in the domestic market, the real price of table grapes increased significantly during the same period. The rise in price in real terms was about 30% in the period 2008/09 to 2016/17 (DAFF, 2017). Therefore, the real price per tonne of table grapes in the local market was R9 478 in the 2016/2017 marketing season. The decrease in supply is associated with an increase in price of table grapes. This is in line with economic theory. Economic theory suggests a decrease in the quantity supplied of a good is associated with an increase in the price of that good. This shift in the supply curve implies that factors other than prices have changed the supply relationships.

3.4.2 Export market trends for South African table grapes

South Africa contributes fewer table grapes to the world's total table grape production, as compared with other countries, yet it is one of the major volume exporters. Accordingly, its contribution to the world's total exports was 6.5% in 2017, and it ranked number 7 in the world (SATI, 2018). Table grape exports have been fairly stable since the 2008/09 marketing season, declined significantly in 2013/14 marketing season, and then picked up strongly from the 2014/15 marketing season onwards (Figure 2.3 above). The drought prevalence in the Western Cape, which began in 2012 and lasted until 2017, might have affected table grape exports with a lag and started to show in the 2013/14 marketing season. Farmers' adaptation strategies might have begun to work after the 2013/14 marketing season, since table grape exports burgeoned once more.

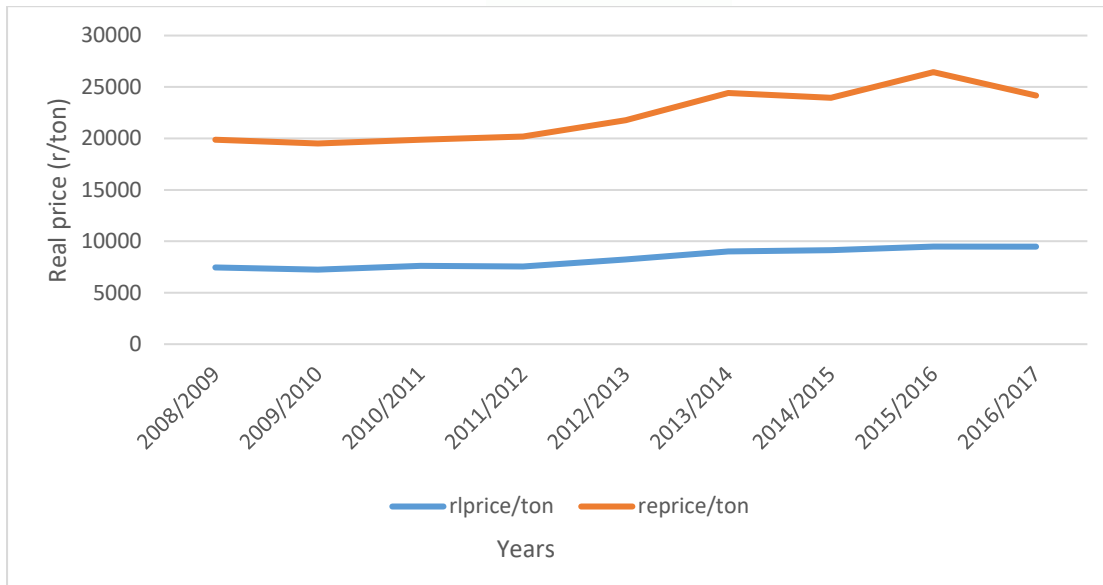


Figure 3.4: Yearly average real prices of table grapes sold both in local and export markets for a period of 9 years (2010 constant prices)

Source: Constructed using nominal price data from DAFF and CPI data from IMF

Table grape farmers receive a premium price for selling their table grapes abroad. The real price that farmers received in export markets was approximately R14 701 in the 2016/17 marketing season (DAFF, 2017) (Figure 2.4 above). This price is about 55% greater than the domestic market price was for the corresponding marketing season (DAFF, 2017). As a consequence, farmers align their management expertise with export markets and acquaint themselves with exportation rules to become successful in table grape production.

Therefore, two factors explain the rise in table grapes exports – the increase in real prices and the increase in the production volumes of table grapes (Figures 2.3 & 2.4 above). With reference to price, the export price observed in the 2016/17 marketing season was about 18% greater than that observed in the 2008/09 marketing season (DAFF, 2017). Thus, export markets are more lucrative for table grapes farmers and it is reasonable for them to sell greater amounts of table grapes abroad as production volumes increases.

South Africa has secured several markets abroad for table grape exports. The European, Asian, United Kingdom, Russian Federation, Americas and African markets are the main export destinations for South Africa (SATI, 2018). With reference to the types of varieties exported, Burger *et al.* (2010) argue that South Africa had minimal exports of seedless varieties in 1985, but it went on to record above 52% in 2006. Consumers' preferences constitute the main driver. Since consumers prefer seedless table varieties to seeded varieties, Redglobe was the only

seeded table grape variety among the top 15 table grape varieties exported by South Africa in the 2017/2018 marketing season (SATI, 2018). This has consequences, not only for the table grape producers, but also for table grape breeders who need to supply seedless varieties to producers.

3.5 ESTABLISHMENT OF THE ARC INFROUTEK-NIETVOORBIIJ INSTITUTE

The Infruitec-Nietvoorbij is one of the ARC crop sciences institutes, situated in Stellenbosch in the Western Cape. The institute is responsible for conducting research and development, as well as the transfer of breeding, cultivation, protection and post-harvest technology for deciduous fruit, grape vines, alternative crops, and indigenous herbal teas.

The ARC Infruitec-Nietvoorbij consists of six divisions. Each division focuses on different aspects of fruit and wine production. These comprise the Crop Development, Plant Protection, Soil and Water Science, Viticulture, Proteomics and Research Services, and the Post-Harvest and Agro-processing Technologies (PHATs) divisions. It is easy to understand the mandate of each division from its name. For example, while the research of the Crop Development division focuses on developing improved cultivars of pome fruit, stone fruit, and table and raisin grapes for South African producers; the Plant Protection division, through its research, seeks to integrate pests and diseases management systems.

Therefore, research and development conducted at ARC Infruitec-Nietvoorbij mainly focuses on improving crop production and mitigating agricultural risks. It also addresses issues related to food security and natural resource sustainability. As a curator of gene-banks for grapevines, deciduous fruits and wine yeast, the campus preserves genetic resources for breeding purposes, training and comparative descriptions.

3.6 TABLE GRAPE CULTIVAR DEVELOPMENT OF THE VITICULTURE DIVISION

The ARC's TGCD has successfully bred a total of 37 cultivars since its establishment in 1952 (Figure 2.5 below). Over the past 10 years (2008 to 2018), the ARC's TGCD Programme has released 6 table grape cultivar varieties. These were solely seedless cultivar varieties (100%). This coincides with the fact that in the past decade, only 1 seeded variety has featured in the top 15 exported table grape varieties. This indicates a higher demand for seedless table grapes,

particularly in Western countries where South Africa’s table grapes are traditionally exported. Table grape breeders, positioned under the TGCD Programme that receives support from SATI and ARC, have fully realigned their breeding objectives with the industry needs. Accordingly, they have resolved to breed more of the seedless table varieties. This explains the increased breeding of seedless table grape cultivar varieties. Nevertheless, the breeding of seeded table grape varieties still occurs for further crossing, mainly because seeded varieties have certain desirable characteristics.

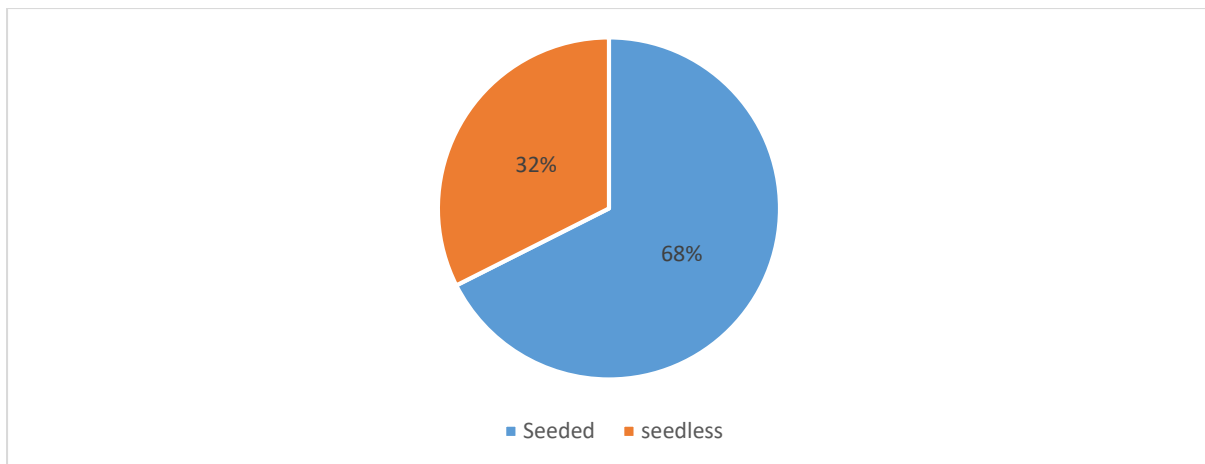


Figure 3.5: Percentage of seeded and seedless table grape varieties released by the ARC's TGCD Programme since 1965

Source: Author's computation with the data obtained from the ARC Infruitec-Nietvoorbij

The breeding programme has the following three small separate projects: the breeding of new table grape cultivars using conventional breeding methods; the breeding of seedless grapes by embryo rescue, and the evaluation and screening of new table grape selections and cultivars. These small separate projects are running concurrently, with a recent takeover by SATI of the evaluation and screening of new table grape selections and cultivars project.

3.6.1 Breeding of new table grape cultivars using conventional (traditional) breeding methods

In this project, breeders use conventional ways of breeding (controlled crosses) to breed new table grapes cultivars. Traditional breeding methods involve preventing self-pollination by removing the male flower parts (stamens that contains pollen) prior to blooming. The process of removing the male flower parts is called emasculation. After the emasculation process has been completed, the breeder pollinates the remaining female flower parts with a preferred pollen. Fertilisation takes place and development of the embryo follows. The embryo can

develop into a plant with its own unique characteristics as it has received genetic material from both parents.

The ovule in which the embryo develops hardens into a seed. When grapes are ripe, breeders begin harvesting and remove the seeds from berries. They stratify seeds (kept in the fridges) at 4 degrees Celsius for three months. After stratification, seeds germinate and the embryos develop into seedlings. Breeders leave the plants to grow in tunnels during the growing season. Collections occur during winter from each plant for grafting onto rootstocks in the vineyard during spring.

3.6.2 Breeding of seedless grapes by embryo rescue

Table grape breeders at Infruitec-Nietvoorbij have also been using the embryo rescue technique to make crosses between seedless varieties. Embryo rescue is a technique which was successfully developed in the 1980s and has been widely used in table grape breeding to develop seedless cultivar varieties. Accordingly, ARC Infruitec-Nietvoorbij breeds new seedless table grapes cultivars with desirable characteristics (crunchy berry flesh, good flavour) that meet the ever-changing consumer preferences. Moreover, newly developed table grapes have lower production costs due to breeding of grapes with lower input costs. Therefore, naturally loose-bunched table grapes, with large natural berries, even berry sizes, and colouring without a need for chemicals, ensure lower production costs. Other desirable characteristics are high fertility and berry crack resistance.

3.6.3 Evaluation and screening of new table grape selections and cultivars

At this stage, the evaluation of hybrids in the vineyard is made to determine their fruit characteristics. Moreover, the selection of individual hybrids with promising characteristics for further evaluation is carried out on the experimental farms in the Paarl and Hex Valley. Table grapes are tested for cold storage when ripe to determine their keeping ability. Breeders select table grapes with good cold storage results for multiplication and intensive evaluation. They also plant the selections at co-operating producers to undertake market evaluations abroad. Several years of evaluation and information collection has to take place to decide on the release of a selection as a new variety. After several years of collaboration between SATI and ARC, the ARC has handed this project over to SATI as means of strengthening the ARC-SATI collaboration. The three aforementioned sub-projects have separate annual budgets.

3.7 FUNDING OF THE ARC’s TABLE GRAPE CULTIVAR DEVELOPMENT

There are two sources of funds for three sub-projects of the ARC’s TGCD Programme, namely the ARC and SATI. The additional work, if any, is funded by the Technology and Human Resource for Industry Programme (THRIP). The ARC contributes a greater amount (about 75%) towards the funding of the programme, with the remaining amount coming from SATI. Figure 2.6 below depicts the budget allocations towards each project, in real terms. The total budget for the programme, as represented by the yellow line, has been fairly stable except a huge decline in 1994/95 and 1995/96 (Figure 2.6). This coincides with the formation of the new government in 1994.

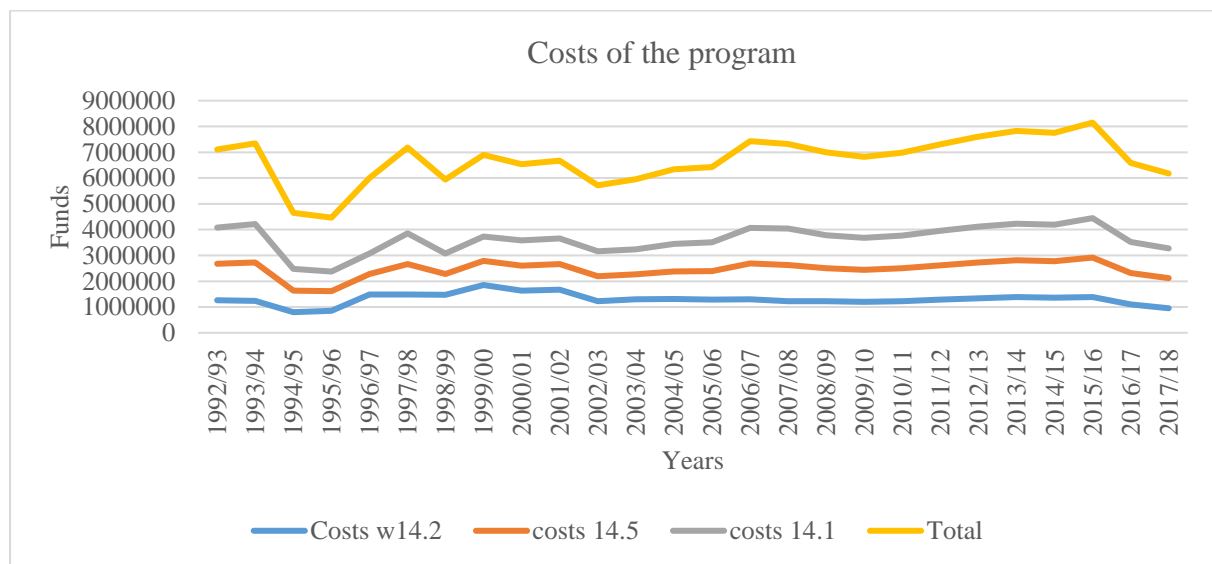


Figure 3.6: Fund allocations towards separate projects of the ARC’s TGCD Programme
Source: Constructed from data obtained from ARC Infruitec-Nietvoorbij

Prior to 1994 and following the Agricultural Research Act, 86 of 1990, (amended by Act 27 of 2001), new major developments occurred in agricultural research in South Africa that led to the establishment of the ARC in 1992. One notable development is the corporatisation of the commodity-based research centres of the Department of Agricultural Development (Liebenberg, Beintema & Kirsten, 2004). This might have affected the TGCD Programme. Moreover, a move away from core funding dispensation to allocation of funds based on competition among Science Councils (Flaherty, Liebenberg & Kirsten, 2010), could also be a possible explanation for the decline in funding in 1994/95- 1995/96.

