Estimating the economic rate of return to plum research in South Africa

By

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Submitted in partial fulfilment of the requirements for the degree MSc Agric (Agricultural Economics)

in the

Department of Agricultural Economics, Extension and Rural Development
Faculty of Natural and Agricultural Sciences
University of Pretoria

February 2015

DECLARATION

I, Precious Makhosazana Tshabalala declare that "**Estimating the economic rate of return to plum research in South Africa**", which I submit for the degree MSc in Agricultural Economics at the University of Pretoria is my own work and has not been submitted by me for a degree at this or any other university.

Signature: ______________________

Date: ______________________

ACKNOWLEDGEMENTS

The completion of this study was made possible by the valuable assistance I received from many people. My first and foremost thanks go to my Heavenly Father for giving me spiritual strength, courage, guidance and commitment to do this work. May his name be praised for he made it possible for me to come this far.

I would like to express my heartfelt gratitude to my respectable and humble supervisor, Dr Frikkie Liebenberg, for his tireless efforts and guidance from the inception of my study up to its completion. His patience and constructive sources of ideas kept alive my motivation and made the completion of this study possible.

It is with pleasure that I acknowledge my co-supervisor, Prof Kirsten, Head of Department of Agricultural Economics, Extension and Rural Development, for his support and encouragement throughout the study.

I would further like to convey my sincere thanks and gratitude to Mr C Smith, Researcher at ARC-Infruitec/Nietvoorbij, for unstintingly describing every process involved in plum breeding and other research and for introducing me to all the stakeholders in the plum industry.

I would like to thank Dr Thula Sizwe Dlamini, Agricultural Economist at the Agricultural Research Council (ARC) for dedicating many hours to review my writing. My sincerest appreciation goes to Dr Aart-Jan Verschoor, Senior Manager: Agricultural Economics Unit at the Agricultural Research Council for selecting me to be part of the Professional Development Programme and for financial support.

I would also like to thank the librarians at the ARC-Infruitec/Nietvoorbij for their tireless efforts in helping me track all the archived information on plum research. Also, I would like to thank the staff at Hortgro for answering all the questions I had and providing any information I requested. Last but not least, I would like to thank my parents for teaching me self-discipline, and for their love, encouragement and support throughout the study.

ABSTRACT

ESTIMATING THE ECONOMIC RATE OF RETURN TO PLUM RESEARCH IN SOUTH AFRICA

By

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Several studies have shown that investing in agricultural research and development (R&D) has enhanced global agricultural productivity by a great deal. Continued investments in agricultural research have led to the development of over 26 successful plum cultivars since 1945 at the Agricultural Research Council's Infruitec/Nietvoorbij in South Africa, and more continue to be developed to meet the specific needs of both producers and consumers. Yet very little is known about the returns on any of these research initiatives.

The objective of the study was to show what the rate of return to plum research investments at Infruitec/Nietvoorbij is. This was done by providing a comprehensive understanding of the role Infruitec/Nietvoorbij and its predecessor institutes have played in making the sector productive and competitive internationally, and the changes in R&D investments as well as the institutions that influence plum production and exports. Secondary data collected from the industry representatives and Infruitec were used in estimating how research at Infruitec has contributed to changes in production output. The production function approach was used as an analysis tool and the rate of return (ROR) to investments since 1980 was found to be 14.23 percent with a 10 year lag. The rate of return being this high is indicative of underinvestment in plum research.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Several studies have shown that investing in agricultural research and development has greatly enhanced global agricultural productivity (Pardey, 2012). In South Africa, continued investments in agricultural research and development have yielded huge benefits to the agricultural sector (Thirtle et al., 1998). For example, continued investments in agricultural research and development in deciduous fruits have led to the development of over 300 deciduous fruit cultivars in South Africa and more continue to be developed to meet the evolving needs of both producers and consumers. During the course of the last 15 years, 63 stone fruit cultivars were released into the agricultural sector of South Africa through the Agricultural Research Council's (ARC) stone fruit breeding programme, and 59 percent of these were released in the last five years (ARC, 2012).

Yet very little is known about the economic benefit of the ARC's stone fruit research initiatives in South Africa. This is especially true for the ARC's plum fruits breeding research programme, which dates back to the early 1940s. With most of the plums available in stores being varieties belonging mainly to the Japanese plum[1] group *Prunus salicina* (Okie and Ramming, 1999), a vast amount of research has gone into producing plum varieties that are adapted to South African climatic conditions. Plums were first introduced into South Africa around 1896 by Mr Pickstone who had been deputed by Cecil John Rhodes, the then Prime Minister of the Cape Colony, to import the Japanese plum from California in the United States of America (Black, 1952). Because these fruits were not native to South Africa, growth of the plum industry was compromised by the poor quality produced. For the industry to be sustainable there was a need for science to intervene. Formal research and development in plums followed three and half decades after their first introduction, and plum-breeding

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[1] Whilst the Japanese plum originated in what is today known as China, it was domesticated in Japan over 400 years ago (Anon, 2012).

research began a decade later. Most plum research was done at the Western Province Fruit Research Station, the forerunner of ARC's Infruitec/Nietvoorbij, and since its inception a number of positive results have come out of the research endeavours.

The role that Infruitec/Nietvoorbij plum research has played in making the sector productive and internationally competitive is an important one. Of the top ten cultivars planted in South Africa, seven were developed by the Infruitec/Nietvoorbij plum-breeding programme. Two of ARC's plum cultivars Laetitia and Songold are produced in the largest quantities in South Africa, with both cultivated on an area comprising 28 percent of the total area on which plums are planted. Songold was released in 1972 and Laetitia in 1985 and several other cultivars have been developed since then. A press release by the ARC in 2012, reported that their cultivars contributed enormously to the plum industry. Other key research focus areas are discussed in Chapter 3.

That the plum industry has grown since the 1940s, is no exaggeration as seen in the increase in the area planted, total production and export earnings shown in Chapter 2. Yet, the industry is faced with many challenges and opportunities. For example, whilst the area planted with plums grew from less than 100 hectares in 1950 to nearly 5 000 hectares in 2012 (Du Preez, 2012), this represents six percent of the total area planted with deciduous fruits in South Africa. By any standards, this illustrates that the cultivation of plums in South Africa can still improve by intensifying plum fruit research. Indeed, as Pardey *et al*. (2012) note: "agricultural R&D is a crucial determinant of agricultural productivity and production."

1.2 PROBLEM STATEMENT

Applied research on plums in South Africa was initiated in 1933 with the main objective of addressing the problem of mixed maturities and internal disorders in export plums. Over time, it evolved from quality maintenance and extension of post-harvest storage to quality improvement and extension of cold storage periods (De Kock and Taylor, 2012). Whilst the South African plum industry has been growing in volumes and in export earnings, it still faces several challenges that need to be addressed by more research in order to realize its full potential. For example, research is needed to overcome the problem of unsuitable storage temperatures for plums, which is a threat to late maturing plums during shipping — especially when plums are transported with other fruits in the same temperature regime.

Similarly, the Institute still needs to engage in research that will lead to the development of new cultivars that have high sugar content and good flavours in order to maintain and increase sales (ARC-Infruitec, 1996). Other research initiatives of the Institute's plum breeding programmes include efforts to develop new and improved plum cultivars of improved fruit size. The priority of the plum-breeding programme is to develop new cultivars that mature early and can prosper under less sunshine or low daylight during the early part of the season. However, for the Institute to meet all of its plum-research objectives, it requires expertise which can only be maintained through adequate funding. In South Africa, plum research is funded predominantly by the government through the ARC's Parliamentary Grant (See Chapter 4).

However, due to a lack of evidence supporting the continuation of funding for the research at the ARC, the funds allocated to the ARC and its institutes have continued to decrease since 1992/93 (Liebenberg, Pardey and Kahn, 2011), this has consequently meant the decrease in funding of the plum-research programme. As a result, the institute became more dependent on external income, with the deciduous fruit industry taking the lead role in funding of deciduous fruit research — including plums at Infruitec/Nietvoorbij. Whilst the ARC claims that continued plum research at Infrutec/Nietvoorbij has contributed about 80 percent towards the growth in the industry (ARC, 2012), the rate of return to investment in plum research is unknown. Although the deciduous fruit industry has also played a pivotal role in funding plum research at the ARC, problems such as lack of expertise to conduct fruit research and gathering supporting empirical evidence showing the value of the ARC's plum research outputs, have seen funds gradually being diverted to competing research institutions such as the University of Stellenbosch, ExperiCo and Stargrow among others.

Yet, despite the decrease in research funding, the local plum industry has continued to grow, but is facing challenges in penetrating other markets such as India and China (Kotzé, 2014). With South Africa being one of the major exporters of deciduous fruits in the highly competitive global deciduous fruit industry, continuing investments — especially increasing public funding — in the development of new plum cultivars with improved fruit yield and quality will certainly go a long way in leveraging South Africa's position in the global plum industry.

It is therefore paramount that the rate of return to research is determined in order to inform R&D decision-makers of the importance of public support for agricultural research and to substantiate the need for more investment in existing plum breeding and other plum research programmes. Showing research impacts is important to ensure an appropriate level of public support. Without clear and convincing evidence of its benefits, research will not be able to attract the necessary funding required for it to be successful.

1.3 OBJECTIVES OF THE STUDY

The main aim of the study is to estimate the economic rate of return to investments in the plum research programme of the Agricultural Research Council at Infruitec/Nietvoorbij. This overall aim was addressed through the following specific objectives:

i. Describing the nature of plum research at the ARC.
i. Determining the trend of investment in plum-research projects.
ii. Evaluating how yield, exports and export earnings have changed since 1945.
iii. Due to data limitations, determining the rate of return on plum research from 1980 to 2012.

1.4 STATEMENT OF HYPOTHESIS

The study hypothesizes that:

- The returns to plum research at Infruitec/Nietvoorbij are positive. The ARC has over the years succeeded in developing new and improved cultivars, which have better quality and adaptability to South African plum production environments.

1.5 APPROACH AND METHODS OF THE STUDY

This study is an *ex-post* evaluation which makes use of secondary data. Several methods exist for estimating the *ex-post* economic rate of return on agricultural research and these methods vary from econometric to non-parametric methods. Econometric methods include production functions, response functions and productivity functions, whilst the non-parametric approaches include index number procedures (Alston, Norton and Pardey, 1998). Due to the quality and quantity of data available for this study, the production function approach was applied to determine the effects of R&D investments on the plum industry in South Africa. As a result of data constraints experienced, this study relied on secondary data and extrapolations of missing data, as well as expert interviews. The data collected was used for regression analysis to determine the extent to which investment in R&D contributes to the changes in the industry.

1.6 OUTLINE OF THE STUDY

In Chapter 2 an overview of plum production in South Africa is presented. The chapter focuses on the production landscape of plums, with emphasis on production practices, input usage, and production trends. The chapter provides a better understanding of the various economic aspects of the plum industry and provides insights into the evolution of the research supporting this. Chapter 3 discusses the evolution of the institutional environment in the plum industry. The aim of the chapter is to provide insights into why and how fruit research started in South Africa. It shows what the major focus areas of plum research were since its inception in South Africa, and what the research outputs have been. Chapter 4 discusses the funding structure for plum research; the level of funding and how the sources and nature of funding have evolved over time. In this chapter staff allocation will also be described in an effort to identify proxy indicators to determine resource allocation from the available aggregates. Chapter 5 describes the main approaches used in *ex-post* rate of return studies and their benefits and constraints. Chapter 6 elucidates the data that were used for this study and shows the results and discusses the data limitations encountered. Chapter 7 summarizes the study and makes recommendations.

CHAPTER 2

THE SOUTH AFRICAN PLUM INDUSTRY AND ITS HISTORY

2.1 INTRODUCTION

To fully understand the analysis central to this study it is paramount to consider where the plum industry in South Africa originated from and its intended direction. This chapter provides an overview of the South African deciduous fruit industry and its position in the global sphere, with special emphasis on the plum industry.

According to Mashabela (2007) the deciduous fruit industry came to life on Saturday the 24th of August, 1652 when Jan Van Riebeeck stated in his diary: “planted some medlar and quince pips”; but little is known about the varieties that were planted. In 1654 Jan Van Riebeeck imported orange and apple trees from St. Helena (Black, 1952). He established his orchards in the Cape yet when the other inhabitants tried to follow suit and practice fruit cultivation their enthusiasm was dampened by poor performance of the trees due to unfavourable conditions. The fruit industry failed to grow at the time as a result of such constraints as poor performance of the fruit, restricted markets and limited transport. There was constant communication with Europe with regards to improving yields in the orchards, and as a result fruit quality started to improve.