Although this anomaly did not last forever and was corrected in the 1996/97 financial year, there has been a steady decline in funds since 2015 (Figure 2.6 above). A possible reason explaining this is the recent shift in research priorities, with a recent focus being placed on

market-based research, particularly research aimed at minimising ex-post-harvest losses (SATI, 2017). It is evident that project number W14.1 (breeding of new cultivars) accrued much of the costs associated with the breeding of new table grapes varieties, followed by project number W14.5 (breeding of seedless grapes by embryo rescue) (Figure 2.6 above). The evaluation project takes up the least of the funds (W14.2). This is mainly because project number W14.1 is the main project, which focuses on breeding, and includes the breeding of both seedless and seeded table grape varieties. The other two projects are subsequent and complementary to project number W14.1. Fund allocations in each project are distributed among fixed, operational and personnel costs.

3.8 SUMMARY

Grape plantations in South Africa date back to 1659. The table grape industry remained regulated until 1997. The deregulation in 1997 meant that the determination of table grape prices would be determined by the regulation-free forces supply and demand. Moreover, the information became fragmented until the establishment of the producer exporter association, SATI, in 2004. Table grape production has mushroomed in South Africa. The TGCD Programme of the ARC has kept up with the industry needs. It has changed its breeding objectives to breed only seedless varieties to meet the ever-changing needs of the consumers. SATI and ARC are supporting the programme with funds. However, the funding has noticeably declined since 2015. This necessitates the making of an evaluation of the returns to programme investments, with the end goal of influencing the provision of additional funds if the findings are positive, and further strategic interventions if the findings indicate negative returns.

CHAPTER 3

REVIEW OF LITURATURE ON ECONOMICS AGRICULTURAL RESEARCH

4.1 INTRODUCTION

There is a large body of literature on the rates of returns to agricultural research. This has a direct bearing on this study since this chapter assesses these studies, draws facts that will provide context within which the study can be understood, and helps to gain insights into important theoretical concepts to inform the study. This chapter is also a guide towards determining the focus of these studies and existing research gaps. Hence, this chapter is organised as follows. First, the concept of agricultural research is covered, followed by the socio-economic importance of agricultural research. A discussion of the concepts of productivity, productivity growth, and agricultural research spending follows thereafter. Ex-post research evaluation follows, along with rate of return studies at different levels of evaluations.

4.2 THE CONCEPT OF AGRICULTURAL RESEARCH

There is a consensus about the nature of agricultural research as a public good. Agricultural research is normally considered as a public good because it possesses major characteristics of public goods, such as non-excludability and non-rivalry. In light of this, Kirsten *et al.* (2009) argue that one's consumption of research outputs upon release, regarding new agronomic practices or pest control, does not prevent others from consuming the same knowledge. Moreover, consumption of such information does not reduce the amount available for others. Evenson (2001) recognises the lack of incentives in the form intellectual property rights (patents), which consequently results in low agricultural research investments, as constituting a major leading factor prompting the establishment of International Agricultural Research Centres (IARCs) and National Agricultural Research Systems (NARS) by national governments.

However, private-sector research systems are still in place. A very special case (involving excludability, however) favours the existence of private research systems. This is done through embodying the research outputs into a product (Kirsten *et al.*, 2009), for example, a fertiliser product. In this regard, a private company can benefit from its research through the sales of the derived fertiliser. Moreover, patents can be issued to prevent competitors from scientifically

advancing their fertiliser in a similar way. Thus, in the United States (US), the division of private sector research into production and food manufacturing was 70% and 30%, respectively, in the late 1990s (Fuglie & Heisey, 2007). Consequently, a world of research, with investments from the private sector and the public sector, has been created with substantial contributions from the latter. According to Kirsten *et al.* (2009), contribution by the former was 2% in 27 sub-Saharan African countries in 2000.

Public sector and private sector participation in agricultural research is normally represented as percentage of research spending. In South Africa, the ARC remains the principal agricultural research institution, and its contribution towards total research spending and staff was at 60% in 2004 (Liebenberg *et al.*, 2004). This reflects higher public-sector participation in agricultural research, relative to the private sector in South Africa. The latter's contribution towards total research spending and staff in South Africa was lower, at 3%. Nevertheless, South Africa's private sector participation in agricultural research is better when compared with other African states (Kirsten *et al.*, 2009). All this is consistent with the theoretical perspective of agricultural research as a public good.

4.3 SOCIO-ECONOMIC IMPORTANCE OF AGRICULTURAL RESEARCH

The absence of incentives to stimulate agricultural research investments might have been the leading cause prompting governments' establishments of IARCs and NARS, but at the heart of that was a recognition of the importance of agricultural research for a productive and sustainable agricultural sector (Maredia, Byerlee & Anderson, 2000). Agricultural research is important for productivity-orientated countries. Evenson (2001) argues that the recognition of the importance of agricultural research in the developed countries, such as the US and European countries, and in the developing countries of today was noted in the beginning and in the middle of the 19th century, respectively.

The benefits of agricultural research can be perceived in various sub-sectors of agriculture, the food sector, and in consumer purchasing power. Farmers have registered considerable cost reductions in the world over the past 50 years (Kirsten *et al.*, 2009). Thus, cost reductions attributable to increased yields per unit of input constitute the main benefit of agricultural research for producers (Benin, 2016). Such benefits normally spill over to the food industry by increasing the amount of food available and, eventually, lower food prices.

With reference to agricultural research in South Africa, the ARC has transformed the agricultural sector, both locally and internationally. Thirtle *et al.* (1995) argue that ARC's research has played a role in increasing incomes of poor smallholder farmers. Industry players have reported that the most important and valued contribution by the ARC is in the field of breeding, for example, biosystematics, wheat success, and recently, table grape success stories and biotechnology. Despite the acknowledgement of the contribution of the ARC, policy makers have raised concerns about the limited evidence of the research of the ARC. They argue that anecdotal evidence exists, but there are no scientific studies to document and disseminate. Thus, this study's aim of estimating the economic contribution of TGCD Programme features, in a legion of efforts, is directed towards producing such evidence.

4.4 THE CONCEPT OF PRODUCTIVITY, PRODUCTIVITY GROWTH AND AGRICULTURAL RESEARCH SPENDING

The identification of trends in agricultural productivity can offer insights into the sources of growth and the limiting factors inhibiting the sustainable enhancement of agricultural productivity (Benin, 2016). The meaning of the term 'productivity' varies with context. Economists have used the term to refer to partial factor productivity (output per labour), Total Factor Productivity (TFP), and technical change (Kumbhakar 2002). Although the meaning varies with contexts, the term generally refers to the ratio of outputs to inputs. Countries always strive for a higher ratio, whether in terms of partial factor productivity or TFP. An increase in this ratio, over time, reflects productivity change/growth. Thus, Kumbhakar (2002) argues that the concept of productivity growth is broad and it includes technical change as a special case.

Whether it is measured as partial factor productivity, TFP, or technical change, the sources of growth in productivity vary. These include the development of new technologies as well as increased utilisation of modern inputs, such as fertilisers and machinery (Fuglie & Heisey, 2007). The development of new technologies through agricultural research, investment in infrastructure such as roads, and investment in education are important sources of productivity growth (Benin, 2016). Moreover, agricultural research allows for the development of new and better combinations of inputs. The broad view is that new wealth perceived in the economy, in the long run, results from growth in TFP. Therefore, various studies have developed and improved econometrics methods to distinguish the contribution of agricultural research towards productivity growth from other sources of growth.

Agricultural research investments comprise a good indication of the contribution of agricultural research towards productivity growth. Fuglie and Heisey (2007) note a strong link between investments in research and innovation, and growth in productivity. Literature reveals that the introduction of the National Institute for Agricultural Research (INIA) in Uruguay revitalised agricultural research funding, thus spurring sustainable productivity growth (Bervejillo, Alston & Tumber, 2011). This provides a premise that today's investments in agricultural research could be a good indication of the future behaviour of productivity growth. Hence, past agricultural research investments are used in modelling the contribution of agricultural research and development towards enhancing productivity growth. Liebenberg *et al.* (2004) add that the total spending on public agricultural research, as a percentage of agricultural Gross Domestic Product (AgGDP), facilitates relative comparisons of agricultural research spending across countries. According to Benin (2016), the African Union (AU) has set a 1% target for African states. This target is part of the Comprehensive Africa Agriculture Development Programme's (CAADP) pledges, made in the Maputo Declaration, that require African states to allocate at least 10% of their national budgets to agriculture and achieve at least 6% agricultural annual growth (ONE, 2013). The AU leaders committed to this by adopting CAADP as part of the New Partnership for Africa's Development (NEPAD) initiative.

4.5 AGRICULTURAL RESEARCH EVALUATION: EX-POST

According to Farrington *et al.* (1997), ex-post evaluation is important for gauging the effectiveness and efficiency of agricultural research in achieving its objectives. Funding for agricultural research is becoming increasingly scarce due to competing agricultural research projects. Kirsten *et al.* (2009) argue that scarcity of funds often forces governments to cut funds to areas that are not considered as being pressing, like agricultural research. The agricultural sector has responded positively through providing evidence of the benefits of agricultural research. Information regarding the returns to agricultural research is important for informing future policy and funding decisions.

Several studies have estimated the rates of returns to agricultural research in South Africa for various industries, including the maize, sugar and wine industries (Townsend & van Zyl, 1998). Moreover, a myriad of studies exist which have evaluated the rates of returns to agricultural research of the ARC in South Africa at various levels of aggregation, including aggregate, enterprise, institute, crop and project levels. Anandajayasekaram and Martella (1999) term

these different levels of research ‘impact assessments’ due to the different levels of aggregation. As such, Thirtle *et al.* (1995) provide a review of the results as well methodologies employed by these studies.

Thirtle *et al.* (1995) find that the ARC’s research is economically justifiable in its generation of new technologies, but its major downfall is in the exclusion of the socio-economic dimension. The ARC’s increase of incomes of the poor smallholder farmers is not accompanied by an improvement in the nutritional status of women and children. Accordingly, Thirtle *et al.* (1995) call for a partnership between the ARC and the Department of Agriculture. They further recommend that crops like groundnuts should receive high scores on the score cards because they have a double effect of increasing incomes and improving nutritional status of farmers. Thirtle, Lin and Piesse (2003) argue that research-led productivity growth has substantially impacted on poverty, reducing the number (1.2 billion) of the worlds’ poorest people who live below \$1 a day, by 27 million per annum.

Moreover, they found that crops with relatively high labour requirements and those with the propensity to earn foreign revenue to be equally important (Thirtle *et al.*, 1995). The table grape industry fits perfectly with the second recommendation, as it meets both requirements.

4.6 RATE OF RETURN STUDIES ON AGRICULTURAL RESEARCH

Analogous to the review by Thirtle *et al.* (1995), this section examines studies conducted at different levels of aggregation for the period 1997-2017. This not only facilitates comparisons to be made of results obtained, but also increases insights into the widely used and most appropriate methods of analysis of agricultural research returns, as well as into problems that often arise at different levels of aggregation. This follows the review by Alston *et al.* (2000) of 281 studies (with outliers removed) that gave an average rate of return of 65%. Alston *et al.* (2000) concluded that such averages give little information, since they arise from rate of return estimates that are often not directly comparable because they use different methods and assume different lag structures. Accordingly, this section firstly reviews studies at the highest levels of aggregation, followed by those at the lower levels of aggregation. The only difference between this review section and that by Thirtle *et al.* (1995) is that this section looks at the results of more recent studies (i.e. all studies published after the review by Thirtle *et al.* (1995) and at the conclusions reached in Thirtle *et al.* (1995).

However, the studies assessed by Thirtle *et al.* (1995) ranged between the years 1993 and 1997. Since then, there has not been another review of the ARC agricultural research studies, let alone a review of rate of return studies in South Africa, except for further discussions of the studies reviewed by Thirtle *et al.* (1995). This is surprising, particularly in the context of South Africa where a successive number of rate of return studies have been conducted since 1997. In the light of this, the focus, approaches and results of these studies are expected to change over time. Thus, the main aim is to review rate of return studies published in the period of 1997-2017.

4.6.1 Aggregate level ex-post research evaluation

There are considerable numbers of studies that have ascertained rates of returns to agricultural research investments at sector level (i.e. aggregate level). A study by Schimmelpfennig *et al.* (2000) is an example in point for South Africa; however, studies of this nature also exist elsewhere in the world. Comparison of results and rates of returns, from studies conducted at different levels of aggregation, is very common in the literature regarding the rate of returns. This is normally done before efforts are made to establish the rate of returns. This is prevalent in the context of South Africa in studies such as those of Rancho (2015) and Tshabalala (2015). The tables presented by such studies offer a narrow scope for a comparison of the results across studies due to issues related to different levels of aggregation, data requirements, etc.

Table 3.1 below presents two studies conducted at aggregate level, one for South Africa and one for China, to facilitate relative comparisons to be made. The selection of these two countries was based on the similar research systems used. Table 3.1 also reports basic approaches, lag types and lengths, rates of returns, and references for these studies. Both these studies show that traditional inputs (land and labour), modern inputs (fertiliser and machinery), the stock variable knowledge constructed from past research expenditures, education, and weather explain changes in TFP. These studies differ in some respects. While Schimmelpfennig *et al.* (2000) treat the capital factor differently under the short run and long run, Fan (2000) attempts to account for input quality differentials across regions and over time.

Nevertheless, both studies present almost similar problems. Despite different ranges and having to deal with different specification issues, Fan (2000) and Schimmelpfennig *et al.* (2000) deal with similar data and lag length issues, and ultimately obtained similar results, 45% and 44%–58% returns to Chinese and South African agricultural research investments,

respectively. Fan (2000) finds that results are sensitive to efforts dealing with unmeasured input quality. This has been a case for many rates of returns studies. Moreover, a sensitivity checks show that an assumed lag length and structure significantly affect the rate of returns.