The discovery and mining of diamonds from 1870 awakened the fruit industry in South Africa (Black, 1952). An influx of people into the country bringing with them new capital, resulted in cities being built and railway lines constructed. As a result of the increase in the number of people, demand for food also increased, including the need for fruit production. In the Cape region fruit farms started being established since the two major constraints had been eliminated, that is, poor transport facilities and the absence of markets (Pickstone, 1917). Fruits planted at the time were mostly peaches, apricots and apples, with a few plum and pear trees being planted. Over the years, the plum industry grew and the production practices as well as the inputs employed in the plum industry changed in response to insights gained from research. The following section discusses how the production landscape changed and in turn how this affected plum production.

2.2 FACTORS AFFECTING PLUM PRODUCTION

2.2.1 PRODUCTION PRACTICES

Ever since their introduction into South Africa, plum trees have mainly been cultivated in the Cape region, using different production practices. According to Vorster and Stadler (1976) a better production system is realizable through dense spacing and training of plum trees. The soils are prepared by adding phosphate and deep-ploughing. Plum trees generally prefer soils that drain well, although they can withstand any soil types. Kraal manure or compost is often applied in between the rows (Vorster and Stadler, 1976).

Most plum farmers use trees from nurseries which are transplanted at the age of one to two years. These trees are usually developed by grafting a rootstock onto a scion (Hurter, 1978). The most common rootstocks which have been used for plums in South Africa are Mariana and Maridon (Mabiya, Mansvelt, Ferreira and Ndimba, 2014). Mariana rootstock is plum propagated from hardwood cuttings and peach grown from Kakamas and Duplessis seedlings (Hurter, 1974). When planting the trees, pollinator species are planted in alternate rows in order to allow for cross-pollination. Plum trees are usually planted in late autumn or early winter as this is when the tree is in its dormancy stage. Bees are introduced during the flowering season to facilitate cross-pollination and on average four to sixteen hives per hectare are used for this.

In the early 1970s, most farmers trained their plum trees to a palmette type of hedgerow on eight or nine strands of wire with the top one being 5m from the ground (Vorster and Stander, 1976). The trees were planted in 4.6m × 2.7m rows. This training was carried out during late summer (Vorster and Stander, 1976). This changed in the 1980s and early 1990s when most farmers started using the conventional central leader training system (Kotzé, 2014). The most important principle in a training system is to obtain as much solar radiation as possible which the trees can then convert into an economic yield — and the central leader training system ensures the most efficient interception of light and crop production (Kotzé, 2014*)*. In this training system the bearing branches are identified and tied to the left and right of the central leader 15 to 20 centimetres apart onto a flat trellis to form a fruiting wall. However, according to Kotzé (2014) farmers have since shifted from the conventional method to using a V-shaped trellising system, also known as Tatura *trellising (after the town Tatura in Australia)*. In this system, the row width is 3.5m to 6m; the V is usually between 16 degrees and 20 degrees and the tree height is 80 percent of the tree width. Trees are planted from north to south for complete exposure to the sun and for total distribution of light in the tree. An advantage of using this training system is that it allows greater air flow, thereby reducing the occurrence of diseases. This system necessitates the institution of other management practices which are considered next.

2.2.2 Input use

Trees obtain their food for growth and fruit development in the form of minerals in the soil. Should these minerals not be adequate, fertilizer is often applied to supplement them. Fertilizer application is carefully conducted according to soil type, and the size, vigour, yield, plant reserves and age of the trees. For newly planted trees, fertilization is done after new leaf formation in spring of the first and second years (Crosse, 1974). Older trees get their nutrients from the previous year's reserves. This occurs during the first six weeks after blossoming. Fertilizer application is therefore carried out only after this period. The most important nutrient for trees is nitrogen, which is used for protein formation and for chlorophyll development. Adequate water is another important component for the growth of plum trees. Because most of the fruit cultivated is for export purposes, production of plums is intensive and exceptionally high levels of irrigation are applied. Soil moisture monitors are used to determine the water requirements of orchards.

2.2.3 Weather

Temperature, precipitation, sunshine duration and intensity, and length of day are some of the important weather variables that influence a plum orchard. Temperature has an important bearing on plum yields. In winter, plum trees enter a dormancy period, which protects them from the low temperatures. During this period, the trees will be resting and growth, including flowering and fruiting, ceases. The chilling requirements of most plum cultivars in South Africa range from 2.5^{o}C to 12.5^{o}C for a period of 850 to 1 000 hours (Anon, 2008). If the chilling requirements have not been met, the trees are likely to face delayed blooming and foliation, resulting in poor fruit quality. On the other hand, if the temperatures are too low, trees suffer from chilling injury. Other climatic factors are also of paramount importance in the growth and fruiting of plum trees; these include humidity and rainfall. Plum trees require rainfall and a humid atmosphere during the dormancy period in winter, because when these are experienced during the growing season, the trees become more susceptible to pests and diseases (Taylor and Gush, 2009).

2.2.4 Management practices

An important component of orchard management is pruning. Pruning is important as it avoids competition between branches and thus leads to higher yields. Pruning is performed so as to give the tree a suitable framework for fruit bearing. Within the first three years of the tree's life, pruning is carefully conducted in order to train the trees to adopt the appropriate shape that would create a canopy, allowing the sun to penetrate without any interruption and also to stimulate the production of fruit (Kirsten, 2001). All dormant, damaged and broken buds are removed. Branches that are thicker than the bearing branch they grow from are also removed. Because plums compete for energy between vegetative growth and fruiting, competing shoots should also be removed. Plum trees bear fruit on spurs, which are small shoots on the older wood; and it is thus important to ensure that the old wood is not pruned away.

In South Africa there are four periods within which pruning can be done: Very early pruning in mid-May, early pruning in mid-June, late pruning in mid-August and very late pruning in mid-September (Crosse, 1974). Plum trees are heavily pruned in winter, and in summer they are pruned lightly to allow for proliferation or dominance of fruit-bearing branches. It is important that trees are trained and pruned in the correct way as this may result in them producing quality fruit and high yields at a very early stage of their life.

When pruning has not been done properly in the previous season, plum trees can produce fruit that they can hardly support (Crosse, 1974). The branches will be overladen to the extent that limb breakage occurs. The excessive fruit also compete with each other for carbohydrates (stored energy) and consequently fail to develop adequately. As air movement will be restricted, the fruits become susceptible to diseases and sunburn. It is therefore vital to do fruit thinning. Thinning is the removal of young immature fruit or flowers with the primary aim of improving fruit size as well as quality. Fruit thinning also prevents alternate bearing, that is, in one year a tree bears excessively and in the next it bears little fruit. For thinning to be effective it should be conducted at the appropriate time — when fruit is fairly small or during bloom. The rule of thumb for plums is that the sooner the better, but it should not be done too early as this can result in split pits. For thorough and accurate results, plum thinning should be done by hand (University of California, 2001).

2.2.5 Disease management

Another production practice that has a bearing on the quantity and quality of fruit produced is monitoring diseases and pest management. Fruit trees are sprayed in order to protect them from various pests as well as fungus and bacterial diseases. As advised by the Cedara School of Agriculture in 1929 (Du Toit, 1929), spraying is to be conducted at least three times in a production cycle. The first application, using concentrated lime-sulphur solution, is made just before the buds burst. The second application is done after the bloom has fallen and the shucks on the young fruits have started shedding. There are some limitations of lime-sulphur — which include spray injury — which were obviated by using Bordeaux mixture[2]. The third application is often done at 30 days intervals until all the leaves have expended and the shoot growth has finished for the season, again using Bordeaux mixture (Du Toit, 1929).

It has since been discovered that spraying during the growing season is not effective, thus spraying should be done during dormancy. Copper-containing compounds are used in the control of fruit diseases (Infruitec, 1994). However, controlling fruit diseases is a cumbersome process, which can be eliminated by the use of resistant cultivars. In principle, disease management involves an integrated approach. In order to reduce the occurrence of diseases, an appropriate canopy management practice is recommended whilst minimal wetness duration, adequate application of pesticides and, of course, the use of disease resistant cultivars (Fourie, 2013) is mandatory in an integrated approach.

[2] Bordeaux mixture: A mixture of copper sulphate ($CuSO_4$) and slaked lime ($Ca(OH)_2$).

2.2.6 Labour

The plum industry has always been labour-intensive. Most of the production practices mentioned in the preceding text cannot be mechanized. Manual labour is mainly used for the pruning, thinning and harvesting of the fruit. A study conducted at the University of Kentucky in the USA revealed that nearly 40 hours of labour per acre are required for land preparation in year zero of the production cycle (Strang, 2012). For the planting and establishment period (year one), an estimated 32 hours per acre are required, and during years two and three, 14 hours per acre are required for general production, with an additional hour per tree for pruning. In the fruit-bearing ages (years three$^+$), labour requirements go up to 100 hours per acre with an additional 1.5 hours per tree for pruning. In a survey conducted by Hortgro, the plum industry in South Africa employed 5 443 (fulltime equivalents) in 2005 (Deciduous Fruit Board Trust, 2005) increasing to 6 373 in 2012 (Hortgro, 2012).

2.2.7 Post-harvest

A common post-harvest practice in fruits is ethylene treatment, and in South Africa it has been done since 1928 in citrus fruits and was later introduced to plums (Marloth, 1933). Different plum cultivars display two different ripening behaviours, and are divided into two groups with respect to this characteristic (Candan *et. al*, 2006). There are *climacteric* cultivars in which ripening is triggered by a burst of ethylene and *suppressed climacteric* cultivars whose ripening is not correlated to ethylene production. Fresh plums are highly perishable and have a limited shelf life, as a result the ripening of harvested fruit triggers the softening of the fruit. Plums are also susceptible to chilling injury after removal from storage. These characteristics act as a constraint in the market life of fruits. Ethylene treatment, which stimulates the internal production of ethylene, has been identified as one measure that can extend post-harvest life after ripening or after removal from cold storage, especially in climacteric cultivars (Marloth, 1933).

Although it is common knowledge that a fruit that matures and ripens on the tree exhibits superior quality and has a rich colour as compared to one that has been picked semi-green and allowed to ripen in storage, it may not be profitable for farmers to leave the fruit on the tree for too long. Ethylene treatment in plums is done at such a time that desired levels of softening, acid loss and colour development are attained. The advantage of using ethylene treatment in plums is that it prolongs the marketing season because the product can be put in the market long before the bulk of the fruit has been harvested (Argenta et al., 2003). The fruit is likely to receive a much higher price, provided the quantity shipped is less than the normal demand at that point in time. Most cultivars bred in South Africa are climacteric and do not require any ethylene treatment. South African plums are in fact protected from their self-produced ethylene. According to a communication by Kotzé (2014) ethylene scrubbing is done, which involves filtering out ethylene from the cold storage. In addition to this, fruits are sprayed with SmartFresh^{TM}, a molecule which blocks ethylene receptors at cell level such that the fruit does not produce ethylene gas (Moelich, 2013). This not only maintains the quality of freshly harvested fruit during storage but also extends the commercial shelf life since it takes two to three weeks to transport plums to their overseas markets.

2.2.8 Post-harvest management practices

The proper execution of the production practices mentioned above influences the risk of fruit lost post-harvest. There are three factors on which post-harvest losses are dependent; the first one is time of picking. Because plums are susceptible to rapid softening and chilling injury, it is important that the fruit is picked at the proper stage of maturity for its market destination in order to avoid deterioration in quality before even reaching the market (Reyneke, 1933). When plums are harvested too mature, they easily become prone to bruising, decay, over-ripeness and bladderiness or internal breakdown (De Kock and Taylor, 2010). When harvested immature, plums tend to ripen abnormally, have a rubbery feel which comes with an acid taste and they experience chilling injury in the form of internal browning. Farmers used to rely on their subjective judgment of the physical changes to determine whether the fruit is mature or not, but now the Department of Agriculture, Forestry and Fisheries (DAFF) has a list of minimum requirements for plum varieties, which is published on an annual basis. These requirements state the maximum and minimum pressure to which the fruit should be exposed as well as the total soluble solids content. Ideally, plums should be harvested mature but not ripe, to be ripened en route to their overseas destinations.

The second factor affecting post-harvest losses is the physiological condition of the fruit, that is, the chemical condition of the fruit which is affected by pre-harvest factors such as mineral nutrition, irrigation and exposure of the fruit to sunlight. The third factor affecting post-harvest losses is careful handling, packing, cold storage and transport. Temperature control plays a pivotal role in post-harvest losses, and the fruit should be refrigerated soon after harvesting. Cold storage requirements vary across different cultivars, but the general temperature regime is between –0.5^{0}C and 7.5^{0}C, and the maximum recommended time for cold storage is 21 days (De Kock and Taylor, 2010). Post-harvest losses due to all these three factors in South Africa have been on average five to seven percent in volume and 20 to 25 percent in revenue (Kotzé, 2014).

2.3 PLUM PRODUCTION

2.3.1 Number of trees

The first tree census in South Africa was conducted in 1661 and revealed that there were only 19 plum trees (Black, 1952). Figure 2.1 below shows the trends in the number of plum trees planted between the years 1940 and 2011. The gaps in the data are due to limited data availability. Starting from a small base in 1941 the number of trees increased almost nine-fold 71 years later. The decrease in trees planted in the season 1961/62 can be attributed to the halting of food rationing in the UK in July of 1954 (*Deciduous Fruit Grower*, 1954). In this period, import restrictions on foreign competitive supplies under Commonwealth preference arrangements were also imposed. This resulted in unfavourable prices and, consequently, fruit growers were discouraged from increasing the scale of new plantings (*Deciduous Fruit Grower*, 1954). Thereafter, the total number of plum trees planted increased.

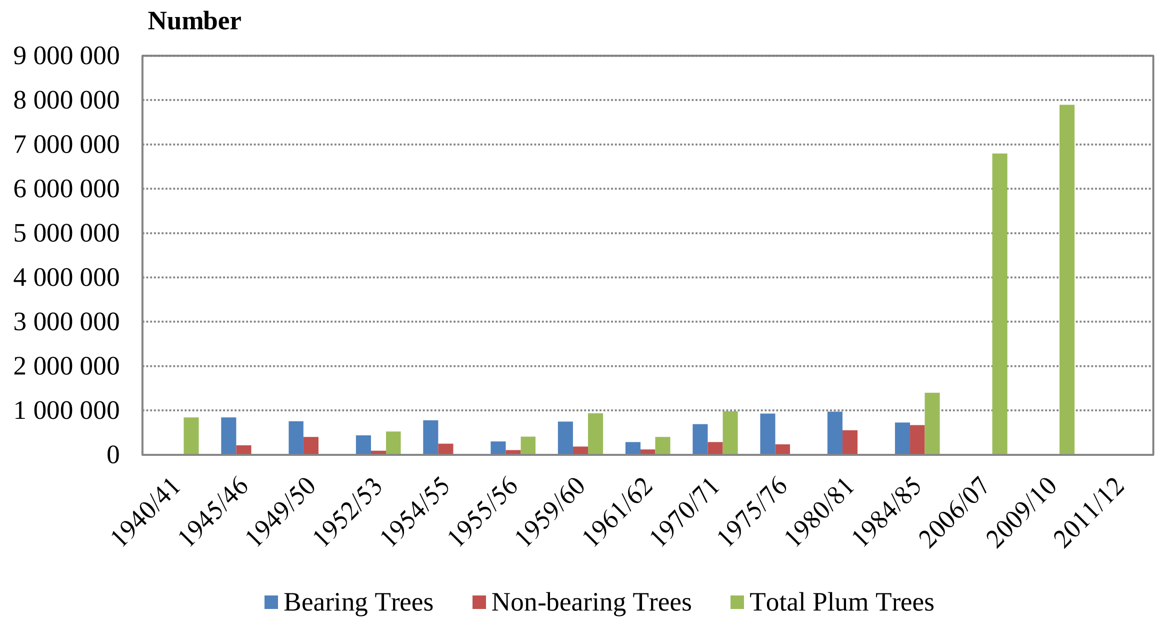

Figure 2.1: Number of plum trees planted, 1940-2012

Source: *Deciduous Fruit Grower* (various articles) and Hortgro (2010-2012).

2.3.2 Area planted with plums

Figure 2.2 below shows the area in hectares used for plum cultivation. As shown in Figure 2.1, the area planted with plums has continued to increase, in line with the total number of plum trees in South Africa. In 1977 the total area designated for plum cultivation was a mere 1 308.3 hectares, and by 1992 this had more than doubled to 2 237 hectares. Farmers realized the profitability and potential of the industry which came about as a result of the new and improved cultivars. As a result, more land has been allocated to plums. In 2010 it had again doubled to 4 466 hectares. At present, 2012/13, an area of 4 814 hectares is planted with plums (Hortgro, 2012).

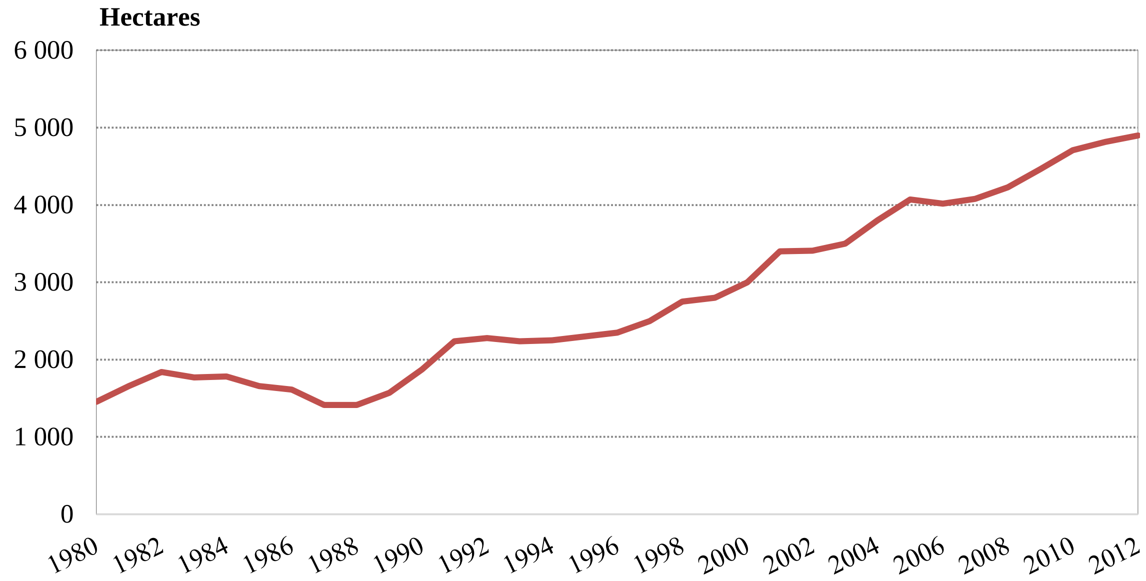

Figure 2.2: Area planted with plums in South Africa, 1980 to 2012

Source: *Deciduous Fruit Grower* various articles

Although plum production areas are spread across geographically diverse areas throughout the country, the Western Cape Province accounts for the greatest part of the area in which all plum varieties are cultivated, and the rest of the provinces account for only 1.4 percent of all plum areas (Conradie, Piesse and Thirtle, 2009).

2.3.3 Production costs

Tomlinson and Van Wyk (1934) found that labour presented more than 40 percent of total farm expenses on most farms. The authors showed that farms that spent less than 35 percent on labour had better financial results than those that spent more. The general breakdown of costs in the deciduous fruit industry in 1981 was given as follows: export costs took up 65 percent, packaging costs were 20 percent and production costs were 15 percent of the total costs. Of the export costs, 61 percent went to ocean freight (*Deciduous Fruit Grower*, 1981). In 1983, the *Deciduous Fruit Grower* (1981) reported that the total cost of producing plums was R351 264.11 (in 2012 values) per hectare. Of this, 29 percent went into labour whilst input costs constituted 29.2 percent. Overheads took up 10.1 percent whereas the rest accounted for depreciation and interest on investment loans (Deciduous Fruit Board memorandum, 1984).

By 2008 the nominal cost of establishing an orchard was estimated to be R92 694/ha with trellising and plant material taking up most of the cost. In the non-bearing years, age one to four, the trees cost R26 665/ha to maintain, with overhead costs constituting at least 65 percent of that. In the bearing years of the orchard, five years and above, the total costs are R119 920/ha. Of this, the transport costs were 8 percent, packaging costs were 40 percent and the cost of production was 25 percent. The cost of labour was 20 percent and post-harvest costs took up over 55 percent of the total cost (Deciduous Fruit Producers Trust, 2008). By 2012 the cost of establishing an orchard had gone up to R158 819 and plant material, land preparation and irrigation costs took up over 45 percent. The cost for maintaining a non-bearing orchard had gone up to R47 148 and that for a bearing orchard had gone up to R198 750. For a bearing orchard the costs were divided as follows: transport costs were 10 percent, packaging costs were 37 percent and the cost of production was 28 percent of the total cost. Of the total cost, labour is 28 percent. From all this investment, a yield of 25 tons per hectare is expected (Hortgro, 2012).

2.4 Trends in production and consumption

The long-run trend in the production quantity is shown in Figure 2.3 below. Beginning in 1940, production volumes fluctuated around 6 000 tons. This was mainly due to the war in Europe, the main export destination of these fruits from South Africa at the time. The British government classified fruits as a luxury commodity and restricted their importation. After 1944 towards the end of the war, production briefly increased in response to the interventions made by the Deciduous Fruit Board. It subsequently decreased in 1948/49 to reach levels lower than those achieved during the war years. From here production stagnated until 1972/73 from where it steadily increased until 1991/92 when sanctions were revoked. Owing to easier access to global markets, demand saw an increase of over 15 percent per year until a sharp decrease was experienced in 1999/2000. This came primarily as a result of the closure of the control boards that regulated the marketing of agricultural products.

However, the industry soon recovered and production grew by another 15 percent per year over the next four years to reach 59 867 tons. The 2005/06 season was a bad one for the plum industry as shown by the sharp decrease in total production. This may have been due to the weakening of the Pound Sterling, the Euro and the US Dollar, which are currencies of the major export destinations. Since the industry is export-driven, weakening of these currencies has implications on sustainable production of most of the producers, and thus reduces the number of fruit farmers in the supply chain. This was also linked to the sluggish demand from the 12 local markets in the previous years. But in 2007/08 the volumes gained momentum and in that season South Africa produced one percent of the world’s plums, a total of 62 720 tons.

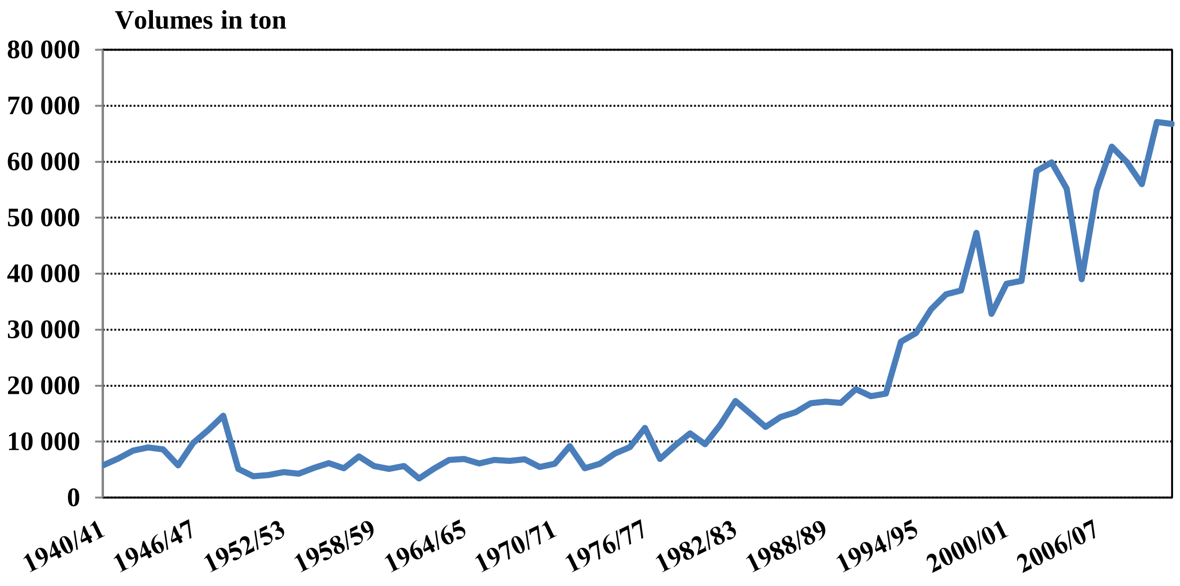

Figure 2.3: Trend in plum volumes produced, 1940-2012

Source: www.quantec.co.za

The long-run trend of plum production is increasing, and this may be attributed to farmer reactions to market incentives enabled by research.