The two studies presented in Table 3.1 below offer good insight for facilitating the comparison of results at aggregate level and are of major interest as they show the rates of returns from two developing economies, China and South Africa. These countries have similar research systems. Contrary to the US research system, which is mostly basic research in nature (Schimmelpfennig *et al.*, 2000), the nature of the research systems in China and South Africa is mostly adaptive applied research (Fan, 2000; Schimmelpfennig *et al.*, 2000). Hence, the lags of R&D in China and SA are relatively shorter than those in the US and other developed economies are. Therefore, a catalogue of studies similar to that adopted in Table 3.1 below enables explanations to be made of differences and similarities across studies.

The rates of returns to agricultural research are high in both South Africa and China, and justify increased agricultural research funding. Fan (2000) asserts that the increased investment in agricultural research will continue to result in increased output and it is justifiable on economic efficiency grounds. According to Fan (2000); there is movement of labour out of agriculture and an increasingly scarcity of land is apparent as development advances. One possible reason is the increased demand for food because of growing population density. This is already the case in the context of South Africa where abundant labour has been replaced by scarce capital, despite the attribution of this by Schimmelpfennig *et al.* (2000) to adverse apartheid policies.

4.6.2 Crop-level research and individual research activity ex-post evaluation

According to Townsend and van Zyl (1998), increased pressure on, and competition for, fiscal and monetary resources not only make efforts necessary to account for the value of science (returns to research) at aggregate agricultural level, but also at crop level. The burgeoning of efforts to account for the values of science at crop level and project level in the ARC are no surprise (Townsend & van Zyl, 1998; Rancho, 2015; Tshabalala, 2015; Tsvakirai, 2015; Dlamini *et al.*, 2017; Coale, 2017). Nevondo (2019) and Naledzani (2019) have estimated the rates of returns for the ARC's research at both these levels. Thus, Tables 3.2 and 3.3 below report some of the studies, basic approaches, assumed lag length and structure, rate of returns, and references.

Table 4.1: Representation of rate of returns to agricultural research at aggregate level in South Africa and China

Study and period	Method	Lag model	Length years	Rate of returns (ROR)	Reference
Research investment and economic returns to Chinese agricultural research (1975–1997).	Production function	Triangular and asymmetric structure	14	45%	Fan (2000)
Short- and long-run returns to agricultural R&D in SA, or will the real rate of return please stand up! (1947–1992)	Two-step approach 1 st step – Total factor productivity 2 nd step – Profit function approach	Asymmetric lag structure (Gama and Beta)	9	44% (short run) & 58% (long run)	Schimmelpfennig <i>et al.</i> (2000)

Source: Constructed by the author from previous studies

Table 3.2 below reports studies that have estimated the returns of improvement research to peach and nectarine, vegetable, and beef cattle in South Africa. The methods used to arrive at the benefits of research – the lag model and length, rate of returns ascertained, and references – are also reported in Table 3.2. With reference to the estimation of returns of research to peach and nectarine, the output is regressed against the costs of packaging materials, research and development, and prices of other deciduous fruits such as table grapes, pears and apricots. The rate of return of about 56% is found, which should justify making an increase in funding for peach and nectarine research. Such a high rate of return to research is not an anomaly, as it is consistent with a range of rates of returns reported by previous studies.

For vegetable research, output is used as a dependant variable and is explained by the area planted to vegetables, real expenditure on public vegetable research, and weather. Despite a relatively lower estimate than that of the peach and nectarine research, a reasonable rate of return to publicly funded vegetable research is 39%. With reference to beef cattle improvement research, Nevondo (2017) regressed carcass weight against feed, public investments, and a weather index that included weather and rainfall. The returns of improvement research to beef

cattle were calculated at 32%. All returns suggest that increased funding for research and development would be beneficial.

The research lag length for peach and nectarine is longer when compared with vegetable public research, and this could possibly justify the larger estimate for the former. Despite the longer lag length associated with lower returns for beef cattle improvement research, the returns are much higher, compared with those of previous studies that estimated returns to livestock improvement research. Therefore, longer lags imply the accumulation of benefits from research investments which span a long period of time. Assuming the similarity of the intensity of derived benefits (output elasticity of research and development expenditure) across studies and over time, the rates of return to research should be higher for longer lags than those for shorter lags are. The longer lag lengths associated with basic research regarding various western economies supports this claim. Although expected benefits and the lags of research investments remain enterprise specific, sensitivity analysis proves that the two are highly correlated.

Table 4.2: Studies estimating rate of returns to agricultural research at crop level

Study and period	Method	Lag model	Lag Length	ROR	References
An economic evaluation of South Africa’s peach and nectarine research (1971–2012)	Supply response function	Almon Polynomial lag distribution	21 years	55.9%	Tsvakirai (2015)
Economic Analysis of publicly funded vegetable research in South Africa (1980–2012).	Production Function	2 nd order degree Polynomial lag distribution	15 years	39%	Rancho (2015)
Economic returns on investment in beef cattle improvement research in South Africa (1970–2014)	Production function	Almon Polynomial lag distribution	22 years	32%	Nevondo (2019)

Source: Constructed by the author from previous studies

Table 3.3 below presents details regarding the study and period, methods, ROR and references for studies conducted at project level. Specifically, these relate to dry beans and wheat breeding projects of the ARC. In contrast to the general production function used by most studies

presented in Table 3.2 above, all these studies employ a Just-Pope production method, mainly to account for the risk factor. There is an assumption of the existence of numerous breeding objectives, with one objective being related to risk being yield stabilisation. The experimental yields per hectare comprise a function of the release year for each cultivar variety, location and time-trend variable. Empirical models used vary only in the inclusion of the qualitative variable. While Dlamini *et al.* (2017) use the dummy RS to distinguish between Red Speckled (RS) and Small White Canning (SWC) dry bean varieties, Coale (2017) includes the dummy variable PLANTING to differentiate types of wheat.

From Table 3.3 below, it is clear that for every R1 invested in dry bean and wheat breeding research, about R6 and R5 in benefits are derived, respectively. The determination of lag lengths is not a common concern in studies employing the Just-Pope production function. Most studies assume a standard lag length of 12 years. Several studies in South Africa have established a 12-year lag for agricultural research investments. Nevertheless, the exclusion of a weather variable could constitute a major source of bias, since weather is an important factor in grain yields.

Table 4.3: Studies estimating rate of returns to research at project level

Study and Period	Method	ROR	Reference
The economic impact of the South African Agricultural Research Council’s Dry Beans Breeding Programme (1982–2014).	Just-Pope production function	Benefit Cost ratio (BCR): 5.67:1	Dlamini <i>et al.</i> (2017)
The economic benefits of the South African Agricultural Research Council’s Wheat Breeding Programme (1992–2015).	Just-Pope Production function	BCR: 4.49:1	Coale (2017)
An economic assessment of the implications of changes in wheat quality standards in South Africa	Combination of Fisher Divisia index, coefficient determination & Benefit-Cost analysis	BCR: 0.62: 1	Naledzani (2019)

Source: Constructed by the author from previous studies

Naledzani (2017) estimated the returns arising from adhering to wheat quality standards in South Africa by using a combination of the Fisher Divisia Index method, econometric modelling, and benefit cost analysis. The returns associated with attempts to improve wheat quality standards were negative. Despite adjustments of the protein content and hectolitre mass improvement for quality, the returns remained negative.

4.7 SUMMARY

Agricultural research, as a public good, implies that it must rely heavily on public funds. This renders agricultural research investments vulnerable to budget cuts in times of budget constraints. Despite existing evidence of the importance of agricultural research, reduced budgets for agricultural research have been noted in the last three decades. Nevertheless, economic analysis has shown a strong and consistently positive relationship between agricultural research and productivity growth. The focuses of studies that evaluate economic returns to agricultural research vary widely in different contexts. Rates of returns to agricultural research in South Africa and China were estimated for the entire agricultural sector, which includes livestock, crops, and fishery. Another study focused on returns to horticulture research

(i.e. peach and nectarine). Moreover, other studies assessed the rates of returns to specific breeding programmes.

While a claim is not laid with regard to covering a full spectrum of technical problems associated with the determination of lag lengths and structures, a recognition of a research gap has been made on the technical approaches that are germane to sensitivity analysis. A proof of sensitivity of rate of return estimates to the assumed lag lengths and structures has been established, despite missing knowledge as to whether assumed lag lengths or lag structure positively or negatively influence rate of return estimates.

Moreover, the increasing efforts to justify the value of science at every level of aggregation, over time, are noteworthy. It is no surprise that almost every research activity within the Agricultural Research Council has had its rate of returns established. This means that crop and livestock research have to prove their resource use efficiency, for every research activity, and also to provide an account of the effectiveness of public funds and accordingly justify increased funding. Although the rate of return is not the only determinant for research priority and allocation of research funds, it is a major factor. Therefore, with almost every research activity having had its rate of return established and justified, there is nothing that prevents the same to be done for other crops, such as table grape breeding research, which has unknown rates of returns.

CHAPTER 4

METHODS AND PROCEDURES OF ESTIMATING ECONOMIC RETURNS TO AGRICULTURAL RESEARCH

5.1 INTRODUCTION

The previous chapter mentioned, without details, the various methods that are most used in the estimation of returns to agricultural research. These methods can be either ex-ante, ex-post, or both. The following evaluation methods are known in literature to be ex-ante: Benefit-Cost analysis, simulation models, and mathematical programming. The economic surplus approach and parametric approaches are known to be ex-post. Parametric approaches can be further divided into primal (production, supply response function, etc.) and dual approaches (profit and cost functions). Although some of the methods mentioned above, like economic surplus and Benefit-Cost analysis, are mostly used in one type of evaluation, these methods can be applied, in principle, in both ex-ante and ex-post evaluations of agricultural research.

This chapter provides a review of the popular ex-post evaluation methods (e.g. the economic surplus approach and the primal production approach). These techniques, particularly primal production function, are the most relevant techniques to this study. The discussion will also provide reasons for the selection of the Just-Pope production evaluation technique over other methods. Accordingly, the chapter discusses the Just-Pope production function in greater detail. The Just-Pope production function is a variation and extension of the general Cobb-Douglas production function. A discussion of the benefit-cost analysis follows, particularly as to how it combines with the Just-Pope results to arrive at the net benefits of the cultivar development programme to South African table grape producers. The remainder of the chapter discusses the process involved in manipulating the data.

5.2 ECONOMIC SURPLUS APPROACH

The basic economic surplus approach is based on the estimation of the net benefits arising from research-induced supply shift. Put differently, the total gains in welfare resulting from agricultural research can be measured using this approach. Moreover, it allows a disaggregation to be made of benefits between consumers and producers (Farrington *et al.*, 1997). Rancho (2015) discusses in detail the derivation of the total welfare gains and benefits for both producers and consumers by using an economic surplus approach. Since its first application by

Shultz (1953), followed by Griliches (1958), major developments have been made to the basic model to account for multiple markets, vertical market integration, market distortions, etc. (Alston, Norton & Pardey, 1995; Farrington *et al.*, 1997).

Adjustments can be made for multiple markets for a single product, with and without technological spill overs, traded goods where the innovation results from either the importer or the exporter, and countries, whether large or small. Adjustments are also made for multiple products related in either consumption or production. With reference to vertical integration, the model can be adjusted to include cases where more than one input is used to produce a farm product, which further requires marketing inputs to produce the retail product. Adjustments can also be made to incorporate supply changes in marketing inputs and processing technology (Farrington *et al.*, 1997).

Allowance can also be made in the model to account for policies that distort markets (Farrington *et al.*, 1997). Such policies include price supports, price ceilings, deficiency payments, input and output subsidies, quotas, tariffs, export taxes, and rigid exchange rates. These adjustments have implications for the type of assumption made about the shift of the supply curve. Rancho (2015) put forward the point that different assumptions made about the shift of the supply curve include parallel, proportional, four shifts, and pivotal shift.

The economic surplus approach has several advantages. The adaptations to account for several varying circumstances, as described above, do not render it intractable. Moreover, the explained variables are input and output prices and other preferred variables. The method also allows for vertical disaggregation of the benefits between consumers and producers, and horizontal disaggregation between countries, regions and agro-ecological zones (Rancho, 2015). Its flexibility also makes it relevant to the analysis of ex-ante agricultural research evaluations. However, Farrington *et al.* (1997) argue that in empirical studies, fairly simple methods are used, regardless of the wide scope offered by the developments of the basic model. The economic surplus approach is limited to estimating the rates of returns for specific projects.

5.3 ECONOMETRIC APPROACH

Several measures of productivity growth in agriculture have helped to develop the literature on the rate of return. These find a basis in the dual relationships that exist between production, cost and profit functions. Other equivalent measures of productivity growth commonly used are economic accounting measures that are based on index number theory. Dual-based

approaches are referred to as integrated approaches (Evenson, 1967), where the inclusion of productivity enhancing factors in the primal or dual representation of production takes place directly. An approach where the calculation of the Total Factor Productivity (TFP) take precedence, followed by attempts to explain it by the conditioning factors which are thought to induce growth, which is called two-stage decomposition. These approaches form a foundation for calculating the rate of returns to research.

Despite the differing approaches mentioned above, Schimmelpfennig *et al.* (2000) note that conditioning factors (such as the knowledge stock generated through past research expenditures, extension services and farmer education, and weather) normally explain changes in productivity. The broad view is that research generates new knowledge, which is then diffused by extension officers, and that educated farmers are better at screening new information. Consequently, on-farm technology generation occurs due to the adaptation of the new technology by farmers. The influence of weather is considered to be significant; hence, the inclusion of a weather variable is expected to reduce the unexplained errors.

The basic production function used in the primal production function approach has been formulated as:

$$Q = A \prod_{i=1}^m X_i^{\beta_i} \prod_{j=1}^n R_{t-j}^{\alpha_{t-j}} u$$

where Q is the value of agricultural output, A is the shift factor, X_i is the i th conventional factor of production, R_{t-j} is research expenditure (extension) in the $t - j$ th year, β_i is the production coefficient of the i th conventional input, α_{t-j} is the partial production coefficient of the research expenditure (and extension), and u is the conventional error term. Production function approaches vary in literature. Normally, research expenditure affects output with a lag. Thus, the length and shape of the time lag is the major source of variation in production function approaches. This might be attributed to the rate of return calculations that are sensitive to the assumed lag structure. Accordingly, preliminary analysis is sometimes conducted in search of the best lag length and structure. The predetermined lag parameters are used in later stages to model the knowledge stock variable in quest of refined estimates of rate of returns (Schimmelpfennig *et al.*, 2000).