2.5 Exports: The early years

The first attempt to export fruit from South Africa was made in 1888 when a small consignment of apples and grapes was sent to Great Britain (De Beer, Paterson and Olivier, 2003). This undertaking was a failure due to the unavailability and/or poor cold storage facilities. The grapes came from Robertson and were transported to Cape Town unrefrigerated and remained unrefrigerated in storage until the arrival of the ships. Fruit exports were then halted until 1892 when Rev. C. Legg, Rector of the then Victoria College (now Stellenbosch University) experimented by exporting the first 14 trays of dessert peaches to Great Britain, a year after the first fruit organisation, Cape Fruit Syndicate, was founded (Pickstone, 1917). This consignment was successful and was followed by further consignments of 8 000 cases of fruit the following week. The fruits that were shipped to Great Britain included peaches which received £4/dozen. Grapes, pineapples and tomatoes also formed part of the consignment (Black, 1952). In 1893 another 15 000 cases were exported, 11 000 of which were grapes and 2 400 were peaches, with a small quantity for the first time being plums.

Until 1903 only small quantities of fruit were exported in fresh form. In that year no more than 100 tons were exported. This was due to a lack of experience and knowledge of this highly specialized endeavour. In 1910 the direct railway link between Cape Town and the diamond fields in Kimberly made it possible for the industry to send fruit to local markets in larger volumes (Black, 1952). In addition to this, 200 000 cases of fruit were also shipped to European markets (De Beer, Paterson and Olivier, 2003).

According to de Beer et al. (2003) deciduous fruit exports had increased to 452 000 cases by 1914. This was suspended from 1914 through 1918 due to World War I. Immediately after the war prices on export markets soared to impressive heights, until 1922 where after they dwindled in response to increased production. Post-harvest facilities and handling were inadequate, resulting in fruit arriving in poor condition.

The plum industry was immensely affected by the outbreak of World War II since all exports to England were suspended as from 1940, at the time the United Kingdom was the biggest market destination of South African plums with more than 90 percent of fruit sent there (Tinely, 1954). In this period plum exports to European markets plunged to a mere 266 tons.

The growers and shippers had been funded by British commission agents who indicated withdrawal of their funds during the war (Tinley, 1954). In the succeeding four years, plum exports averaged fewer than 500 tons each year. In the production season 1945/46 just a small quantity of fruits were exported to Sweden only. These events forced the South African government to subsidize the industry (Neveling, 1947).

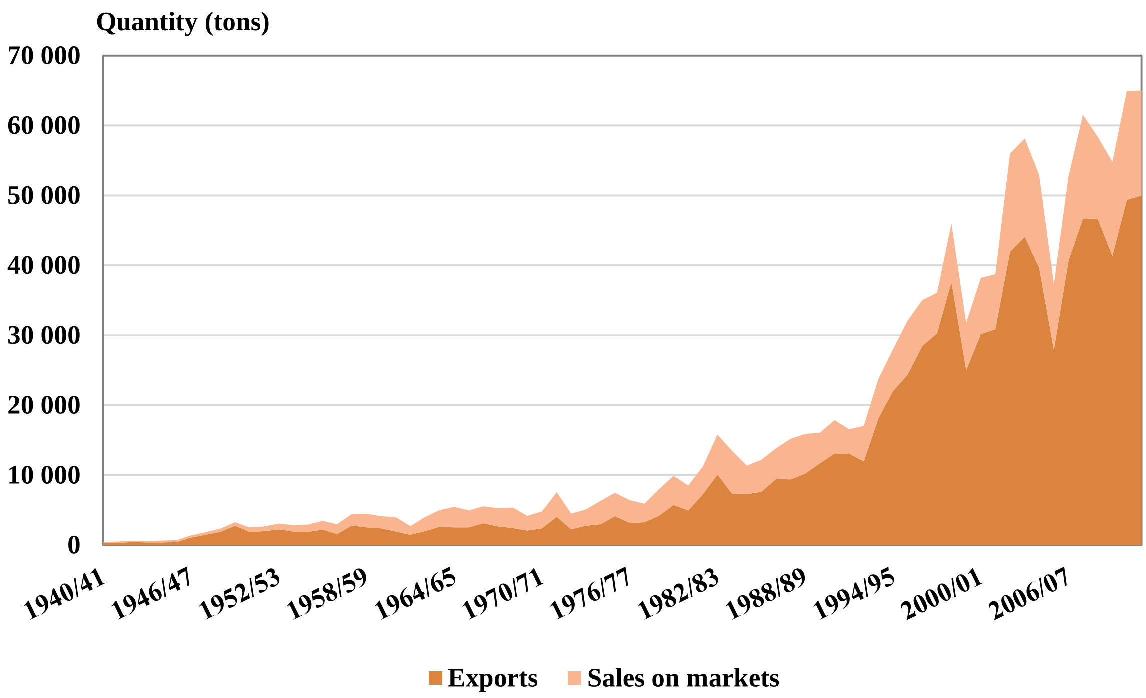

Figure 2.4: Sales of plums on local markets and export volumes, 1940-2012

Source: Abstract of Agricultural Statistics

As a result of government intervention, several years after the war, production increased and this led to increases in the exports of plums to the UK and European markets (De Swardt, 1947). In this period, the export industry was only controlled by a few parties, with the Deciduous Fruit Board being the main driver. By 1946/47 plum exports had increased to 1 051 tons. Plum exports continued to increase to reach 2 762 tons in 1949/50. Thereafter it stagnated around 2 000 until 1971/72 when the figures almost doubled to 4 015 tons.

Export volumes continued increasing, and in the season 1982/83 they reached 10 061 tons. More markets were penetrated such as the Irish Republic, Belgium, Holland, Norway, Denmark, Finland, Switzerland, West Germany, France, the USA, Canada and Portugal (Deciduous Fruit Board, 1983). The Rand weakened after 1983, and since the plum industry was export oriented, a depreciating domestic currency would make exports more profitable and as a result push the export volumes up. The currency continued to plunge and export volumes continued to grow. After deregulation in 1997, exports were no longer controlled centrally and by 2005 there were over 375 registered exporters encompassing both small individual operators and large multi-national companies (Carter, 1999). Since 2005, the volumes exported have continued to grow and in the 2011/12 season a total of 50 014 tons was exported, five times more than 1982/83 volume.

Figure 2.5 illustrates the trends in the drying and processing of plums. Drying of plums was initiated in 1940/41 with just 68 tons dried, and was stopped in the season 1987/88 mainly because they fetched low prices.

Plum processing started in 1958/59 and in that season only 644 tons of plums were passed on to processing. The fruit was processed into plum sauce, juice, jams and jellies and the quantity processed depended on the crop size as well as the volume of exports. Thereafter, the volume of processed plums continued to decrease and reached a low of 276 tons in the production season 1972/73. Production season 1993/94 a total amount of 3 256 tons were sent for processing. Volumes processed declined from 2 156 tons in 2010/11 to 1 712 tons in 2011/12.

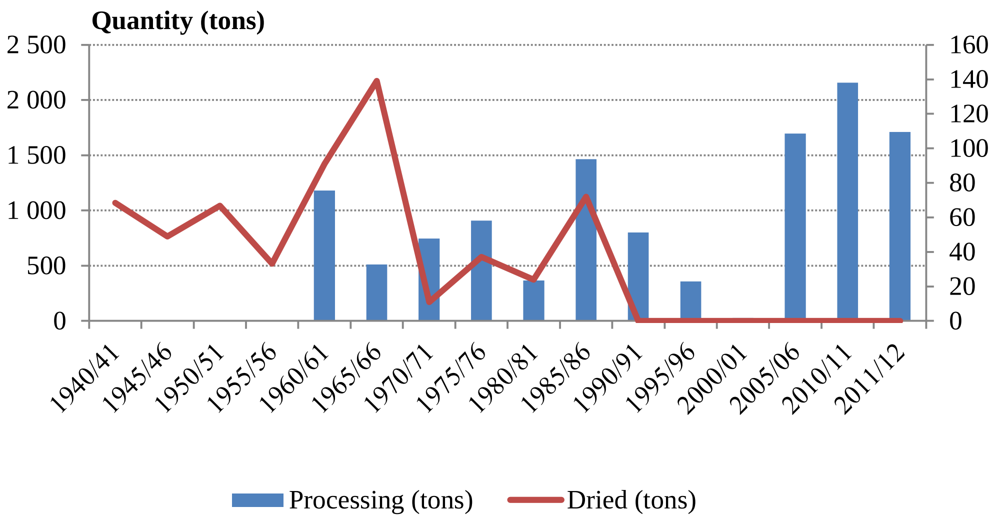

Figure 2.5: Processed and Dried plums, 1940-2012

Source: Abstract of Agricultural Statistics

2.5.1 Prices and gross value of production

The fresh export market has always received higher prices than the other markets; in 1940 a net realization of R84.60/ton was attained by exporting farmers whilst the local markets received R22.10/ton (all in nominal terms). The price continued to increase and by 1950/51 it had reached R165.41/ton. The nominal price continued to rise such that in the season 1960/61 it was at R288.10/ton. By 1972/73, exporting farmers received R550.53/ton for their produce (Deciduous Fruit Board annual reports, various articles). Almost four decades later the net realization of plum exports had increased to R10 384/ton.

The value of the South African plum industry increased from R317 000 in 1945/46 to R740 000 a decade later. The nominal export value was estimated to be around R596 000 in 1960/61. At this stage, South Africa was ranked 7th in the FAO index of world plum exporters (FAO statistics). The gross value of production of plums increased to R1.26 million in 1970/71, a growth of 11.1 percent per annum and it maintained its 7th position rank. In 1980/81 the value of the South African plum industry had increased to R5.025 million and in this period it went up the rank to 4th amongst world largest plum exporters. In 1990/91 the total value of the plum industry increased again to R51.081 million, but dropped back to 7th in rankings, after being overtaken by the Netherlands, France and Chile. The nominal value of the industry increased yet again to R258.28 million in 2000/01 and was 6th in ranking. In 2011/12 the nominal total value of the plum industry was R587.151 million, giving a year-on-year growth of 11.6 percent and it went up to the rank to 4th among top plum exporters in the world (FAO statistics).

2.6 GLOBAL COMPETITIVENESS

During 2011, 7 577 538 tons of plums were produced in the whole world (FAO statistics). China, Romania, the USA and Serbia were the largest producers of plums whilst the biggest exporters were Spain, Italy, Chile and the United States in order of ranking. According to Cass (1996) South Africa has a large market share in the EU and faces competition from Chile, New Zealand and Australia. Chile is the largest exporter to the EU markets (contributing 60 percent) and ranks highly in the world competitiveness index. It also enjoys free trade agreements with the European Union, USA, Mexico and Canada among other countries.

South Africa is a relatively small producer and exporter as compared to Chile (2010/2011). In Table 2.1 below, it is shown that Chile produces almost twice the quantity produced by South Africa and it exports almost twice as much.

This contrasts to three decades ago when South Africa's plum industry was twice the size of the Chilean industry. In 1983 South Africa was the second largest exporter of plums to the European market with almost 1.7 million cartons being delivered. In the same period, Chile only supplied the European market with 11 000 cartons. Chilean export volumes continued to grow progressively and less than ten years later, in 1989 Chile sent almost 1.6 million cartons which were more than the 1.43 million cartons delivered by South Africa (Deciduous Fruit Board, 1990). According to Nyhodo et al. (2010), Chile has continued to be the leader in the European market. The enabling macroeconomic policy and research system in Chile has made this possible. Chile has a market oriented national system of research and technology transfer which has seen small farmers being given assistance and large commercial farmers being fully responsible for their own technical assistance. Between 1983 and 1990, Chilean farmers were given vouchers by their government to contract an organisation for technical assistance, making research more demand driven (Valdes, 2008).

Table 2.2: Comparison of the South African plum industry to the Chilean plum industry in 2010

Plums	**SA Industry**	**Chilean Industry**
Annual production (tons)	67 087	130 500
Cultivars	> 20	> 36
Export volumes (tons)	49 331	95 500

Source: USDA Foreign Agricultural Services (Hennicke, 2010)

However, although Chile may export more plums in volume than South Africa, South African plums are preferred due to their above average quality. Plums of the same grade get 50 percent more in price than the Chilean fruits (Esterhuizen and van Rooyen, 1999). Also because of its relative closeness to the EU market as compared to other exporting countries, South Africa has a comparative advantage over its main competitors. The other competitive advantage that the South African plum industry has over Chile is the longer harvesting period. South Africa has a harvesting period that stretches from November to May, while Chile has a harvesting period that starts in December and ends in April.

The major constraints on South African exports are limited availability of improved cultivars. The industry lacks cultivars that will address post-harvest losses as a result of diseases, and that have low chilling requirements. According to Steenkamp and Gevers (2010) South Africa faces enormous pressure in terms of its competitiveness in the global deciduous fruit industry in general. Whilst global prices have remained stagnant, South Africa struggles with rising input costs. One way to recover the country's competitiveness is to make use of improved cultivars that could keep unit costs low.

2.7 CONCLUSION

The purpose of this chapter was to give a comprehensive overview of the plum industry. As discussed in the chapter, plum production has continued to increase in South Africa. Although plums are not produced abundantly, the industry competes successfully in international markets due to high quality standards. The chapter also presented a review of the evolving production practices that are used in the farming of plums. Farmers in South Africa have moved from traditional to modern production practices that ensure high productivity. However, the plum industry is still hampered by post-harvest losses, which could be prevented by the development of improved cultivars that could withstand some of these challenges. Research on the challenges that have hampered the plum industry has been done at ARC-Infruitec. Details of plum research to address the challenges faced by the industry over time are described in the next chapter.

CHAPTER 3

AN OVERVIEW OF PLUM RESEARCH IN SOUTH AFRICA

3.1 INTRODUCTION

The objective of the chapter is to provide an overview of the institutions that influenced the plum industry as well as the origin of fruit research in South Africa and how this shaped plum research. The chapter goes on to show how and why plum cultivar development started in South Africa, and how research focus has evolved overtime.

3.2 INSTITUTIONAL EVOLUTION

The first known representative body of fruit farmers in South Africa was the Western Province Fruit Exporters' Association formed in 1899 (De Beer, Paterson and Olivier, 2003). A group of export farmers met in an attempt to mitigate the problem of inadequate refrigeration facilities. As a result of their representation to government, the refrigeration facilities were increased in the years 1904, 1911 and 1918 (Black, 1952). Its success was not only limited to improvements in refrigeration facilities, the coordination and control of deciduous fruit exports were improved and the quantity exported also increased. Deciduous fruit farmers then formulated their own regulations and the first fruit inspections were done in 1904; this was not successful as the powers of inspectors were limited only to those who requested the service (Black 1952).

In 1922 the Fruit Growers' Cooperation Exchange of South Africa was formed following collective action taken by fruit growers in an attempt to deal with the delays in shipping (Black, 1952). This organization was mandated to coordinate exports and to counter the low prices that farmers used to receive from export agents. It represented deciduous fruit, citrus and pineapple growers. The Perishable Products Export Control Board (PPECB) was formed in 1926 and was responsible for all shipping and cold storage of deciduous fruits at ports. According to De Beer *et al*. (2003), the PPECB was established mainly to specify minimum quality standards for the export of fruit. The organisation brought an end to the speculation in shipping space and for the first time in many years made an equitable allocation for all perishable products. The control board ensured the refrigeration techniques were changed by pre-cooling fruit and by better control of the temperature in ships' chambers. Through a more scientific organization of the exports the facilities were better equipped to deal with the expansion that was to follow (Black, 1952).

Black (1952) writes that at the end of 1926, the relationship between the deciduous fruit industry and citrus industry was severed as the Fruit Growers' Cooperation Exchange split into two independent organizations, namely the Deciduous Fruit Exchange and the Citrus Fruit Exchange. Despite the many improvements brought about by the Cooperation Exchange, the export trade did not flow smoothly under the control of this body. Since membership was voluntary, the levy which members had to pay was one of the many reasons why the citrus growers decided to turn against deciduous fruit growers and form their own independent organization. By 1926 fruit export volumes had grown to more than ten times what they were in 1906 and the industry was still not adequately equipped to handle the volumes delivered for export (Cockwell, undated). Consequently, fruit growers faced a great challenge of orderly marketing of their fruit. As production was increasing rapidly, new markets were proving hard to develop. Due to their perishable nature, the fruits could not be sent from one market to the other and there was a need to establish a central organization that would be responsible for finding information on which destination producers should ship their fruit to. Realization on exports dropped, not because of saturation of the market but because of the condition of the fruit at export destination (Black, 1952).

In 1934, the Viljoen Committee recommended the establishment of controls over the marketing of agricultural products, the aim being to improve the profitability of farmers (Carter, 1999). A new Marketing Act was promulgated in 1937, to enable the task of managing produce prices such that rural farm incomes remained at the same level as those of urban producers (De Beer, Paterson and Olivier, 2003). The Deciduous Fruit Board, otherwise referred to as "the Board" throughout the remainder of study, was established in 1939 to administer the new scheme. Initially the Board had only eleven members, seven of whom represented co-operatives affiliated with the Deciduous Fruit Exchange, and three represented producers who were not members of such societies and one officer from the Department of Agriculture and Forestry (Cockwell, undated).

The Board was given monopolistic powers over the export of all deciduous fruit during World War II when exports to Britain were halted. It was granted extensive control over fruit purchases, as well as the buying and selling prices. It was chosen as the sole buyer of plums and pears destined for export. The produce would be combined and the proceeds would be shared among all the farmers (Kirsten, Edwards & Vink, 2007). In the period within which fruit exports to the British market were halted, the Board compensated farmers using a relief scheme which was made available to the Board by the Land Bank under a Government guarantee. One of the tasks of the Board was to assist by grant, loan or otherwise, any research relating to the improvement, production, processing and marketing of deciduous fruit. Hence, it was responsible for creating and managing the industry research budget with most of the research projects being carried out by the Western Province Fruit Research Station (WPFRS) and the University of Stellenbosch (Cockwell, undated).

The next significant institutional change occurred in 1987 when the Universal Fruit Trade Co-operative (Unifruco) was appointed by the Board to carry out its duties on its behalf. It was aimed at playing the role of the sole marketing agent for the export of deciduous fruit and arranged the exports according to the regulations set under the Deciduous Fruit Scheme. Unifruco operated as a single monopoly exporter and made all decisions regarding export marketing. It was responsible for recording all the industry information and also controlled the dissemination of this information, as well as rationing the industry research funds (Chambers, 1996). In August of 1990, the Plum Producers' Association and the Nectarine and Peach Producers' Association merged to form the South African Stone Fruit Producers Association (SASPA).

In 1997 the Board was abolished and Unifruco took over the marketing of fresh fruits. Before deregulation, in 1994, Unifruco merged with Outspan for citrus fruits to form Capespan. The deregulation of the South African fruit industry in October of 1997 saw Capespan growing to be one of the biggest exporters of South African fruit internationally. Capespan still maintains its dominance in the industry and currently holds approximately 60 percent of the market share, although there is now a large number of private exporters (Carter, 1999).

Immediately after abolition of the Board, the Deciduous Fruit Producers Trust (DFPT) was formed. This new body was aimed at providing a cost-effective system that would engage farmers in providing activities such as research and development, plant improvements, and general information distribution so as to ensure that the functions of Unifruco were not lost. Hortec, the research funding arm, was responsible for allocating research funds to different institutions that served the industry.

DFPT is a voluntary body, and seeks to ensure the wellbeing of the fruit industry. It consists of three main industry representative bodies, that is, the South African Apple and Pear Producers Association (SAAPPA), the South African Table Grape Producers Association (SATGPA) and the South African Stone Fruit Producers Association (SASPA). SASPA became a part of DFPT in 1997 following the changes made by the new Agricultural Marketing Act of 1996 and was converted to a non-profit company (Hortgro, 2013).

SASPA is now a body under the umbrella industry body Hortgro^{Science}. It has been given the task of coordinating and handling all stone fruit related matters, to meet the specific needs of producers in South Africa and to act as the representing body to both the government and other stakeholders. It also seeks to rationalize and promote the production and marketing of stone fruits and their products. Its other function is to provide farmers with market information to enable them to make informed market decisions. Hortgro^{Science} now takes the responsibility of managing the research portfolio of SASPA in alignment with the different deciduous fruit industries. In March 2013 Fruitgro, an organization which independently facilitated, managed and administered research for the deciduous fruit industry as requested by the growers, was incorporated into Hortgro^{Science}. In the next section, the history of deciduous fruit research is reviewed in an attempt to give more clarity on the role of agricultural research and development in the industry.

3.3 HISTORY OF PLUM RESEARCH

By 1910, the deciduous fruit industry was fully functional with support from the government and the private sector. The industry was developing well, but for it to be successful there was a need for research and extension services (Black, 1952). The precarious challenges faced by the industry included pre-cooling and refrigerated transport of fruits. The Low Temperature Research Station was established in Cape Town in the year 1925 to investigate the cold storage technological aspects. Research into production matters was the responsibility of the

Stellenbosch-Elsenburg College of Agriculture of the University of Stellenbosch (Black, 1952).

As mentioned earlier, the years 1935 and 1936 were critical for the deciduous fruit industry. In order for it to be competitive and profitable scientific intervention was required to investigate problems affecting the quality of fruits arriving at export destinations; exported peaches, for example, reached destinations in a woolly condition. If these problems could not be identified and resolved, the fruit industry would have faced a premature decline in market demand and possibly diminishing export earnings. There was need for better technical facilities to preserve fruit quality after harvesting. Government intervened by appointing an international commission of enquiry to give a detailed report on the position of the industry. Based on the report, it was fully acknowledged that there was a need for extensive research and some work was carried out at the Stellenbosch-Elsenburg College of Agriculture of the University of Stellenbosch and the Low Temperature Laboratory of the Department of Agriculture and Forestry (Black, 1952).

In 1937 the Department of Agriculture established the Western Province Fruit Research Station (WPFRS). The research station was later incorporated in the Low Temperature Laboratory and specialized in all research for deciduous fruits. Although attention was given mainly to tree-fruit and grapes, the institute was also responsible for research on the problems experienced by other perennial horticultural crops grown in the winter rainfall region. The fruits included apples, pears, peaches, plums, apricots, table grapes, grapes for drying, wine grapes, cherries, olives, berries, nuts, kiwi-fruit, figs, dates, rooibos tea and buchu (Black, 1952). Most experiments were conducted at Bien Donné Experimental Farm and several others were conducted at the WPFRS, these included tests to determine the role played by irrigation, investigations in connection with the nutritional physiology of trees, and experiments on the requirements of orchard soils. Research on determining the best methods for combating insect pests and plant diseases was also conducted. The Low Temperature Laboratory was also responsible for giving fruit farmers assistance with respect to the pre-cooling of fruits and fruit marketing (Viljoen, 1939).

The deciduous fruit growers were the only farmers who were disadvantaged as compared to other farmers, as their fruits used to fetch the lowest prices in markets (Viljoen, 1939).

Technical research would therefore address this by ensuring that the cost of producing each unit was kept low. WPFRS was predominantly responsible for probing problems regarding the cultivation and storage of deciduous fruits in the winter rainfall region. From research, it was concluded that the genotype x environment (GxE) interaction of the fruits was not suitable for the South African environment. At the time, most of the plum cultivars that were grown in South Africa originated from the USA and others from Australia, France and England. Most of the cultivars had medium to high chilling requirements. In 1945, a plum-breeding programme was initiated to develop cultivars that were better adapted to South African growing conditions.

In 1962 the WPFRS changed its name to Fruit and Food Technology Research Institute (FFTRI). It received most of its funding from the Board who at the time had control over the export of deciduous fruits from South Africa. The Board occasionally awarded post-graduate scholarships to individuals to study abroad on specific subjects in the deciduous fruit industry. In 1970 the institute changed its name again to Fruit and Fruit Technology Research Institute (FFTRI, 1972). The new institute developed its own research objectives emphasizing industry problems. These were not significantly different from the programme that exists today. The aims were:

i. To develop production practices that would optimize yield per unit area.
ii. To breed new cultivars that would replace the weak existing ones.
iii. To eliminate factors which adversely affect production of quality fruits and fruit products.
iv. To develop alternative uses for deciduous fruits and other crops.

In 1991, the research institute became a part of the Agricultural Research Council (ARC) and changed its name to Stellenbosch Institute for Fruit Technology (Infruitec). It later merged with Nietvoorbij in 2000 to form Infruitec/Nietvoorbij.

3.4 TECHNOLOGIES AND CULTIVARS RELEASED OVER TIME

From research conducted at ARC-Infruitec, several technologies were developed. Between 1945 and 2012 a large number of cultivars have been developed, with 23 of them being successful. Other scientific interventions have also been made that have impacted the plum industry. Sections below present the details on the technologies developed since 1962.

3.4.1 Cultivar and rootstock breeding

Until the Western Province Fruit Research Station (WPFRS) was formed, South Africa was largely dependent on plum cultivars imported from Europe and America. In the initial years after the establishment of the WPFRS, research was based on a list of projects pursued in Chile. This suggests a research strategy that sought to emulate the research of competing countries that were leading in plum research. Due to the poor performance of the cultivars that existed at the time, research had to be shifted towards the needs of local farmers.