This simple production function has been useful since at least 1928, when Cobb and Douglass fitted it to US manufacturing data. However, Farrington *et al.* (1997) argue that its usability is

expected to change as the relationship between inputs and outputs is altered by technological advancements. Developments of the fairly simple method have occurred, accompanied by a progression of using variables which are thought to account for a shift in production over time. An example in point is the extension of the Cobb-Douglass production function in sub-Saharan Africa by Thirtle *et al.* (1995) to include three traditional inputs (land, labour and livestock), two modern inputs (fertiliser and machinery), investments in infrastructure (irrigation and machinery), public R&D, extension and education, and policy environment.

However, this has offered little help in studies that have sought to establish the elasticity of substitution between explanatory variables (i.e. whether the technology has been capital-using and labour saving, or labour using and capital using). Hence, flexible functional forms have been attractive in such studies. Dual approaches that include cost and profit functions have also been used. Nevertheless, the production function and its dual representations can limit one in modelling the risk factor where risk implications are significant. For example, yield stability is important in agriculture, and agricultural breeding programs often strive to reduce fluctuations in yields through the breeding of drought tolerant, disease and pest tolerant crops, etc. In this regard, the modelling of the risk factor becomes relevant in production relationships.

Therefore, Just and Pope (1978) offers a production function specification with reasonable risk implications. As mentioned above, productivity growth modelling forms the basis for the estimation of rates of return and the procedures employed largely influence the final results (i.e. rate of returns). Farrington *et al.* (1997) put forward the point that the best methods to be employed are solely dependent on the type of data available, the economic environment, and the results required – otherwise, there are no universally best methods.

5.3.1 The Just-Pope production function

Usually, a breeding programme will have different breeding objectives. This is normally assumed to cause the error terms to be heteroscedastic in nature. Other methods, like the well-known general production function, do not offer an advantage of dealing directly with multiplicative heteroscedasticity by incorporating it into the model. These rather require complicated procedures to be followed to deal with heteroscedastic errors. Moreover, the use of the lagged values of research investment in the model requires extra efforts to be made to deal with the problem of collinearity, which according to Schimmelpfennig (2000) and

Townsend and van Zyl (1998), involves determining the lag length and structure of research investments.

An econometric estimation of the Just-Pope production function has been used to estimate the genetic gains of various breeding programmes. Past studies which have used this approach include, but are not limited to, Nalley *et al.* (2010) who used it to estimate the genetic and economic impacts of a wheat breeding programme on local producers in the Yaqui Valley, Sonora, Mexico; and Coale (2017) and Dlamini *et al.* (2017), who used it in estimating the rates of returns to various breeding programmes of the ARC. The view is that factors which influence yield also have an impact on variance of output. Thus, any efforts devoted towards enhancements of yields through the breeding of high-yielding modern varieties also influence the variance of outputs. As a result, these scholars argue that the Just-Pope production function provides flexibility in the description of stochastic technological process that might involve changes in average and variance of output. In this regard, the effects of yield enhancement on yield stability can be tested right away. Specifically, the Just-Pope production function allows the inputs to affect both the mean and variance of the output. Therefore, the Just-Pope production function, in combination with benefit-cost analysis, was adopted in this study since the genetic gains and economic benefits of table grape cultivar development were to be estimated. Accordingly, the general model of the Just-Pope production function is specified as follows:

$$Y_{ilt} = F(\mathbf{X}_{ilt}, \beta) + h(\mathbf{X}_{ilt}, \alpha)\varepsilon_{ilt} \quad (1)$$

where Y_{ilt} is yield of the i th varietal test at location l and in time t , \mathbf{X}_{ilt} represents explanatory variables also for i th varietal test at location l in time t , β and α are parameter vectors, and ε_{ilt} is the conventional error term with a mean of zero. The first right-hand side term in the above equation, $(\mathbf{X}_{ilt}, \beta)$, captures factors affecting the mean of the output (Y_{ilt}), whereas the second term, $h(\mathbf{X}_{ilt}, \alpha)\varepsilon_{ilt}$, captures factors affecting the variance of the output (σ_{ilt}^2).

The incorporation of multiplicative heteroscedasticity into the model is one benefit for which the Just-Pope production function is exploited. This is important to deal with, since varietal characteristics differ due to different breeding objectives (yield improvement, disease resistance, etc.) which differ across varieties and over time. Consequently, different breeding objectives imply heteroscedastic error terms across varieties. Moreover, the heterogeneity of the table grape growing regions implies the breeding of table grape varieties suited to different

viticultural practices. In this regard, the chances that random errors may be heteroscedastic are high. Therefore, Just-Pope provides an opportunity to account for differences in breeding aims. An assumption that variance $\varepsilon_{ilt}(\sigma_{ilt}^2)$ is an exponential function of K explanatory variables allows for the derivation of the general model with heteroscedastic errors. The model is as follows:

$$Y_{ilt} = X'_{ilt} + e_{ilt} \quad (2),$$

$$E(e_{ilt})^2 = \sigma_{ilt}^2 = \exp(X'_{ilt}\alpha) \quad (3),$$

where $X'_{ilt}\alpha = (x_{1ilt}, x_{2ilt}, \dots, x_{kilt})$ is a row vector of observations on K independent variables. The vector $\alpha = (\alpha_1, \alpha_2, \dots, \alpha_k)$ is $K \times 1$. $E(e_{ilt}) = 0$ and $E(e_{ilt} \cdot e_{jlt}) = 0$ for all off-diagonal elements of the covariance matrix of the error terms. Equation (3) can be written as:

$$\ln \sigma_{ilt}^2 = X'_{ilt}\alpha \quad (4),$$

where σ_{ilt} is not known, but the marginal effects of the explanatory variables on the variance of production, using Ordinary Least Squares (OLS) residuals from Equation (2), can be estimated such that:

$$\ln (\hat{e}_{ilt})^2 = X'_{ilt}\alpha + \mu_{ilt} \quad (5),$$

where, \hat{e}_{ilt} are residuals from the least squares estimates of Equation (2). The μ_{ilt} are error terms for the variance equation. The estimates of the output variance $((\hat{e}_{ilt})^2)$ are calculated from the estimation of Equation (5):

$$\ln (\hat{e}_{ilt})^2 = X'_{ilt}\alpha \quad (6)$$

The predicted values from Equation (6) are used as weights for estimating generalised least squares (GLS) coefficients for the mean output in Equation (2). That is, the estimates of α from Equation (5), α , can be viewed as the effects of the independent variables on yield variability σ_{ilt}^2 . $\ln (\hat{e}_{ilt})^2$ are exponentiated, and these exponentiated values are then used as weights when re-estimating Equation (2). Using these weights, the estimated GLS coefficients of α are obtained to provide the efficient, estimated effects of the independent variables on yield.

5.3.2 Just-Pope empirical model specification

The mean and variance of yield were modelled as follows:

$$Y_{it} = \beta_0 + \beta_1 RLYR_{ijt} + B_2 L_{it} + \beta_3 W_{it} + \varepsilon_{it} \quad (7)$$

$$\ln(\hat{\varepsilon}_{it})^2 = \beta_0 + \beta_1 RLYR_{ijt} + B_2 L_{ijt} + \beta_3 W_{it} + \varepsilon_{it} \quad (8)$$

where, Y_{it} and $(\hat{\varepsilon}_{it})^2$ is the mean and output variance for variety i at time t , respectively, $\ln RLYR_{it}$ is the release year of each variety also at time t , L_{it} is a dummy variable describing whether or not variety i released at time t is seedless, W_{it} weather index constructed using rainfall data from the five table grape growing regions at time t , β_i are parameter vectors to be estimated, and ε_{it} is the conventional error term.

The release year variable can be construed as the “vintage” of a breeding technology (Arrow, 1962; Traxler *et al.*, 1995; Nalley *et al.*, 2010; Coale, 2017; Dlamini *et al.*, 2017). The coefficient on the RLYR measures the impact (on yield and yield variance) of the breeding programme (in this case, the TGCD Programme). This is because it captures the progression of the breeding technology, over time. Nevertheless, there is a difference between RLYR and the trial date. For each variety, there is a single release year, the date of release of each cultivar to the general public for commercialisation, and each cultivar released has a breeding technology for that particular year incorporated in it. The trial date is the test period for a particular cultivar.

Thus, in the estimation of the multiple regression model, the effect of the technology in the newly released table grape cultivar was captured by the coefficient of the RLYR. According to Nalley *et al.* (2010), a variety’s life cycle is assumed to exist as long as the cultivar is higher yielding than its predecessors were, until relatively higher yielding successors are released. RLYR does not represent a time-trend variable, but is viewed in the same way that Arrow’s (1962) growth model embodied technology in capital (Dlamini *et al.*, 2017). Accordingly, Nalley *et al.* (2010) argue that this method has been standardised to measure the impacts of advances in technology on output.

Ideally, a dummy variable, representing the type of variety (i.e. 1 if the variable is seedless and 0 if otherwise) of the table grape, is to be included to capture inherent differences across table grape species. Weather, particularly rainfall, has a significant impact on table grape yields and other table grape attributes, such as (but not limited to) quality (Burger *et al.*, 2010). Accordingly, a weather index was constructed using rainfall data from five different table grape growing regions. Then, the weather variable (i.e. rainfall index) was included in the model to account for differences in weather across the regions and for changes in weather over time.

5.4 ESTIMATION OF CUMULATIVE BENEFITS AND COSTS

To calculate cumulative genetic gains, the coefficient of RLYR from the Just-Pope production function was multiplied by the number of years under investigation. According to Nalley *et al.* (2010), it is important to calculate the genetic gains associated with a breeding programme. This is done by taking into account the cumulative effects of the programme over the entire period. For example, yield gains that can be attributed to the breeding programme in 2016 are those observed in that year and the previous year (2015). Therefore, the genetic gains associated with the ARC's TGCD in 2016 would be the sum of the year-specific genetic gain from 1965 to 2016.

The economic benefits for South African table grape producers is a function of a number of factors that are exogenous to the breeding programme (acreage, price, adoption rate, etc.) and an endogenous factor, being the genetic gains derived from the ARC breeding programme. Therefore, the cumulative economic gains for the entire period under investigation derived from the ARC breeding programme were calculated as follows:

$$A_{ARCt} = A_{Tt} \times \phi_t \quad (9)$$

where, A_{ARCt} is area planted only to ARC cultivars in SA in year t, A_{Tt} is the total area planted to table grapes in SA also in year t, and ϕ_t is the adoption rate of ARC varieties in year t.

$$Y_{ARCt} = A_{Tt} \times \varphi_t \quad (10)$$

where, Y_{ARCt} is the additional production from ARC in year t, A_{ARCt} area planted only to ARC cultivars in SA in year t, obtained in Equation 9, and φ_t is the cumulative genetic gains in year t.

$$R_{ARCt} = Y_{ARCt} \times P_t \quad (11)$$

where the cumulative economic gains from ARC are expressed in rand in year t, Y_{ARCt} is the additional production from ARC in year t, and P_t is the price of table grapes in year t.

Therefore, to ascertain the net benefits of the cultivar development programme, the benefit cost ratio was calculated. An annual average interest rate on savings was used as proxy for a discount rate to discount cost and benefits to 2010 rand values. Moreover, to gauge research effectiveness and efficiency, the Internal Rate of Return (IRR) of the breeding programme and

ultimately the Modified Internal Rate of return (MIRR) were both estimated. Kierulff (2008) defines IRR as the discount rate which makes the present value of the opportunity equal to that of the investment. In other words, it is the discount rate that makes the value of NPV equal to zero. Accordingly, the following formulas were used:

For Benefit Cost ratio:

$$\frac{B}{C} = \left[\frac{B_0}{(1+i)^0} + \dots + \frac{B_0}{(1+i)^T} \right] / \left[\frac{C_0}{(1+i)^0} \dots + \frac{C_T}{(1+i)^T} \right] \quad (12)$$

Rule of thumb: a BCR greater than 1 suggests that the TGCD Programme is worth the investment.

For IRR:

$$0 = \left[\frac{B_0}{(1+i)^0} + \dots + \frac{B_0}{(1+i)^T} \right] - \left[\frac{C_0}{(1+i)^0} \dots + \frac{C_T}{(1+i)^T} \right] \quad (13)$$

Several studies have estimated high IRRs for agricultural research. As such, the Modified IRR (MIRR) was considered due to concerns raised by policy makers regarding high IRRs for agricultural research (Dlamini *et al.*, 2017). The MIRR is a better measure because it solves three major drawbacks associated with the IRR calculation (Kierulff, 2008). Firstly, multiple solutions are likely to arise with the traditional IRR when cash flows fluctuate from negative to positive more than once. Secondly, the IRR assumes that positive cash flows are reinvested into the project at the IRR. There have been concerns on how this assumption conforms with reality. Thirdly, there are difficulties in ranking mutually exclusive projects when they have different lifespans and are not equal in sizes. However, with the MIRR, the study is once again justified in the calculation of reliable returns for the TGCD Programme of the ARC. In this regard, the MIRR calculated the projects' returns on investment by using the organisation's cost of capital (i.e. interest rates on savings) for both reinvestments of positive cash flows and initial outlays.

The following formula is used to calculate the MIRR:

$$MIRR = \sqrt[n]{\frac{FVCF(c)}{PVCF(c)}} - 1 \quad (14)$$

where $FVCF(c)$ is the future value of positive cash flows at the cost of capital, $PVCF(c)$ is the present value of negative cash flows, also at the cost of capital, and n is the number of periods. The IRR and MIRR share a rule thumb. In this regard, the project is attractive when the IRR

and MIRR are greater than the discount rate is. An IRR and MIRR that exceed the discount rate signal a decision to invest. Despite being weaker than the MIRR in gauging investment attractiveness, the IRR was also estimated because it has been used extensively in the literature on research evaluation. It was estimated for comparison with other studies. With regard to gauging research effectiveness and efficiency of the TGCD Programme, the MIRR was used.

5.5 DATA MANIPULATION

The study sought to estimate the economic returns attributable to the TGCD Programme of the ARC. The focus was placed mainly on all the varieties released by the ARC (i.e. varieties released through private breeding programmes were excluded). This is due to difficulty involved in obtaining information related to private research. The period covered in determining the yield gains and variability in yields attributable to the ARC's TGCD runs from 1965 to 2014. With reference to the estimation of the net economic benefits, BCR, IRR and MIRR, the data used covered a period of 10 years, 2008 to 2017, and only seven popular ARC table grapes varieties. The following data items were used in the regression to assess yield increases and changes in variability attributable to the ARC breeding programme: whether variety *i* developed was seedless or seeded (type of variety), years in which the cultivar was released (release year), and average yields per hectare for each variety (average yield).