Table 3.1 below shows the earliest plum cultivars planted in South Africa, their origin and the limitations. Research emphasized adaptability of the imported cultivars, fruit size, and season of ripening, maturity and keeping quality. South Africa only produced 0.2 percent of the world plums in 1974 because of a lack of suitable cultivars for the environment (FFTRI, 1974). It was therefore necessary to breed improved cultivars that would breathe new life into the country's plum industry. The ideal plum which was being sought was one which would be bold, firm, juicy with body not prone to being mushy, and that would have the ability to withstand three weeks' storage at -0.5^{o}C (Ginsburg, Eksteen and Stubbings, 1976). However, this required many years of research before the desired results could be obtained.

Table 3.1: Early cultivars in South Africa

Cultivar	Country of origin	Year of origin	Year of introduction to South Africa	Characteristics
Apple plum	USA	1898	-	Poor keeping quality, small fruit
Beauty	USA	1911	-	Poor keeping quality, small fruit, susceptible to bacterial spot
Eclipse	Australia	1935	-	Poor keeping quality, small fruit
Eldorado	USA	1904	-	Susceptible to bacterial spot
Gaviota	USA	1900	1919	High chilling requirement and susceptible to bacterial spot
Golden King	Australia	1936	-	Susceptible to bacterial spot and high chilling requirements
Kelsey	Japan	1877	1901	Poor keeping quality, prone to bacterial spot
Mariposa	USA	1935	1948	Fruit prone to splitting
Methley	South Africa	1907	-	Small fruit
Nubiana	USA	1954	1965	Susceptible to bacterial spot
President	England	1894	1924	Poor keeping quality
Prune d'Agen	France	1792	1892	Poor keeping quality, small fruit and high chilling requirements
Red Ace	USA	1931	-	Prone to tree blemish and apex split
Santa Rosa	USA	1906	1915	Acidic around the stone
Satsuma	USA	1886	-	Poor keeping quality
Sugar Prune	USA	1899	-	Poor keeping quality, poor bearer
Wickson	USA	1892	1908	Poor keeping quality

Source: Author's own compilation

Initially the plum-breeding programme focus was on developing a large-fruited early plum variety. According to Hurter and van Tonder (1975), the industry was hard-hit by the catastrophic bacterial spot (*Xanthomonas pruni)* in 1960. Breakthrough research revealed that the pathogen would penetrate and spread systemically through plums. This disease caused plum trees to lose their leaves. Other negative effects of the disease were that fruits ended up being discoloured, mottled and spotted reducing yields by up to 50 percent — which led to huge financial loss (Hurter and van Tonder, 1975). The disease had been controlled by spraying, but research revealed that the fruit was not covered completely by the spray. As a result, the plum-breeding programme was altered and priority was placed on breeding for bacterial spot resistant cultivars. Field observations showed that the cultivars Mariposa, Wickson and Eclipse were resistant to the viral disease while the cultivars Methley, Red Ace and Santa Rosa were found to be tolerant. Researchers continued testing a number of anti-biotics that would remedy this disease and in 1966, it was discovered from research that Terramycin decreased the infection on leaves, shoots, and fruits but it did not solve the problem (FFTRI, 1968). Breeding had to be continued, in pursuit of a bacterial spot resistant cultivar.

Figure 3.1 shows the phases in the development of a new cultivar until its release. According to Smith (2010) the first step involved pollen collection which was followed by emasculation of blossoms and then pollination. This was followed by stratification, a process of pre-treating seeds by refrigerating them in order to break a seed's dormancy so as to catalyse the germination of the seed. Thereafter, the young plants were placed in hot houses and monitored to ensure healthy growth. This stage was followed by acclimatization, a process in which the plants are inured to the climate in which they would be grown. Resulting progenies were then planted in the experimental farm.

This step was followed by Phase 1 Evaluation, in which susceptibility of the cultivars was evaluated. At this stage, mother trees were tested separately on their own. This evaluation considered the fruit size, appearance and organoleptic properties of the fruit when ripened on the mother tree. This phase took between 1 to 5 years. It was followed by Phase 1 Sampling of the promising cultivars. This is the Inter-phase as shown on Figure 3.1 and may take place between year 6 and year 8. Following this, Phase 2 evaluations were done where the pomologist evaluates the ability of the fruit to withstand cold storage and its keeping quality. At this stage adaptability studies and climate monitoring were also done, between years 6 to 10. The South African Plant Improvement Organisation (SAPO) is then responsible for the evaluation of the trees at the nursery (Smith, 2010).

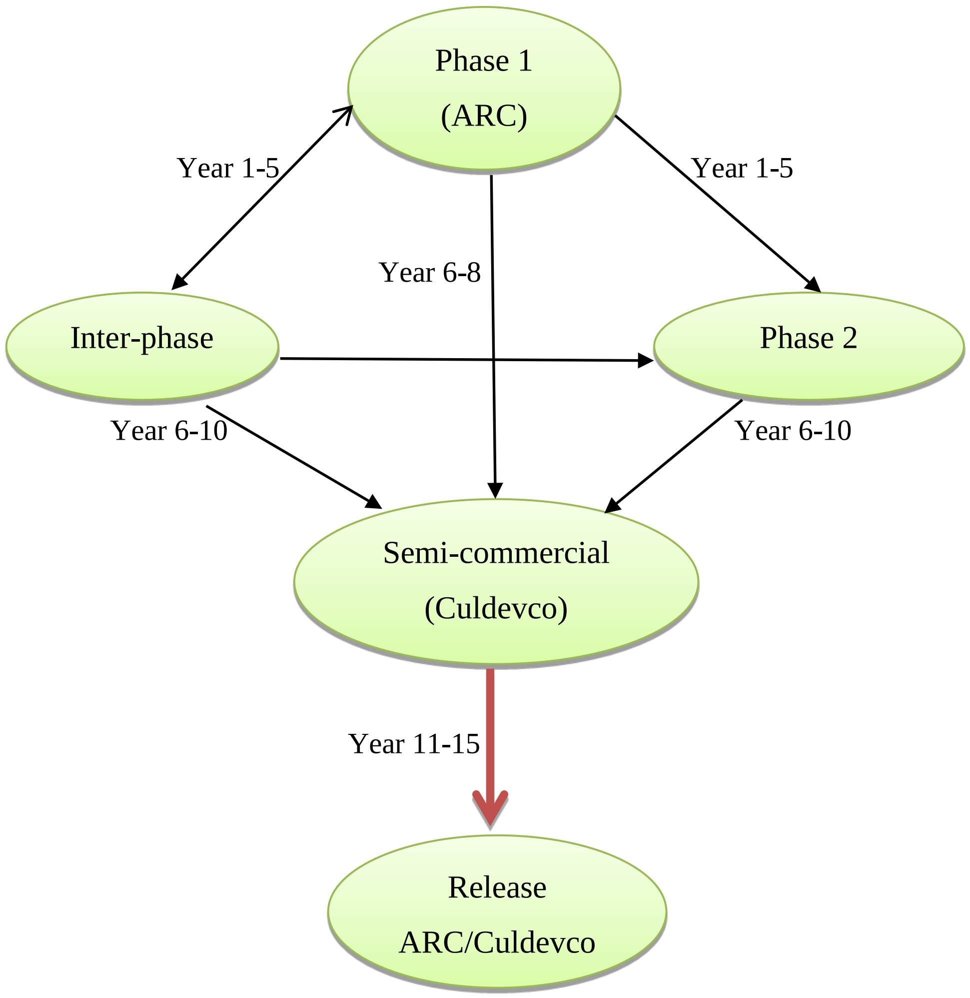

Figure 3.1: Cultivar development phases

Source: Author's own compilation

In 2006, cultivar development included a further Phase 3 evaluation in which the successful varieties are licensed by Culdevco and planted at a semi-commercial scale. Culdevco was formed in 2006 as a private company and was founded by producer associations. It is responsible for the commercialization of all ARC-bred varieties, that is, the phase 3 selections and the released varieties. Besides licensing ARC's varieties and being responsible for the royalties, Culdevco also plays the advisory role in the ARC's breeding programme as they direct the breeding to meet the diverse world markets (Culdveco, 2013-09-29). When the variety has proven to be outstanding, it is then released between the years 11-15.

Prior to 2006, the research institute was responsible for marketing its own cultivars. The variety would just be patented and sent to the market. The aim was not to exploit the varieties commercially, therefore little regard was taken of the potential for the varieties to generate additional revenue for the institute through royalties.

To develop a variety that was resistant to bacterial spot, several years were spent on crossing, back-crossing, and evaluating promising selections, and the first locally bred plum was released under the name 'Songold'. This name was derived from its breeding parents, Wickson and Golden King. Wickson was chosen for its resistance to the bacterial spot pathogen, but it was prone to internal breakdown and was about to be removed from the export list. Golden King was used because of its excellent keeping quality and was a vigorous grower, but suffered from bacterial spot. This cross was made in 1960 by Dr N. Hurter and the first tree plantings were done in 1961 at the Bien Donné experimental farm. Its first commercial fruits were yielded in the season 1968/69 (Hurter, 1972). Because of the impressive characteristics of this cultivar, it was decided that it would be released in 1970, earlier than normally would have been the case, since it had not yet been evaluated in all areas. Further evaluation showed that the trees of this cultivar could also withstand medium chilling requirements.

The cultivar Songold was well received in the industry and adopted by many farmers (Deciduous Fruit Board, 1976). In 1975, the number of single-layer trays of Songold exported were 13 029 as compared to 6 594 trays of Golden King (Deciduous Fruit Board, 1976). Growers realized R50.87/tray (in inflation adjusted 2012 values) for this cultivar which continued to increase every year, and by 1977/78 had reached R73.44/tray (in inflation adjusted 2012 values). This was the highest price when compared with other cultivars (Deciduous Fruit Board, 1979). It was thus more profitable for farmers to replace the old cultivars with the new and improved cultivar. During the same season, total plum yield increased to 9 061 tons up from an average of 6 550 tons in the preceding three years and earnings increased up to R3 393 133, the highest ever reached since 1940 (Deciduous Fruit Board, 1979). This increase may be attributed to the introduction of the new plum cultivar since it coincided with the average age in which the first Songold trees started producing. By season 1977/78, Songold exports reached a remarkable 22 797 single-layer trays while

Golden King achieved only 6 951 trays exported (Deciduous Fruit Board annual report, 1979). Songold remains the second largest planted, produced and exported variety.

In 1973 a new mid-season cultivar Harry Pickstone was released; developed from the crosses made in 1961 by Dr N. Hurter and Mr M. J. van Tonder of the FFTRI (Hurter, 1972). The cultivar was meant to replace Wickson. The improved characteristics that it possessed were its ability to self-fruit and its resistance to bacterial spot. The cultivar had good cold storage ability and it could bear fruit well. The first commercial tree plantings of Harry Pickstone were made in 1973, in which a mere 75 trees were planted. In the following season, tree plantings had increased to 13 089, but decreased to 5 821 in 1975. The first exports of this cultivar were made in the 1976/77 season and 7 853 single-layer trays were passed, a volume almost twice as much as Wickson. It is harvested early January and today remains one of the top 30 exported cultivars in South Africa (Hortgro, 2012).

In 1977 the third locally bred mid-season plum cultivar, Reubennel, was released (Hurter, 1977). It was meant to be a replacement for Gaviota and had its breeding parents as Gaviota, Wickson and Methley. Hurter and van Tonder made the crosses between Methley and Wickson in 1951 and the resultant progeny was planted in 1953, with the first commercial crop obtained in the 1957/58 season. A promising selection was crossed with Gaviota in 1959 and the resultant progeny was planted in an orchard in 1961. The seedlings from the cross yielded their first commercial fruit in the season 1965/66. The cultivar was deemed to have superior characteristics to its breeding parents. It was resistant to bacterial spot, had reduced delayed foliation, and had good yield and fruit size. Propagation material was available to nurserymen and producers in 1978. Reubennel's lifetime still continues and it has been amongst the top 14 exported cultivars to date.

Next, was the release of the cultivar Redgold which followed in 1979 (Hurter and Stadler, 1979). This cultivar was developed aiming to close the gap that existed between the ripening of Harry Pickstone` and Kelsey. It had good yield, high resistance to bacterial spot and had good keeping quality. The cultivar, however, did not have a sustainable lifespan like the rest that were bred prior to it. By the year 2007, the cultivar was no longer amongst the significantly produced varieties.

Prior to 1982, the leading cultivars were Santa Rosa, Gaviota, Kelsey and Golden King. By 1982 improved cultivars represented more than 60 percent of the plantings (Hurter and van Tonder, 1982). Plantings increased as new producers entered the field and there were dramatic increases in total production. Sixty-six percent of the total quantity produced was ascribed to the four new cultivars — all mid-season varieties — and the industry was faced with the hurdle of peak deliveries with gaps in-between (Bester, 1985). To curb this, plums would be stored for long periods with the consequence that the fruit arrived at overseas markets in poor condition. The problem would only be solved by developing a new cultivar that would fill in that gap between peak deliveries.

In 1972, Hurter and van Tonder collected open pollinated Golden King seeds whose seedlings started bearing in 1977. The resulting new cultivar, Laetitia was released in 1985. It was bred to ensure a uniform supply of plums to the markets. The first tree plantings were in 1980, yielding 5 kg per tree in 1982. The following year, the yield had doubled to 10 kg of fruit per tree, and by 1984 this had gone up to 25 kg per tree (Bester, 1985). The performance of Laeticia superseded that of all other varieties and it has maintained its position as leader in terms of area planted and volumes exported. Laetitia became popular due to its high resistance to the bacterial spot disease.

In 1989, the first late-season black skinned plum cultivar, Celebration, was released to the industry. It was bred by Hurter and van Tonder. The cultivar ripened five to seven days after Songold and did not extend the marketing season significantly. It was bred from Songold seeds that were open-pollinated in 1976. The first seedling selections were made in 1979 and evaluations were started in 1981. In the fourth year of planting, Celebration trees produced an average yield of 6.8 kg per tree, and it was envisaged to produce approximately 11.3 tons per hectare (Oosthuizen and Stadler, 1989). In his research reported in 1990, Oosthuizen found that the first commercial fruits of Celebration had poor keeping quality, for this reason the cultivar was not recommended to producers. Instead, more research was continued on the variety.

Sapphire, another mid-season cultivar which was envisaged to be successful, was released in 1992. In 1979 Hurter and van Tonder open-pollinated the seeds of Laroda V2 and stratified them in the same year. The first seedlings were planted in 1980 and selections were made in

1984. The first fruits of these seedlings were harvested on the 3rd of December 1990. Average yield in the fifth year was between 13 and 14 tons per hectare. Before it was released it was already in demand by the producers, and was well received. Farmers were expecting to receive a higher net income from this cultivar since it bore good fruit from its second year. When evaluated, the cultivar showed no signs of internal breakdown and had good storage ability, but it was found to be susceptible to bacterial spot (Oosthuizen, Visagie and Smith, 1992). This cultivar has maintained its top third position in total area planted, and has been among the top six most exported cultivars.

Souvenir was released in 1993 (Oosthuizen, Barnard and Smith, 1993). It came from the open-pollinated seeds of Songold in 1976 by Hurter and van Tonder. A year later seedlings were planted, and selections were made in 1981. The first commercial fruits were harvested on the 12th of December 1990 with an average production of 12 kg per tree. The trees of this cultivar were envisaged to produce average yields of between 17 and 22 tons/ha in their fifth year. The cultivar was observed not to be susceptible to bacterial spot and was well received by growers due to demand for plums of good quality early in the season. Although in recent years the area planted with Souvenir has been decreasing, it has maintained its 12th position amongst the most exported South African cultivars (Hortgro, 2012).

Pioneer, an early-season red cultivar was released in 1995. The cultivar was found to have good storage ability that allowed it to be transported to overseas markets by sea. It is harvested mid-late November and has been amongst the top six most exported plums (Infruitec, 1995). Export sales in 1994/95 were approximately R60 million and 79 percent of this was from the contribution of ARC-bred cultivars (Infruitec, 1996). Another mid-season red plum, Lady Red, was released to the industry in 1996 with the intention to replace Reubennel. Since it was bigger in size than Reubennel, Lady Red is doing well and is among the significantly producers cultivars.

Two new cultivars, Sun Kiss and Sundew, were released in 1999. These were the first full bright yellow plums and were both registered under the trademark African Pride™. These two were developed to close the gap in the European markets post-Christmas. African Pride™ is a unique product of South Africa as it remains yellow even after ripening. The cultivars have good storage ability and were the first to be released under controlled commercialization

(Halgryn, Smith, von Mollendorff and Labuschagne, 2000). Sun Kiss is among the top eight most exported cultivars in South Africa, whilst Sundew, although among the significant export cultivars, has been lagging behind. In the same period, a mid-season red cultivar, Ruby Red, was released. This cultivar has good storage ability, higher yield and is of better quality than other varieties.

In 2003 two more yellow plums were released. These cultivars were given the names Golden Kiss and Sun Breeze, with Sun Breeze being an improvement on Songold. Amongst yellow plums, Golden Kiss was outstanding in terms of cold storage and shelf life performance. However, Sun Breeze failed to live up to its expectations and five years later it was not amongst the significantly produced cultivars. Golden Kiss is still in the top 24 significantly produced and exported cultivars in the country (Hortgro, 2012).

In 2008, Infruitec released the much anticipated African Delight plum whose aim was to reduce production costs. This cultivar was well received by producers as it had the following characteristics; high sugar content, good storage ability allowing the marketing period to be manipulated, and low chilling requirements. Due to its excellent performance, within four years of its release, this cultivar was the country's fourth largest produced and exported variety (Hortgro, 2012).

Infruitec has released a number of new cultivars in the last four years and Chris Smith has been responsible for their breeding. In 2009 three new cultivars were released, and these were: a black-skinned plum, Solar eclipse, a red-skin late season plum, African Rose, and an early season red-skin plum, Ruby Star. These cultivars have great potential as they have all proven themselves to have a high yield/tree ratio of more than 20 kg/tree. These cultivars are meant to be improvements on existing plums and Ruby Star has been shown to be an improvement on Songold. In 2012, three more cultivars were released and these are: Ruby Sun late-season red-skin plum which is an improvement on Sapphire, Red Crunch a red-skin plum, as well as Satin Gold a yellow plum which is an improvement on Songold.

Although impressive results have come out of the plum-breeding programme of the ARC, Chris Smith continues to breed in pursuit of more new and improved cultivars. The largest produced cultivars, Laetitia and Songold, are harvested in the 3rd and 4th week of the season respectively and there is consequently a large supply of the fruit at the same time and during the rest of the season supply is low. Late maturing cultivars which will extend the season have been at the top of the list of the breeding objectives and more work continues to be done in this regard.

Table 3.2 below gives a summary of the performance of ARC cultivars in exports. More than 50 percent of the top 30 exported cultivars were bred at the ARC, this shows how breeding research has had a positive impact on the industry.

Table 3.2: Export performance of ARC plum cultivars

Cultivar	Year of release	Ranking in export performance
Laetitia	1983	1
Songold	1972	2
Pioneer	1995	5
Sapphire	1992	6
African Pride	1999	8
African delight	2008	9
Lady red	1995	10
Souvenir	1992	12
Ruby Nel	1979	16
African Rose	2009	17
Sundew	1999	19
Ruby Red	1999	20
Golden Kiss	2003	24
Harry Pickstone	1973	27
Solar eclipse	2009	30

Source: Hortgro (2012)

The success of ARC plum cultivars is not just local. Evidence suggests that the institute was the world's first research institute to regenerate plum trees from single leaf cells in 1993 (Infruitec, 1994). Several cultivars had their unique fingerprints generated from this programme. This was done through the use of molecular biotechnology. The biotechnology division was started in 1987. Through this process, plant scientists conducted genetic engineering to manipulate the pathogens of bacterial canker and bacterial spot and to improve the crop yields. The institute had one of the best-equipped molecular research laboratories in the world and within three years of establishment was making remarkable progress. *In vitro* breeding of plum cultivars and plum rootstocks also became part of the research projects under plant biotechnology.

Genetic resistance to plum pox was examined with the aim of obtaining cultivars that are resistant to this virus and other diseases (Infruitec, 1992). The use of biotechnology was meant to curb the limitations faced by breeders using conventional breeding methods. Since plums are perennial, the results from conventional breeding would take a long time to show. The use of biotechnology techniques hastens the process of breeding. Biotechnologists continue to work with breeders to manipulate the genotype of plant material in order to come up with better cultivars.

The institute has also conducted research on rootstock breeding. The aim was to find rootstocks that induced higher yields, controlled the vigour of the tree, and were dwarfing (Hurter and van Tonder, 1975). The plum rootstock programme involved breeding as well as evaluation of imported rootstocks to determine whether they were compatible with the scions or not. In 1971 Bester started an evaluation project of imported plum rootstocks. The aim was to find the rootstocks on which plum cultivars could be grafted to produce higher yield per area in different geographical distributions and soil types. This was done over a period of 15 years, and Mariana proved itself to be outstanding in performance in comparison with all the cultivars it was compared with. Mariana was propagated from hardwood plum cuttings and peach grown from Kakamas and Duplessis seedlings. Although it had good characteristics, it was susceptible to root-knot nematodes and ‘wet feet’ and had to be replaced by better rootstocks.

Another new plum-rootstock breeding programme was started by Hurter. Hurter in 1972 and was projected to end in 1984. Its primary aim was to have a rootstock that would have an influence on the vigour, yield and disease resistance of the Gaviota and Santa Rosa scions (FFTRI, 1976). This programme involved planting trials and evaluations of several plum rootstocks. Rootstock breeding was also conducted by Stassen and Van Zyl. It ran through from 1971 and aimed at producing a compatible rootstock for plums that would affect the size of trees that are adaptable to different soil types and production areas.

Plum rootstock breeding and evaluation continued and the rootstock Maridon was released to the industry in the season 1989/1990. This rootstock induced resistance to bacterial canker. In the same season research results revealed that Harry Pickstone cultivars performed better on the rootstock Citation as compared to the widely used Marianna. Investigations into the selection and evaluation of especially clonal rootstocks for plums continue to be one of the primary activities in the rootstock breeding division. The breeders are being complemented by horticulturalists, plant physiologists, plant pathologists and entomologists, who all participate at varying degrees and levels of plum-breeding research, including cultivation research which is considered next.

3.4.2 Cultivation research

A research project on the propagation and maintenance of plum cultivars commenced in 1972. This research project focused on establishing and maintaining trees of existing cultivars as well as selected new ones. The trees, fruit, quality and breeding value of the cultivars were thoroughly assessed in order to pick the right ones for the inclusion in gene banks (Infruitec, 2001).

A considerable amount of time was also spent on cultivation research with the purpose to determine whether training systems affect fruit size. In 1974, Bergh compared the central leader and the palmette training systems using the cultivars Santa Rosa, Gaviota, Kelsey and Songold. The results from this were that the two training systems did not have any significant differences in yield in the two seasons evaluated. The investigation concluded in 1977 that cultivars trained on the palmette system had significantly less wind damage than those trained on the central leader system. It was also concluded that training systems had no effect on the size of the fruit. Most farmers had shifted to the palmette production system because of the minimal wind damage it caused. However, this system was found to be labour-intensive and increased the cost of production, and investigation on better training systems was needed. The importance of tree shape in cropping and fruit quality has been shown by testing several training systems. Improvements for various cultivars were made in order to optimize the quality and quantity of fruits per tree. Research to improve the quality of nursery trees continues to be done (FFTRI, 1978).

A field experiment was initiated in 1985 to determine the lime requirements of plums. The results showed that liming increased the yield and decreased the concentration of phosphorous and potassium in the fruits (FFTRI, 1986). In the production season 1989/1990, researchers conducted a field study that looked at the fertilizer requirements of plums. It was realized that the FFTRI guidelines on fertilizer requirements overstated the fertilizer needs of plums and in 1991 it was determined that decreasing seasonal nitrogen fertilizer by 30 percent did not have any detrimental effects on growth and yield but instead improved the fruit quality (Infruitec, 1992). Contrary to what previous research results had suggested, it was reported in 1991 that the lime requirements of plum trees differed across cultivars. In 1993 research results showed that plum trees were intolerant of excessive lime application and that they were sensitive to lime-induced magnesium and zinc deficits (Infruitec, 1993). Researchers continue to probe the efficient production practices and inputs that would make plum farmers realize more profits. Research of this nature is complemented by other forms of research, for example, chemical thinning to reduce labour costs.

3.4.3 Research on chemical thinning

Research into chemical thinning of plums was conducted from 1967 through 1974. Results showed that the chemicals 3-chlorophenoxy-alpha-proprionamide (3-CPA) and dinitro-ortho-sec-butylphenol (Gebutox or Premerge) worked well when sprayed on the fruit. In 1984 some experiments were conducted on the use of chemical thinning agents on the Harry Pickstone cultivar. Investigations of chemical thinning concluded in the year 1989/90 indicated that early chemical thinning of plums was vital to ensure good quality fruit. In 1994 chemical thinning trials were conducted on Ruby Nel, Santa Rosa and Harry Pickstone plums. Armothin was registered in 1996 as the chemical that would be used for thinning of the cultivars Santa Rosa, Ruby Nel and Songold. Various methods of thinning that would reduce the use of labour and that are eco-friendly are being explored, although less effort is dedicated to chemical thinning.