Previous studies have used experimental yields to estimate returns to breeding research regarding grain crops. According to Dlamini *et al.* (2017), an implicit assumption exists with regard to the use of experimental yields. The assumption is that the actual yields from producers are equal to the yields from test plots. Annual changes in relative yields are measured by using performance test data that reflect ideal management and agronomic practices, rather than actual grain crop performance yields. In this regard, Dlamini *et al.* (2017) acknowledge the existing difference between experimental and actual yields, and put forward the point that variety trials are the only reliable sources of relative yields. This means that the absolute yield/yield variance could be higher/lower in test plots, but the relative difference should be the same between test plots and actual producer yields. Nevertheless, quality improvements have also been found to be an important contributor to the adoption of modern crop varieties. As such, Brennan (1989) argues that little consideration has been given to quality adjustments in studies that estimate the returns of breeding programmes to grain crops.

In the context of table grapes, actual yields were used because experimental yield data were not available. The consequence of this could be enormous. Townsend and van Zyl (1998) argue that inadequate time series and specific project data should not be taken lightly, as these prevent rigorous economic analysis being performed. However, the fact that absolute yield/yield variances might be higher/lower in test plots, but the relative differences should be the same between test plots and actual producer yields, once again justifies the use of actual aggregate producer yields. Since table grape yields are not an important factor in the breeding of table grapes but quality is, it is of little significance for a table grape breeder to give much attention to yields per hectare, let alone collect data, as grapes often have their berries pruned, a yield-reducing activity, for purposes relating to quality enhancement.

Adjusting for quality is always beneficial in horticultural research. Townsend and van Zyl (1998) estimated returns to wine grape research by using both quality adjusted and quality unadjusted yields, and obtained results that varied considerably. Estimating the benefits that involve quality for any breeding programme had always been difficult task, until Townsend and van Zyl (1998) shed some light by assuming that prices reflect the quality of a final product. Accordingly, to account for quality, a major breeding objective in horticulture, a ratio of the Gross Value of Production (GVP) of each cultivar variety to the GVP of all grapes, normalised to 1 in 2010 prices, was constructed. As postulated by Townsend and van Zyl (1998), an increase in this ratio reflects quality changes. Hence, a product of this ratio and yields was formed for the purpose of adjusting for quality. Thus, this study only used adjusted quality yields because the approach of accounting for quality improvements proves to be strikingly relevant in horticultural research, particularly grape breeding research. (The results of unadjusted yields are also provided in Appendix 1). Moreover, industrial yields per hectare, made available by ARC, CULDEVCO and SATI, are used in calculating GVP (GVP = yield multiplied by price).

Figure 4.1 below shows the adjusted and unadjusted quality yields for ARC table grape varieties. The quality adjusted yields indicate significant variations, as compared with the unadjusted yields (Figure 4.1). For example, table grape variety number 7 (Ronelle) reflects high yields when quality is taken into consideration, as compared to Ronelle, in the quality unadjusted yields (Figure 4.1).

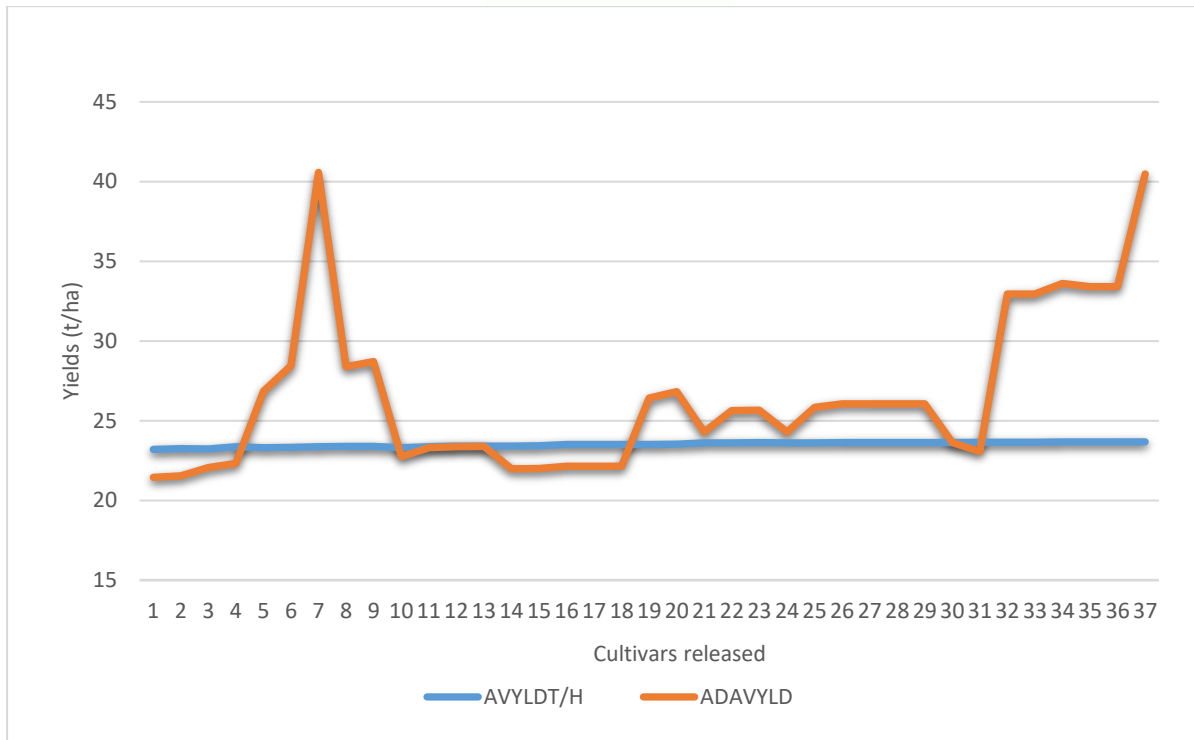


Figure 5.1: 37 cultivars released by the ARC since 1965 and their respective adjusted and unadjusted potential yields in tons per hectare

Source: Constructed from the data obtained from ARC, CULDEVCO, SATI and DAFF

Furthermore, data on annual table grape prices, adoption rates for ARC varieties, and the fixed and annual costs of running the breeding programme were obtained from the Abstract of Agricultural Statistics, SATI and ARC, respectively, for BCR, IRR and MIRR estimation. The annual average prices of table grapes and the costs of running the breeding programme were adjusted for inflation using a Consumer Price Index (CPI) solicited from International Monetary Fund (IMF). The study used annual average interest rates, also solicited from IMF, as a proxy for a discount rate for calculations of discounted benefits and costs. The table of the CPI is found on the Appendix.

5.6 SUMMARY

This chapter reviewed the commonly used approaches in rate of return estimation studies to select the best technique for this study. Two widely used ex-post evaluation methods were discussed in greater detail, particularly a variant of the general production function approach (Just-Pope). The progress made to date in developing these two methods has been considerable. Although both methods proved to be useful, the major drawbacks, such as the exclusion of the risk factor in modelling production relationships in the context of the production function

approach, prevent their use in this kind of analysis. The Just-Pope production function remained attractive and was used in analysing data.

Combining the results of the Just-Pope production function with the time period under consideration provided a segue to ascertaining the cumulative benefits associated with the programme. The BCR, IRR and MIRR were selected because they are methods generally used to estimate net returns of projects, and they account for the time value of money (i.e. they use discounted costs and benefits). Moreover, the MIRR has proved to have several advantages over the MIRR. Therefore, the results of the MIRR were preferred.

CHAPTER 5

EMPIRICAL RESULTS OF THE RATE OF RETURNS TO THE TABLE GRAPE CULTIVAR DEVELOPMENT PROGRAMMEME

5.7 INTRODUCTION

The ARC's TGCD Programme has released several table grape varieties. These varieties are suited to South African conditions and have made a tremendous contribution to the growth of the table grape industry. The breeding of new cultivar varieties in South Africa relies on the continuous injection of funds into the programme. While the programme has been sustained to date, public agricultural research investments in the form of parliamentary grants have declined in recent years. Moreover, the budget share for the TGCD Programme has declined since 2015. A need arises to evaluate research effectiveness and efficiency, mainly to give an account to policy makers at organisational level so that they would increase or maintain funding at programme level, particularly if the returns are positive. Therefore, this chapter estimates and evaluates the returns to investments in the programme through quantifying the genetic gains associated with the breeding programme, and ultimately provide an estimate of the BCR, IRR and MIRR. Therefore, the organisation of this chapter is as follows. Firstly, it presents descriptive statistics of selected variables and describes the battery of diagnostic tests performed. The analysis of the data ensues. Lastly, the results are interpreted and discussed.

5.8 DATA ANALYSIS AND RESULTS

This study employed the Just-Pope production function to analyse data. This technique has been more commonly used in studies that have endeavoured to estimate yield gains arising from breeding programmes, focusing mainly on grain crops. This is the first application of this kind of method in a horticultural crop-based breeding programme. Townsend and van Zyl (1998) used a general production function to evaluate the returns to wine grape research. Therefore, the average actual producer yields of the table grape varieties of the TGCD of ARC were modelled against the release years and the type of variety released (i.e. whether a variety released in a particular year is seedless or seeded).

The absence of experimental data on table grapes for various cultivars of the ARC rendered some of the efforts impossible or worthless. One example was the attempt to account for location-specific effects and another was encountered in efforts directed towards establishing

the effects of weather on different varieties. This resulted in the use of aggregate, actual producer yields per hectare for each variety. A variable trend, designed to capture time-fixed effects, caused heteroscedastic errors and was dropped from the model. This could be because of its high correlation with the release year variable.

5.8.1 Descriptive analysis

Table 5.1 below presents the univariate characteristics of the average yields and the type of variety released for ARC table grapes varieties. The univariate characteristics of release year variable are not presented. As has been previously mentioned, it captures the breeding technology embedded in a particular variety. Therefore, it is not a time series variable even though it is highly correlated to the trend variable. ARC table grapes cultivar varieties had an overall mean of 26.5 t/ha with a standard deviation of about 5 t/ha, after the yield has been adjusted for quality.

Table 0.1: Univariate characteristics for yield of table grapes

Variable	Number of varieties	Mean	Std. Dev.	Min	Max
Adjusted yield (t/ha)	37	26.50	4.99	21.45	40.58

Source: Computed by the author from the data

However, the two groups of varieties had different statistics when considered separately (Table 5.2 below). Accordingly, the mean and standard deviations of seeded varieties were 24.83 t/ha and 3.99 t/ha, respectively, whereas the seedless varieties had a relatively higher mean of 29.97 t/ha and a standard deviation of 5.23 t/ha. The ARC seedless table grape varieties seem to have higher average yields, compared with seeded varieties (Table 5.2), even though the ARC has released more seeded varieties than seedless varieties. Moreover, the yields of seeded varieties are more closely spread around the mean than those of seedless varieties are, as revealed by their corresponding standard deviations.

Table 0.2: Bivariate characteristics of table grape yields by type of variety

Varietal type	Mean (Adjusted yield (t/ha))	Standard Deviation (Adjusted yield (t/ha))
Seeded	24.83	3.99
Seedless	29.97	5.23

Source: Computed by the author from the data

A hypothesis testing process was performed to test whether the mean differences observed above were statistically significant (i.e. to test if the two groups of varieties have the same average yields). Accordingly, a two-tailed t-test and a one-tailed t-test were conducted. The student t distribution (t-test) is normally used for small samples (samples less than 100). Specifically, the two-tailed t-test examined whether there is a significant difference between the means of the two varieties, whereas the one-tailed t-tests examined whether the seeded varieties had a mean that was lesser or greater than that of the seedless varieties.

Table 5.3 below shows the results of the three statistical tests that were conducted. The means of the two types of varieties were statistically different at all conventional levels of significance ($Pr < 0.01$), when the two-tailed test is considered. Therefore, the null hypothesis of similar average yields was rejected in favour of the alternative hypothesis. With reference to the one-tailed t-tests, the mean of the seedless varieties is greater than that of the seeded varieties, also at all levels of significance ($Pr < 0.001$). This means that the breeding of seedless varieties is beneficial as it produces high yielding and good quality table grape varieties, as the yields were adjusted for quality. However, the information that answers the question of how much, on average, the yields of seedless table grapes might exceed those of seeded table grapes is missing. The Just-Pope results provide an answer to such a question.

Table 0.3: Hypothesis testing of the means of the two varietal groups

Difference = mean (seeded) - mean seedless		
Null hypothesis	Alternative hypothesis	Pr (T < t)
Difference = 0	Difference < 0	0.0011
	Difference not = 0	0.0021
	Difference > 0	0.9989

*Notes: Significance Levels are as follows *P<0.1, **P<0.05, ***P<0.01. RLYR, release year
Source: Computed by the author from the data*

The following subsections present the results of the Jus-Pope production function and the results of the BCR, IRR and MIRR, together with discussion thereof.

5.8.2 Battery of diagnostic tests

A battery of diagnostic tests was performed on the Ordinary Least Squares (OLS) residuals to determine any violation of the normal classical OLS assumptions. The tests performed included normality, misspecification and serial correlation (the results are included in the Appendix). There was not enough evidence found, from the data available, to reject a null hypothesis of no misspecification and no serial correlation. Moreover, a Breusch-Pagan Lagrange multiplier test for heteroscedasticity, which assumes normal distributed errors, was carried out. Accordingly, there was not enough evidence found to reject the null hypothesis of constant variance. However, the errors were found to be non-normally distributed. Errors were also found to be heteroscedastic. Thus, the use of the Just-Pope Production function was once again justified, as it corrects for heteroscedasticity. With regard to normality of residuals, the Central Limit Theorem (CLT) was assumed as only few cultivars were released. CLT suggests that estimators are asymptotically normal (Wooldridge, 2015). This means that, even though a variable is not from a normal distribution, it can be approximated to a normal distribution in larger sample sizes.

5.8.3 Regression results

Table 5.4 below shows the results of the Just-Pope production function, including the effects on yield and the yield variances, and OLS estimates. The Just-Pope model (Table 5.4, “Just-pope yield”) had the largest coefficient of determination (R^2). This means that 58% of the mean yield is accounted for by the explanatory variables included in the model. This is a large R-squared, relative to the values obtained in previous studies of this nature. For example, Dlamini *et al.* (2017) obtained an R^2 as low as 24%. This could be attributable to the different number of explanatory variables being included in a model. The adjusted R-squared penalises one for adding irrelevant variables into the model. While this study only used two explanatory variables, previous studies have included other variables, such as location dummies. Such variables could result in poor model fit (lower R-squared) if they poorly correlate with the dependent variable. For example, the weather variable was statistically insignificant and resulted in poor model fit. Therefore, it was dropped from the model.

Table 0.4: Regression results of adjusted-for quality yields from the Ordinary Least Squares (OLS) and Just-Pope Production Functions

Variable	OLS Yield	Just-Pope Yield	Just-Pope Variance
Intercept	-275.81 (146.44)**	-396.24 (119.27)***	-72.46 (60.83)
RLYR	0.15 (0.073)**	0.21 (0.060)***	0.037 (0.03)
Seeded	-2.48 (1.95)	-2.13 (1.17)*	- 0.39 (0.81)
Adjusted R ²	0.29	0.58	0.062

Notes: Significance Levels are as follows * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$. RLYR, release year

Figures in parentheses are standard errors

Source: Computed by the author from the data

The variable RLYR was the variable of interest because it captures the “vintage” (i.e. the level of technology incorporated in each table grape variety). Accordingly, after a transformation of the variable RLYR from the Just-Pope model into annual average gains, the results showed that the ARC’s TGCD Programme had a marginal addition of 0.21 t/ha ($P < 0.001$) from 1965 (with the release of Muska) to 2014 (with the release of Joybells) in table grapes yields varietal releases by the ARC, holding other factors constant (Table 5.4 above). With reference to Just-Pope yield variance, the varieties released by the ARC TGCD Programme since 1965 did not lead to an increase in the yield variance ($P > 0.1$) (Table 5.7), *ceteris paribus*.

Another variable of interest was varietal type (seeded). Seeded table grape varieties of ARC’s TGCD Programme had 2.13 t/ha less in yields, on average, compared with seedless varieties ($P < 0.1$) (Table 5.4, Just-Pope Yield), *ceteris paribus*. Moreover, the type of variety had no influence on yield variance ($P > 0.1$), holding other factors constant.

5.8.4 Results of the BCR, IRR AND MIRR

It was difficult to obtain data beyond 1965 and data that stretch beyond 1990s, since they do not exist. The period covered to calculate BCR and IRR is from 2008 to 2017. The ARC’s TGCD Programme experiences high competition from international breeding organisations, such as the United States Department of Agriculture - Agriculture Research Service. The department has released Crimson seedless (a table grape variety that is currently a leading variety in South Africa in terms of production and exports). The widespread adoption of other table grape varieties may be a leading factor contributing to low and declining adoption rates of the ARC’s table grapes varieties (Figure 5.1 below). Consequently, the gap between the total

area planted to table grapes and the area planted to ARC table grape varieties in South Africa grew over a 10-year period (Figure 5.1 below)

Most of the ARC’s TGCD varieties end up at the experimental level. However, there is renewed hope with the recent release of Joybells in 2014. Therefore, the estimated BCR, IRR and MIRR are limited to seven popular varieties of the ARC which did not end up at experimental level, and for which data was collected and available in complete form for a period of 10 years. Expert opinion from SATI helped in the selection of these varieties, based on the availability of the data.

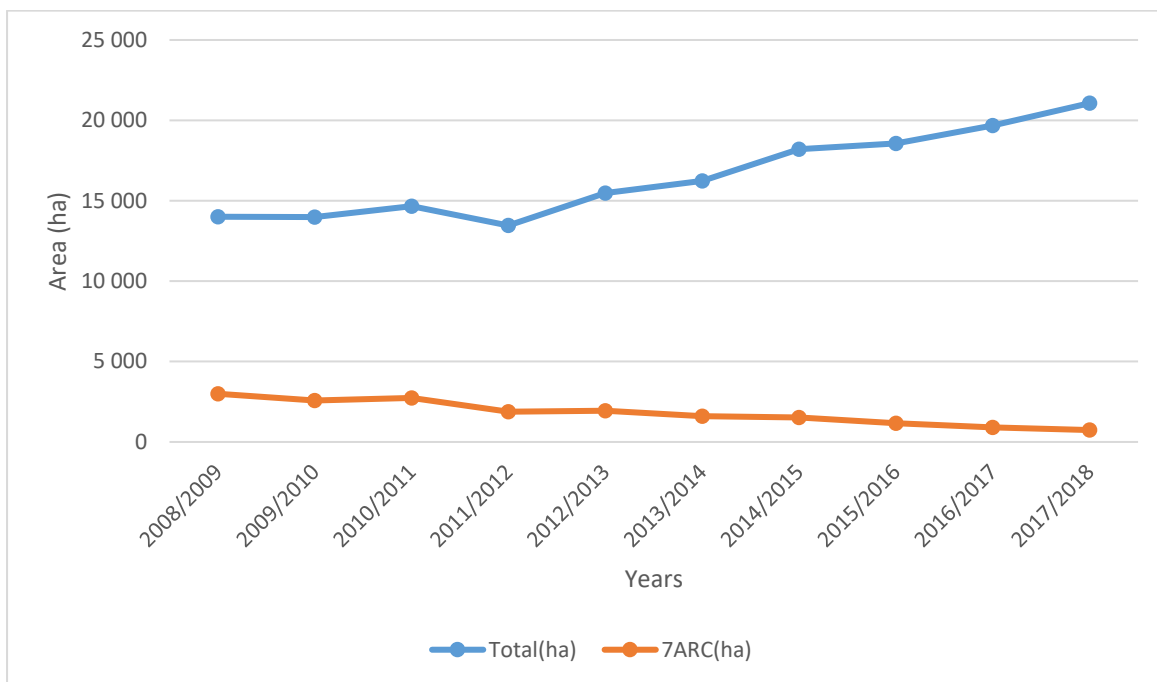


Figure 0.1: Total area planted to table Grapes VS area planted to 7 popular table grapes varieties released by the ARC's TGCD Programme in S.A. over a period of 10 years

Source: Constructed with the data obtained from SATI statistical booklet

Table 5.5 below is a representation of the cumulative genetic gains and economic benefits that accrue to table grape farmers in South Africa as a result of the ARC’s TGCD Programme (all monetary values are expressed in 2010 terms). A rough estimate of revenue gains that accrue to South African table grapes producers as a result of the ARC TGCD Programme was calculated using the cumulative annual genetic gains, area planted to ARC varieties, and real price data from 2008 to 2017.

Table 0.5: Per hectare cumulative genetic gains associated with the Agricultural Research Council TGCD Programme, 2008–2017

Year ¹	Cumulative Genetic Gain (t/ha)	Total area (ha)	ARC Adoption Rates (%)	Additional Production from 7 ARC Varieties (t)	Real Price(R/t)	Economic Gains (R/year)
2008	9,03	14 011	21.39	27058.94	7456.44	201,763,295.1
2009	9,24	13 982	18.49	23890.18	7244.90	173,082,015.7
2010	9,45	14 660	18.65	25837.93	7600.00	196,368,272.9
2011	9,66	13 462	13.91	18096.43	7557.81	136,769,399.5
2012	9,87	15 484	12.48	19076.12	8227.63	156,951,306.7
2013	10,08	16 229	9.93	16247.45	9027.46	146,673,102.6
2014	10,29	18 212	8.41	15761.29	9144.95	144,136,297.1
2015	10,5	18 575	6.24	12175.36	9487.32	115,511,495.4
2016	10,71	19 674	4.62	9741.675	9478.66	92,338,014.0
2017	10,92	21067	3.52	8090.237	9696.43	78,446,438.3
Average						144203963.7
Total						1,442,039,637

Source: Created with the data provided by SATI, DAFF, IMF and RLYR estimate from Table 1

The annual average gains and total gains for table grape farmers that can be attributed to the ARC’s TGCD Programme were R144 203 963.70 and R1 442 039 637, respectively, over the period from 2008 to 2017 (Table 5.5 above). The costs of running the TGCD Programme were obtained from the ARC and were used to calculate BCR and MIRR for the same period, and the data revealed the annual average costs of running the Programme to be R3 064 463.26 in 2010 terms. These costs included fixed improvements, and operational and personnel costs.

The annual cost data and estimated annual benefits were discounted to account for the time value of money by using the interest rate for government funds (obtained from IMF) as a proxy for a discount rate. This also took into consideration the 12-year lag that exists between the initial cross and the release year. The estimation using discounted annual cost data and estimated annual benefits yielded a BCR of 4.85:1. This means that every South African rand

¹ The Muska variety was released in 1965, but holistic table grape production data in South Africa was not available until 2008. As such, the cumulative gain between 1965 and 2008 is 9.03 t/ha (the Just-Pope release year [RLYR] coefficient from Table 1 [multiplied by 43 years]).

of public funds invested in the ARC's TGCD Programme is associated with R4.58 benefits. Furthermore, to gauge the research effectiveness, the IRR was calculated. The IRR answers the question of what would have happened if the funds invested in the Programme had been invested somewhere else, and interest had been earned there, by comparing the two interest rates (i.e. the deposit interest rate and interest rate earned by reinvesting money into the Programme). Accordingly, an IRR and an MIRR of 80% and 18%, respectively, were found.

5.9 INTERPRETATION AND DISCUSSION OF RESULTS

The results of the Just-Pope production function are ostensibly positive. Nevertheless, the findings referred to above are not interpreted, but only reported. Therefore, the results are given meaning through interpretation and discussion to facilitate their subtle understanding.

5.9.1 Interpretation and discussion of the Just-Pope Results

Before interpretation of the coefficient of the focus variable RLYR, it is important to first evaluate the sign and the magnitude of the coefficient against economic theory and the results of past studies. The results give an indication of positive genetic gains arising from the ARC's TGCD Programme. The positive sign makes economic sense as it is consistent with the theory and previous studies of this nature. In principle, breeding programmes are means of improving yields, yield qualities, and reducing variability for purposes of bettering the lives of key stakeholders such as producers and consumers. Thus, the positive sign is also in line with the results of the following studies which found a positive relationship between yields and breeding programmes: Dlamini *et al.* (2017), Coale (2017) and Nalley *et al.* (2010) for the bean breeding programme, the wheat breeding programme of the ARC, and the CIMMYT wheat breeding programme, respectively.

At first glance, the magnitude of the coefficient of RLYR seems to be very small relative to those found in other past studies. This is no surprise as this is measured in tonnes per hectare. The conversion of this value of the coefficient from t/ha to kg/ha (multiply by 1000) gives a considerable coefficient. This can now be evaluated statistically. The coefficient is statistically significant at all levels of significance (i.e. at 1%, 5% and 10% levels of significance) for both the Just-Pope yield and OLS yield. As has been previously postulated, the discussion is based on the results of the Just-Pope and the reason for this has been provided in the methodology section. The level at which this is significant is comparable with the previous findings by

Nalley *et al.* (2010), Dlamini *et al.* (2017) and Coale (2017). This means that the ARC's TGCD Programme increases the mean yield of its varieties by 0.21 t/ha (210 kg/ha) through the release of a new cultivar, *ceteris paribus*.

Moreover, the average mean yield of ARC table grape varieties is 26.5 t/ha for the period from 1965 to 2014. There are several factors that have contributed towards this average yield. These include viticultural practices, farmer experience, etc. Nevertheless, there it can be affirmed that 0.21 t/ha or 0.79% (0.21/26.5) annually results directly from the ARC's TGCD Programme. Cumulatively, the ARC's TGCD Programme has contributed 10.92 t/ha over the period from 1965 to 2017, which is equivalent to a 41.2% (10.92/26.5) increase in the yields of producers that is directly attributable to the ARC's genetic improvement programme. Nalley *et al.* (2010), Coale (2017) and Dlamini *et al.* (2017) found the annual yield gains (by the CIMMYT wheat, ARC wheat, and dry bean breeding programmes) to be 0.46%, 0.72% and 1.06%, respectively. The results obtained in this study compare well with the findings of these studies. This supports the hypothesis made that there is indeed a proportion of the mean yield that is directly attributable to the ARC's TGCD Programme. Furthermore, what is worthy of note and indicated by this finding is that attempts to adjust for quality did not compromise the end results.

With reference to the type of variety dummy variable, various reasons exist which may cause the type of variety released to have an effect on the average yields of table grapes. Normally, there are inherent differences across different species (Coale, 2017). Seedless varieties may generally have higher yields, compared with seeded table grapes varieties. The opposite case may also hold true. However, the negative intercept for seedless table grapes is not very meaningful in this case. The coefficient on seeded table grapes is interesting because it is a measure of the average difference in per-hectare yields between a seedless variety and a seeded variety of the same release year. This means that if a seedless variety and a seeded variety released in the same year are taken, the seeded variety yields, on average, 2.13 t/ha less per hectare than the seedless variety does. This compares well with the results obtained in the hypothesis testing. However, there is extra information that is provided (i.e. the amount by which yields of a seedless variety exceed those of a seeded variety). The above reasoning and inclusion of this dummy variable is based on the fact that the multiple regression implies a control of other factors, such as release year, such that the 2.13 t/ha yield differential cannot be explained by different release years. Thus, a conclusion can be reached that the yield

differential of 2.13 t/ha is due to the type of variety or to factors associated with the type of variety released that is not controlled for in the regression.

With regard to yield variance (risk), neither the release of the new variety nor the type variety increased the yield variance. This is in line with the objective of many breeding programmes, which is to increase yield/yield quality without an increase in yield variability. Thus, the study found yields to be increasing without a significant risk increase ($P > 0.1$). Several studies have also found yield variability not to be affected by factors such as release year, except in a study by Coale (2017) where yields and yield variability were both found to be increasing with the release of winter wheat varieties.

5.9.2 Interpretation and discussion of BCR, IRR and MIRR

The BCR of 4.85: 1 suggests that every South African rand of public funds invested in the ARC's TGCD Programme is associated with R4.58 benefits. This BCR would have been a bit higher if the benefits associated with all ARC varieties were taken into account. Moreover, the benefits would have been underestimated, provided that the quality unadjusted yield data have been used. To juxtapose the BCR associated with the unadjusted to those of the quality adjusted yields, the BCR associated with the former were also calculated and found to be 0.23:1. Thus, the difference is significant between the two results, and the BCR associated with quality unadjusted yields implies negative returns. It is no surprise, as the pioneering work of adjusting for quality by Townsend and van Zyl (1998) shows different rate of return results between adjusted and unadjusted for quality wine grapes. Moreover, the results compare well with other studies which estimated rates of returns to breeding research, both in South Africa and elsewhere in the world. Hence, the BCR obtained in this study falls between BCR in the study by Coale (2017) (4.49:1) and Dlamini *et al.* (2017) (5.67:1), for wheat and bean breeding, respectively. Nevertheless, the above BCRs, including that of this study, are in contrast with the findings of Naledzani (2017) who found that breeding for quality in wheat is associated with a BCR of 0.62:1.

With regard to gauging research effectiveness, an IRR of 80% was found. This IRR is common in horticultural research, as Thirtle *et al.* (1995) found an IRR of 100%. With reference to enterprise level, returns to research of 60% and 78% were established for Infruitec and Nietvoorbij, respectively (Thirtle *et al.*, 1995). Nevertheless, an IRR as high as this for programme-level evaluation is strange. Normally, IRR is expected to increase with the level of

aggregation. High IRRs associated with agricultural research have been questioned by policy makers. This has led to the calculation of the MIRR that is highly related to BCR (Dlamini *et al.*, 2017). In light of this, computation of the MIRR for the ARC's TGCD Programme indicated 18% return on investment. The BCR and MIRR, however, underestimate the benefits derived from the ARC's varieties, since the net economic benefits include only seven popular varieties.

5.9.3 Implications of the estimation and variables used on the obtained results

There were five explanatory variables that were initially considered (weather, type of variety, release year, time, and location-specific effects) for inclusion in the empirical estimation of the Just-Pope production function. However, problems related to unavailability of data resulted in the model being estimated with only two independent variables. It was foreseen, during the proposal stage, that the experimental yields would be used for estimation; however, the unavailability of such type of data rendered an investigation of the effects of explanatory variables, particularly weather and location-specific effects, on the dependent variables not worth pursuing.

With regard to weather, rainfall was used as a proxy for weather. This follows Burger *et al.* (2010) who regard rainfall as a major factor that influences the yields of table grapes. However, efforts to include this variable in the regression analysis were obstructed by the fact that aggregate actual producer yields, instead of experimental yields, were used in the estimation of results. As a result, the variable was statistically insignificant and gave poor model fit in terms of adjusted R-squared, as compared with the adjusted R-squared of the final selected model (Table 5.4 above). This is because of the fact that weather varies according to location; hence, effects of weather on yields would also be expected to vary according to regions (Dlamini *et al.*, 2017). Therefore, the absence of disaggregated experimental yield details rendered the weather variable insignificant. Nevertheless, earlier works of this nature were devoid of the weather variable, also due to data limitations. Yet, these studies were fortunate because experimental yields were available and could only hope that weather effects would be captured by the location-specific effects.

The use of aggregate table grape yields is in contrast with the work of Nalley *et al.* (2010), Dlamini *et al.* (2017) and Coale (2017) who used experimental yields. These studies took regard of the existing gap between the experimental yields and industry yields, and put forward

a motivation that relative yield differences in the farm and experimental yields are always expected to be equal. However, there is no consensus in the literature as to which yields are appropriate and would give accurate results. Therefore, it is this fact on which the use of aggregate industry yields found basis in this study. However, the study remains regardful of the marred efforts to account for location-specific effects that might have yielded rich results, because specific-location effects solely reflect differences in soils and other differences between agro-ecological zones, such as weather differences.

Furthermore, a time-specific effect variable was excluded. The time-specific effect was desired for capturing the changes in average yields that are attributable to technical change. The concept of technical change is a broad concept. Thus, this variable was excluded because it was causing errors to be heteroscedastic – a characteristic that is highly undesirable in the study of econometrics. According to Benin (2016), agricultural research also results in the technical change. Therefore, the time variable was highly correlated with the release years.

The Just-Pope production function provides allowance for a reasonable risk consideration in estimation, since agricultural production is not without risk. Therefore, the Just-Pope production function was still beneficial and justifiable, even after many variables had been dropped. Evidence of this claim can be perceived in the improvement in the model fit given by the adjusted R squared, from 0.29 for the OLS to 0.58 for the Just-Pope (Table 5.1 above). Furthermore, the R squared obtained here for the Just-Pope yield is relatively higher, 34 and 8 units higher than those obtained by Dlamini *et al.* (2017) and Nalley *et al.* (2010), respectively.

5.10 SUMMARY

The impact of the ARC TGCD programme was estimated by using a two-stage approach. In the first stage of analysis, the impact on the yield of table grapes was estimated using the Just-Pope production function. The results revealed that the impact of the ARC's TGCD programme on yields of table grapes was significantly positive. Nevertheless, the two types of table grape varieties made significantly different contributions towards yields, with the seedless varieties contributing more than the seeded varieties did. The second stage of analysis employed the benefit cost analysis to quantify the benefits in monetary terms. Specifically, the BCR, IRR and MIRR were estimated. The programme benefits were found to be greater than the programme costs were. Despite the exclusion of some important variables in the estimation of yield gains and benefits associated with other varieties in estimation of net economic benefits,

the results are similar to those reported in earlier works. Accordingly, the estimates of yield gains, BCR, IRR and MIRR proved to be reasonably high. The results clearly indicate that the ARC's TGCD Programme is beneficial to the South Africa community.

CHAPTER 6

CONCLUSIONS

5.11 INTRODUCTION

This chapter presents the conclusion of this study. The organisation of this chapter is as follows. Firstly, it presents the summary and results of the study. Secondly, the implications and recommendations are set out. Lastly, the chapter notes limitations of the study and recommendations for future research.

5.12 SUMMARY OF THE STUDY

This study aimed at estimating the economic returns of the ARC's TGCD Programme through pursuing three specific objectives. Firstly, the study sought to establish yield gains directly attributable to the ARC's TGCD Programme. This objective was based on the fact that the programme continuously develops high yielding and good quality table grape varieties that are suited to South African conditions. In light of this, there has been some increase in average annual yields which has been noted, and this can be attributed to several factors, which include improvement in viticultural practices over time, farmer experience, the TGCD Programme, etc. The Just-Pope production function was used to determine the yield gains in table grape yields that can be attributed to the ARC's TGCD Programme.

The Just-Pope production function is a special type of the general Cobb-Douglass production function that not only investigates factors affecting the mean, but also those factors that influence variance. In the context of this study, it provided allowance for linking the first objective and the second objective, with the latter seeking to evaluate whether attempts to improve yield and quality of table grapes compromised yield stability. Therefore, the second objective sought to investigate changes in yield variability that are directly attributable to the ARC's TGCD Programme. The Just-Pope production function was applied as a precursor to establishing BCR and IRR, and ultimately, MIRR.

The ultimate goal of the study was to establish BCR and MIRR in order to gauge research effectiveness and efficiency. These are highly important and relevant decision-making tools for a policy maker who might be eager to determine whether a project or programme is worth undertaking. As such, the BCR, IRR and ultimately MIRR were calculated, using their respective formulas, as discussed in the methodology chapter above.

5.13 KEY FINDINGS

The following key findings were established:

- The ARC's TGCD Programme led to an average annual yield gain of 0.79% for South African table grape producers during the period from 1965 to 2014. For the same period under consideration, the total increase in yields attributable to the programme was 41%.
- The table grape varieties of the ARC's TGCD Programme have not affected the yield variability since 1965. The new cultivar varieties have not increased nor decreased yield variability, even though they have been high yielding and of good quality, as compared with their predecessors. This suggests that maintenance breeding has played a significant role in this regard.
- There is a significant relationship between the type of variety released by the ARC TGCD Programme and price of table grapes when quality is considered.
- Yield differences between ARC seedless and ARC seeded table grape varieties reflect quality differences when quality adjustments are made (i.e. seedless table grape varieties have higher quality, compared with seeded table grapes).
- Moreover, there is a low adoption rate for ARC table grape varieties. Only a few ARC table varieties feature in the top 20 table grape varieties planted and exported by South Africa. There has been a decay in the adoption rate over the past decade.
- The economic returns associated with the ARC TGCD Programme are high. The average annual economic benefits that accrued to South African table grape farmers as a result of the ARC's TGCD Programme is R144 203 963.70 (in 2010 monetary values) for the period 1965 to 2014. This then gave a BCR and an MIRR of 4.85 and 18%, respectively, for the period 2008 to 2017.
- There are significant differences between the rates of returns derived from quality unadjusted (Appendix 1) and quality adjusted yields. This means that much of the research conducted not only improves yields, but also the quality of table grapes.

5.14 CONCLUSIONS

With reference to the first specific objective, the Just-Pope and OLS give comparable results. This increases the confidence in the results, as they seem to be reliable and robust. Therefore, there was sufficient evidence to support the hypothesis that there is indeed a proportion of yields that is attributable to the ARC's TGCD Programme. *Ceteris paribus*, the ARC's breeding programme continuously contributes a certain proportion towards the yield increase of table grapes over time.

Moreover, the attempts to increase yield or yield quality of table grapes through the development of new table grape varieties by the ARC neither increased nor decreased yield stability. Therefore, the producers benefit, because if yield stability is not affected, but the yield quality or yields are, then the overall effect is that reduced risk is incurred in the production of table grapes from one season to another. This leads to increased profit margins being experienced, over time. Therefore, there was not enough evidence found to support the hypothesis that modern varieties have higher yields which vary across growing seasons, when compared with traditional varieties in developing countries.

Furthermore, with regard to the third specific objective, the benefits derived from the table grape breeding programme are larger than the costs of running it are by a multiple of about 5, given the evaluations of this study. The ARC's TGCD Breeding Programme has been providing huge and sustainable net economic benefits to table grape farmers in South Africa. The area planted to ARC table grapes varieties is declining relative to the area planted to non-ARC varieties.

5.15 RECOMMENDATIONS AND IMPLICATIONS

Several implications for policy makers and other relevant stakeholders, such as breeders and farmers, arise from the study. High RORs suggest that there is a room for increasing investments in TGCD Programme by policy makers. Moreover, the larger benefits imply that other beneficiaries, such as table grape farmers, could also increase their economic benefits through involvement in the funding process. Table grape producers could derive greater benefits by growing more of the seedless table grapes varieties, since they are not only favourable to consumers but also have higher yields per hectare, as compared with seeded varieties, despite pruning and all other yield-reducing activities. Breeders should also breed

more of the seedless varieties, as this would increase benefits for both consumers and producers.

The ARC TGCD Programme targets commercial table grape producers that are based in a few provinces. Since nothing in the programme talks to the land reform programme, the TGCD Programme should also be restructured, such that greater numbers of smallholder table grape farmers would benefit from the programme. This could increase the adoption rates of the ARC table grape varieties, as well as the expansion of the programme to other regions of South Africa where table grapes have not been previously grown. The programme will receive considerable attention, provided that Joybells continues to do well, given its good start.

5.16 LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Future research should probe and seek to address the issues set out below.

- Future studies should attempt to put a value on the benefits of maintenance breeding. The most easily perceived improvements by the ARC's TGCD Programme are the increased yields and enhanced quality. Nevertheless, there are other considerable economic benefits derivable from maintenance breeding. When new varieties are bred, yield losses and quality deterioration are avoided through maintenance breeding. However, the study did not quantify or attempt to monetarise the benefits that might accrue as a result of maintenance breeding. Dlamini *et al.* (2017) postulate that, in the absence of a breeding programme, yield destabilisation or deterioration of quality could occur due to pathogens becoming more resistant over time, mainly as a result of climate change.
- An evaluation of the competitiveness of the TGCD Programme, in terms of Porter determinants, should be undertaken to shed more light on the sources of growth of, and the factors constraining, the adoption rate of ARC table grape varieties. Accordingly, an examination of factor and demand conditions, supporting industries; and the programme strategy, structure and rivalry, would be beneficial to the programme. The ARC has developed several table grape varieties with relatively poor adoption rates, as compared with international varieties.
- At least one economist should be involved at every stage of the project formulation, mainly for gathering and compiling relevant data in a systematic manner and

appropriate series, so that the evaluation of the impact of the programme could be facilitated. This is because the lack of time series and project-specific data are apparent problems which limit in-depth economic analysis.

REFERENCES

- ARC (Agricultural Research Council). 2016. *Annual report for 2015/2016*. Pretoria: Agricultural Research Council
- Alston, J. M., Norton, G. W., & Pardey, P. G. 1995. *Science under scarcity: principles and practice for agricultural research evaluation and priority setting*. Ithaca: Cornell University Press. [Online] Available from: <https://www.cabdirect.org/cabdirect/abstract/19986772609> [Accessed: 2018- 06- 11].
- Alston, J. M., Marra, M. C., Pardey, P. G., & Wyatt, T. J. 2000. Research returns redux: a meta-analysis of the returns to agricultural R&D. *Australian Journal of Agricultural and Resource Economics*, 44(2):185-215. [Online] Available from: <https://doi.org/10.1111/1467-8489.00107> [Accessed: 2018- 04-30].
- Anandajayasekeram, P., & Martella, D. R. 1999. Evaluation of agricultural research in Eastern, Central, and Southern Africa. *Knowledge, Technology & Policy*, 11(4):13-41. [Online] Available from: <https://link.springer.com/article/10.1007/s12130-999-1002-8#citeas> [Accessed: 2018- 06-11].
- Arrow, K. J. 1962. The economic implications of learning by doing. *The review of economic studies*, 29(3):155-173. [Online] Available from: https://www.jstor.org/stable/2295952?seq=1#metadata_info_tab_contents [Accessed: 2018-07-04].
- Benin, S. (Ed.). 2016. *Agricultural productivity in Africa: Trends, patterns, and determinants*. International Food Policy Research Institute.
- Bervejillo, J. E., Alston, J. M., & Tumber, K. P. 2011. The Economic Returns to Public Agricultural Research in Uruguay. *Robert Mondavi Institute Centre for Wine Economics Working Paper*, (1103). [Online] Available from: <http://vinecon.ucdavis.edu/publications/cwe1103.pdf> [Accessed: 2018-06-11].
- Brennan, J. P. 1989. An analysis of the economic potential of some innovations in a wheat breeding Programme. *Australian Journal of Agricultural and Resource Economics*, 33(1):48-55. [Online] Available from: <https://doi.org/10.1111/j.1467-8489.1989.tb00480.x> [Accessed: 2018- 03-13].

- Burger, P., Vermeulen, A., Halleen, F., Koopman, T., Van Heerden, C. J., & Prins, R. 2010. Table grape breeding at the ARC Infruitec-Nietvoorbij, South Africa; its impact on the SA industry and latest developments. In *X International Conference on Grapevine Breeding and Genetics (1046)*:245-249. [Online] Available from: 10.17660/ActaHortic.2014.1046.31 [Accessed: 2018- 06-11].
- Coale, M. J. 2017. *The Economic Benefits of the South African Agricultural Research Council's Wheat Breeding Program: 1992-2015* (Masters Dissertation, University of Arkansas). [Online] Available from: <https://scholarworks.uark.edu/etd/2600/> [Accessed: 2018-03-13].
- Dey, M. M., & Deb, U. K. 1990. The economics of investment in agricultural research in Bangladesh. *Bangladesh Journal of Agricultural Economics*, 13(1):1-23. [Online] Available from: https://ageconsearch.umn.edu/bitstream/207869/2/Article_01%20Vol-XIII.pdf [Accessed: 2018-03-13].
- DAFF (Department of Agriculture, Forestry and fisheries). 2012a. *A Profile of the South African Table Grapes Market Value Chain*. [Online] Available from: <https://www.nda.agric.za/docs/AMCP/Tgmvp2012.pdf> [Accessed: 2018-02-31].
- DAFF (Department of Agriculture forestry and fisheries). 2012b. *Grapes Production Guideline*. [Online] Available from: <https://www.nda.agric.za/docs/Brochures/grapesprod.pdf> [Accessed: 2018-10-23].
- DAFF (Department of Agriculture, Forestry and fisheries). 2016. *A Profile of the South African Table Grapes Market Value Chain*. [Online] Available from: <https://www.nda.agric.za/daaDev/sideMenu/Marketing/Annual%20Publications/Commodity%20Profiles/field%20crops/Table%20grape%20market%20value%20chain%202016.pdf> [Accessed: 2018-03-11].
- DAFF (Department of Agriculture, Forestry and Fisheries). 2017. Abstract of Agricultural Statistics; 2017. [Online] Available from: [http://www.daff.gov.za/Daffweb3/Portals/0/Statistics%20and%20Economic%20Anal](http://www.daff.gov.za/Daffweb3/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/Abstract%202017.pdf) ysis/Statistical%20Information/Abstract%202017.pdf [Accessed: 2018-07-10].

- Dlamini, T., Nalley, L., Tsiboe, F., Barkley, A., & Shew, A. 2017. The Economic Impact of the South African Agricultural Research Council's Dry Beans Breeding Program. *Journal of Agricultural and Applied Economics*, 49(2):232-250 [Online] Available from: <https://doi.org/10.1017/aae.2016.46> [Accessed: 2018- 01-29].
- Evenson, R. 1967. The contribution of agricultural research to production. *Journal of Farm Economics*, 49(5):1415-1425. [Online] Available from: https://www.jstor.org/stable/1237038#metadata_info_tab_contents [Accessed: 2018-06-14].
- Evenson, R. E. 2001. Economic impacts of agricultural research and extension. *Handbook of agricultural economics*, 1:573-628. [Online] Available from: [https://doi.org/10.1016/S1574-0072\(01\)10014-9](https://doi.org/10.1016/S1574-0072(01)10014-9) [Accessed: 2018- 05-2].
- Fan, S. 2000. Research investment and the economic returns to Chinese agricultural research. *Journal of Productivity Analysis*, 14(2):163-182. [Online] Available from: <https://link.springer.com/article/10.1023/A:1007803108805> [Accessed: 2018-06-11].
- Farrington, J., Thirtle, C., & Henderson, S. 1997. Methodologies for monitoring and evaluating agricultural and natural resources research. *Agricultural Systems*, 55(2), 273-300. [Online] Available from: <https://www.sciencedirect.com/science/article/pii/S0308521X97000115> [Accessed: 2018-05-2].
- FAO (Food and Agricultural Organization). 2009. *How to feed the world 2050*. [Online] Available from: http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf [Accessed: 2018-05-2].
- FAO (Food and Agriculture Organization). 2016. *Table and Dried Grapes: Non-alcoholic products of the vitivincultural sector intended for human consumption*. [Online] Available from: <http://www.fao.org/3/a-i7042e.pdf> [Accessed:2018- 05-2].
- Flaherty, K., Liebenberg, F & Kirsten, J .2010. *Agricultural Science and Technology Indicators*. [Online] Available from: <https://www.asti.cgiar.org/pdf/SouthAfrica-Note.pdf> [Accessed: 2018- 12-22].

- Fuglie, K. O., & Heisey, P. W. 2007. *Economic returns to public agricultural research*. Washington, DC: US Department of Agriculture, Economic Research Service.
[Online] Available from:
<http://cuke.hort.ncsu.edu/gpb/publications/agresearchreturns.pdf> [Accessed: 2018- 05- 2].
- Griliches, Z. 1958. Research costs and social returns: Hybrid corn and related innovations. *Journal of political economy*, 66(5):419-431. [Online] Available from:
[fromhttps://www.journals.uchicago.edu/doi/abs/10.1086/258077?journalCode=jpe](https://www.journals.uchicago.edu/doi/abs/10.1086/258077?journalCode=jpe)
[Accessed: 2018- 03-13].
- HORTGRO. 2017. *Key Deciduous Fruit Statistics 2017*. [Online] Available from:
www.hortgro.co.za [Accessed: 2018-05-2].
- Just, R.E & Pope, R.D. 1978. Stochastic Specification of Production Functions and Economic Implications.
- Kierulff, H. 2008. MIRR: A better measure. *Business Horizons*, 51(4): 321-329. [Online] Available from: <https://doi.org/10.1016/j.bushor.2008.02.005> [Accessed: 21-12- 2018].
- Kirsten, J. (Ed.). 2009. Institutional economics perspectives on African agricultural development. In: Johann F. Kirsten, Andrew R. Dorward, Colin Poulton, and Nick Vink (Eds). Washington, D.C: International Food Policy Research Institute.
- Kumbhakar, S. C. 2002. Productivity measurement: a profit function approach. *Applied Economics Letters*, 9(5):331-334. [Online] Available from:
<https://doi.org/10.1080/13504850110067469> [Accessed: 2018-06-18].
- Liebenberg, F., Beintema, N. M., & Kirsten, J. F. 2004. *Agricultural science and technology indicators*. [Online] Available from:
https://www.asti.cgiar.org/pdf/SouthAfrica_CB14.pdf [Accessed: 2018-07-10].
- Maredia, M., Byerlee, D., & Anderson, J. R. 2000. Ex post evaluation of economic impacts of agricultural research programs: a tour of good practice: Paper presented to the Workshop on “The Future of Impact Assessment in CGIAR: Needs, Constraints, and

- Options”, Standing Panel on Impact Assessment (SPIA) of the Technical Advisory Committee, Rome, May 3-5, Rome. [Online] Available from: <https://hdl.handle.net/10947/503> [Accessed: 2018-07-14].
- Naledzani, Z., Chaminuka, P., Nhundu, K., Machethe, C. L., & Liebenberg, F. 2019. Economic value of quality restrictions on the wheat industry in South Africa. *Agrekon*, 1-11.
- Nalley, L. L., Barkley, A. P., & Featherstone, A. M. 2010. The genetic and economic impact of the CIMMYT wheat breeding program on local producers in the Yaqui Valley, Sonora Mexico. *Agricultural Economics*, 41(5):453-462. [Online] Available from: <https://doi.org/10.1111/j.1574-0862.2010.00457.x> [Accessed: 2018-05-2].
- Naseem, A., Spielman, D. J., & Omamo, S. W. 2010. Private-sector investment in R&D: a review of policy options to promote its growth in developing-country agriculture. *Agribusiness*, 26(1):143-173. [Online] Available from: <https://doi.org/10.1002/agr.20221> [Accessed: 2018-07-14].
- Nevondo, T. T., Chaminuka, P., Nhundu, K., & Liebenberg, F. 2019. Economic returns from investment in beef cattle improvement research in South Africa. *Agrekon*, 1-12.
- NPC (National Planning Commission). 2011. *National Development Plan: Vision for 2030*. [Online] Available from: https://www.gov.za/sites/default/files/devplan_2.pdf [Accessed: 2018-01-29]
- ONE. 2013. The Maputo Commitments and the 2014 African Union Year of Agriculture. [Online] Available from: https://s3.amazonaws.com/one.org/images/131008_ONE_Maputo_FINAL.pdf [Accessed: 2018-12-08].
- Rancho, M, 2015. *An Analysis of publicly funded Vegetable Research in South Africa* (Unpublished Masters’ thesis, University of South Africa). [Online] Available from: <http://hdl.handle.net/2263/50677> [Accessed: 2018-02-24].
- Reynolds, S. 2009. Analysing the South African table grape industry within a partial equilibrium framework. *Agrekon*, 48(2):124-145. [Online] Available from:

<https://www.tandfonline.com/doi/abs/10.1080/03031853.2009.9523820> [Accessed: 2018-07-14].

SATI (South African Table Grape Industry). 2017. *Research report*. [Online] Available from: http://www.satgi.co.za/Media/Default/Documents/SATI_Research_Report_2017_18.01.18.pdf [Accessed: 2018-01-29].

SATI (South African Table Grape Industry). 2018. *2018 Statistics*. [Online] Available from: <http://www.satgi.co.za/industry-info/statistics/statistics-booklet> [Accessed: 2018-10-29].

Schimmelpfennig, D., Thirtle, C., van Zyl, J., Arnade, C., & Khatri, Y. 2000. Short and long-run returns to agricultural R&D in South Africa, or will the real rate of return please stand up?. *Agricultural Economics*, 23(1):1-15. [Online] Available: <https://doi.org/10.1111/j.1574-0862.2000.tb00079.x> [Accessed: 2018-06-18].

Shultz, T. W. 1953. *The Economic Organization of Agriculture*, New York: McGraw Hill.

Symington, S. 2008. *Staying ahead of the global pack: [creating sustainable competitive advantage in the marketing of South African table grapes to the United Kingdom in the deregulated era]* (Doctoral dissertation, University of Cape Town).

Thirtle, C., Hadley, D., & Townsend, R. 1995. Policy-induced Innovation in Sub-Saharan African Agriculture: A Multilateral Malmquist Productivity Index Approach. *Development Policy Review*, 13(4):323-348. [Online] Available from: <https://doi.org/10.1111/j.1467-7679.1995.tb00097.x> [Accessed: 2018-03-13].

Thirtle, C., Lin, L. and Piesse, J., 2003. The impact of research-led agricultural productivity growth on poverty reduction in Africa, Asia and Latin America. *World Development*, 31(12):1959-1975. [Online] Available from: <https://doi.org/10.1016/j.worlddev.2003.07.001> [Accessed: 2018-07-14].

Townsend, R & van Zyl, J .1998. Estimation of the Rate of Return to Wine Grape Research and Technology Development Expenditures in South Africa. *Agrikon: Agricultural Economics Research, Policy and Practice in Southern Africa*, 32(2):189-210 [Online] Available at: <http://dx.doi.org/10.1080/03031853.1998.9523505> [Accessed: 2018-03-13].

Traxler, G., Falck-Zepeda, J., Ortiz-Monasterio R, J. I., & Sayre, K. 1995. Production risk and the Evolution of Varietal Technology. *American Journal of Agricultural Economics*, 77(1), 1-7. [Online] Available from: <https://doi.org/10.2307/1243883> [Accessed: 2018-07-14].

Tshabalala, P. M. 2015. Estimating the rate of return of plum research in South Africa (Unpublished Masters' thesis, University of Pretoria). [Online] Available from: <http://hdl.handle.net/2263/45909> [Accessed: 2018-06-18].

Tsvakirai, C. Z. 2015. *An economic evaluation of South Africa's peach and nectarine research* (Unpublished Masters' thesis, University of Pretoria). [Online] Available from: <http://hdl.handle.net/2263/50809> [Accessed: 2018-01-29].

Vink, N. 2000. Agricultural policy research in South Africa: Challenges for the future. *Agrekon*, 39(4):432-470. [Online] Available from: <https://doi.org/10.1080/03031853.2000.9523664> [Accessed: 2018-01-29].

Wooldridge, J. M. 2015. *Introductory econometrics: A modern approach*. Nelson Education.

APPENDICES

Appendix 1

Table A.1. Regression results of unadjusted yields from the Ordinary Least Squares(OLS) and Just-Pope Production Functions

Variable	OLS Yield	Just-Pope Yield	Just-Pope Variance	Mean Yield (t/ha)
Intercept	1.98 (1.93)	3.006 (2.12)	-45.94 (44.77)	23.50
RLYR	0.01(0.0009)***	0.01(0.001)***	0.02 (0.22)	
Seeded	0.004 (0.025)	0.02 (0.025)	- 0.09 (0.59)	
Adjusted R ²	0.29	0.83	0.008	

Notes: Significance Levels are as follows * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$. RLYR, release year

Source: Stata output

Table A.2: Per Hectare Cumulative Genetic Gains Associated with the Agricultural Research Council TGCD Programme for un adjusted yields, 2008-2017

Year	Cumulative Genetic Gain (t/ha)	Hectares of Table Grapes in South Africa (ha)	ARC Adoption Rates(%)	Additional Production from 7 ARC Varieties (t)	Real Price(R/t)	Economic Gains (R/year)
2008	0,43	14 011	21.39	1288,521	7456.44	9607775,957
2009	0,44	13 982	18.49	1137,627	7244.90	8242000,747
2010	0,45	14 660	18.65	1230,378	7600.00	9350870,14
2011	0,46	13 462	13.91	861,7346	7557.81	6512828,549
2012	0,47	15 484	12.48	908,3866	8227.63	7473871,748
2013	0,48	16 229	9.93	773,6879	9027.46	6984433,458
2014	0,49	18 212	8.41	750,5377	9144.95	6863633,193
2015	0,5	18 575	6.24	579,7788	9487.32	5500547,399
2016	0,51	19 674	4.62	463,8893	9478.66	4397048,287
2017	0,52	21067	3.52	385,2494	9696.43	3735544,681
Average						6866855,416
Total						68668554,16

IRR: -33%

MIRR: -8%

BCR: 0.23: 1

Table A.3: ARC varieties in their ascending order of release

Cultivars	Cultivar numbers according to their release years
Muska	1
Pirobella	2
Jakaranda	3
Golden City	4
Erlihane	5
Bien Donné	6
Ronelle	7
Rosete	8
Bellevue	9
Dauphine	10
Belair	11
Pêrel	12
Rubistar	13
Sonita	14
Bonheur	15
Bonita	16
Muscat Seedless	17
La Rochelle	18
Esmeralda	19
Sunred seedless	20
Muscat Supreme	21
Eclipse seedless	22
Majestic	23
Muscat Supreme	24
Rodette	25
Lady Ann	26
White gem	27
Sundance Seedless	28
Regal Seedless	29
Muscat delight	30
Ebony star	31
Autumn Queen	32
Scarlet Dew	33
Black Velvet	34
Desert Dawn	35
Rosidawn	36
Joybells	37

Table A.4: CPI Index for the period 2008 to 2018

Years	CPI
2008/2009	89,59
2009/2010	96,10
2010/2011	100,00
2011/2012	105,02
2012/2013	111,03
2013/2014	117,44
2014/2015	124,65
2015/2016	130,27
2016/2017	138,86
2017/2018	146,05

Table A.5: Battery of diagnostic tests

Diagnostic tests: Test	H_0	Test Statistic	p -Value	Conclusion
Shapiro-Wilk	Residuals are normally distributed	JB(2) = 12.30	0.0069	Residuals are not normally distributed
Ramsey RESET	No misspecification	F(3, 31) = 1.23	0.323	No misspecification
Breusch-Godfrey LM	No 2nd-order serial correlation in residuals	nR2(2) = 1.845	0.398	No 2nd-order serial correlation
Breusch-Pagan	No heteroscedasticity	chi2(1) = 1.32	0.2501	No heteroscedasticity