3.4.4 Physiology research

The dent caused by black spot disease in the plum industry in 1962, motivated research into what alternatives could be used on plum trees instead of spraying to control the disease. Bacterial spot had a detrimental economic effect on the plum industry, and most of the physiological research concentrated on this disease. By 1964 South Africa had established a growing market in the USA, but the physiological conditions of the plums upon arrival proved to be a major stumbling block (FFTRI, 1965). From the research conducted it was discovered that low temperature sterilization was one measure of controlling the damage caused by bacterial spot. Plums were stored at –0.5oC for 14 days, but some cultivars such as Santa Rosa could not withstand such drastic storage conditions and arrived in the overseas markets in a bad state. In 1964 research on developing a suitable gas fumigation technique for sterilization to reduce the effect of bacterial spot was initiated.

Tormann conducted research in 1971 on methods of determining the degree of ripeness of plums. The purpose was to determine the correct picking stage of plum cultivars in relation to storage temperature. From this, it was discovered that internal breakdown in plums during cold storage was mainly dependent on the picking date, and late picked fruit had more incidence of internal breakdown (FFTRI, 1976). Physiological research continued in pursuit of the optimum maturity standards of plums. As the annual report of the FFTRI (1977/78) stated, the objective was to determine the colour, pressure, sugar content, pH value and acid levels of mature plums at the date of picking. It was determined that when plums were picked at the appropriate maturity level, they would maintain their optimal eating quality for up to 21 days. In 1979 Tormann continued working on the maturity of plums, but this time the project involved only the cultivars Santa Rosa, Gaviota, Reubennel, Songold and Harry Pickstone. From the results it was concluded that colour intensity had a close relation to the taste of Santa Rosa plums, whilst it only indicated picking maturity for Gaviota, Reubennel and Songold plums. For Harry Pickstone it was found that the appearance of red flush on the skin had nothing to do with the picking maturity of this cultivar (FFTRI, 1979).

By the late 1970s, South Africa was a recognized world leader in plum research and especially in dealing with the most virulent plum disease, bacterial canker. This is attributable to the fact that bacterial canker disease had the most devastating results in South Africa compared to any other country. It would cause trees as young as one to two years to die and a reduction in yields of older trees. By 1987, research discovered that the disease was caused by just one pathogen that affected both stone and pome fruits. The disease could not be controlled by chemical spraying, and in 1990 molecular biological measures were used to study the pathogen and determine how it causes disease in the host (Infruitec, 1992).

The problem of internal breakdown had been prevalent for a long time and was previously controlled by use of dual temperatures as well as acetylene, but these efforts were all in vain. This instigated research on internal disorders in plums in 1982 (De Kock and Taylor, 2010). In 1983, Tormann started investigating the relationship that exists between orchard temperature, fruit size, nutrient uptake and internal breakdown in plums. In 1986 the results revealed that temperature treatment had no effect on internal breakdown of plums after cold storage. Investigations were also made with regards to the chemical composition of plums and the incidence of internal breakdown. The objective was to find what threshold values for nutrient elements controlled the occurrence of internal breakdown of plums. Results indicated that internal breakdown was associated with picking maturity. It was found that the low calcium and high phosphorus concentrations in the fruit at the time of harvest were the main cause of this physiological disorder. From this project it was concluded that, in order to minimize the occurrence of this physiological disorder, crop control and manipulation of nutrition was to be carefully conducted.

A similar study on internal breakdown in plums was initiated in 1984 and carried out by Steenkamp. The aim was to determine how the chemical or biochemical composition of plums during the development of plums affected internal breakdown in plums. The results showed that there was a correlation between calcium, potassium and magnesium levels found in the leaves and internal breakdown. In the season 1989/90 it was discovered that internal breakdown in plums was a consequence of limited ascorbic acid in the fruit, and that fruit with this disorder had increased enzyme activity as the cold storage periods increased.

Research was also done on other diseases and disorders. In 1982 two projects were initiated. Van Zyl looked at the pathogens that were responsible for brown rot disease in plums. In his results he found that brown rot, also known as blossom blight can cause up to 80 percent loss in blossoms which would severely reduce the yield per tree. This study took more than 3 years, and was concluded in 1986. The second project was conducted by Fourie (2013) and investigated the geographical distribution of pathogens responsible for post-harvest decay in plums. Researchers had to come up with an integrated approach of breeding that incorporated biotechnology, and as a result a new research approach was then designed as shown in figure 3.2 below.

According to researchers biotechnology assisted breeding can reduce the breeding process by up to seven years. When breeding is coupled with biotechnology intelligence, genes are identified, isolated and sent to gene banks, which makes it easier for them to be accessed by other breeders.

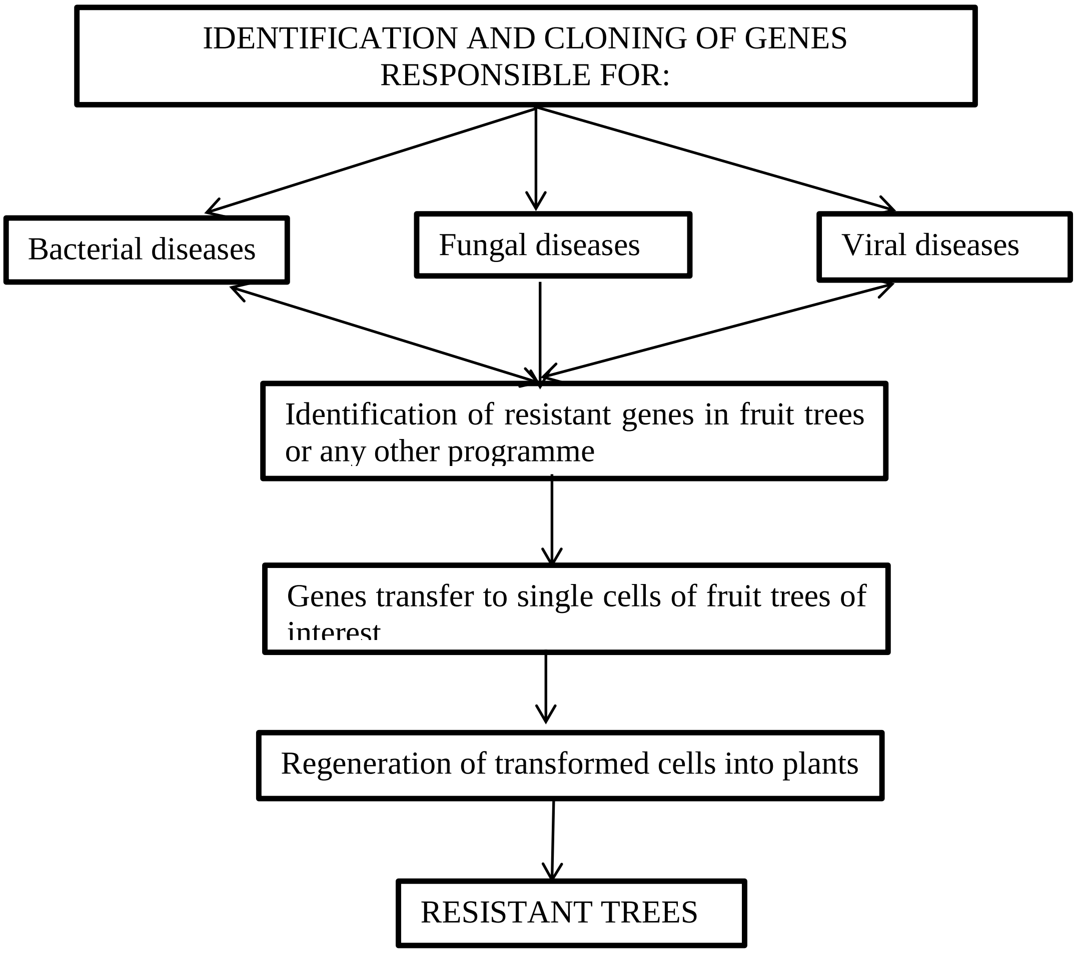

Figure 3.2: Breeding for disease resistant cultivars

Source: FFTRI technical bulletins

In 1990/91, more research was commissioned to determine the effect of climate on fruit quality. Researchers also looked at the effect of harvesting plums late and results suggested that, although fruits that were harvested late had a rich colour, the late harvesting of plums caused them to exhibit a high incidence of gel breakdown. In 1991 it was reported that there is a relationship between the poor keeping quality of plums and the position of the fruit on the tree (Infruitec, 1992). Fruit borne from shoots on the top half of the tree were more prone to stem-end-split and had poor keeping quality. Further investigations in this regard were conducted. Dr Combrink, in a survey that was initiated in 1993 on the geographical distribution of fungi causing post-harvest decay in plums found four pathogens responsible for this. In 1995 research was conducted on the biology of ring nematodes that caused large-scale deaths in plum trees in that season. Measures of controlling the pathogens and reducing their effects were the primary focus of the investigation. Fruit fly infestation was found to be responsible for compromised quality of plums and, because fruit flies are international quarantine pests, the other immediate effect was restriction of free trade when exporting the fruit. There are two species of fruit flies that are of economic importance and that affected the deciduous fruits in South Africa, namely, Mediterranean fruit fly and Natal fruit fly.

In 1997 Infruitec received funding from the Nuclear Techniques in Food and Agriculture section of the Joint Food and Agriculture Organisation/International Atomic Energy Agency (FAO/IAEA) Program of the United Nations to carry out a four-year project on sterile fruit fly (Barnes and Venter, 2006). A project on implementing the Sterile Insect Technique (SIT) to combat the Mediterranean fruit flies in the Hex River Valley was initiated in 1999 in a region solely for table grapes production. The aim was to supress the effect of the fruit flies. Following the success of this programme in the Hex River Valley, SIT was extended to other deciduous fruit production regions (FruitflyAfrica, 2013-10-05). Until 2003 sterile fruit flies were sprayed aerially using planes, but due to high costs incurred ground releases were encouraged in home gardens, farm backyards and in urban areas. Although the programme proved successful, it was impossible and costly to undertake in a relatively small area and in 2008 area-wide sterile releases were started. To counter the high costs involved in this programme, the distribution of sterile fruit flies was commercialized in 2003 through the formation of SIT Africa (Pty) Ltd a private company which now manages the production of sterile fruit flies.

SIT focuses only on the Mediterranean fruit fly, primarily because it is prevalent in most fruit production regions and because the SIT for Natal fruit fly is not yet feasible (Barnes and Venter, 2006). In 2006, 15 million sterile male Mediterranean fruit flies were produced and released weekly by hand in the main fruit fly breeding areas. The programme has been successful and to date fruit damage has been reduced to 0.025 percent, insecticide use has dramatically reduced and the mean fruit fly population has been decreased from 0.9 to 1 flies/trap/day three years before the release to 0.1 to 0.4 flies/trap/day after release. The programme is continued and by 2015 aims to have covered 70 percent of the total fruit production areas in the country.

Current research focus has shifted to the use of molecular techniques to identify bacterial spot.

3.4.5 Research on pollination requirements

In 1965, it was discovered that the previously deemed self-fertile varieties Eldorado and Beauty did not form any fruits when self-pollinated. From this, research established that the best pollinator for these cultivars was Golden King. Research has continued in this field with regards to temperatures within which pollination can occur (FFTRI annual report, 1965).

3.4.6 Storage

Several experiments were done in 1964 on cold storage of plums so as to control internal breakdown. Dual temperatures and different temperature combinations were tried but none of these controlled the disorder (FFTRI, 1965). Fourie (2013) looked at the factors that influence the storage conditions of plums. In the season 1989/90 the FFTRI advised farmers to pack and cool plums soon after harvesting to prevent decreases in quality. This followed conclusive results that suggested that Songold plums stored well under controlled atmosphere conditions for two weeks followed by storage at 7.5^0 for two to four weeks (FFTRI, 1989/90). The experiments also established that delaying storage adversely affected fruit quality. The effect of storage under controlled atmosphere conditions on other cultivars was also investigated. It was established that controlled atmosphere storage extended the marketing period of late cultivars and that it also stimulated organized marketing. Due to the increase in post-harvest losses that came as a result of physiological disorders and consumers' resistance to the use of post-harvest chemicals, in 1992 the research focus shifted to developing new cold storage methods. This followed results that suggested that gel breakdown and internal breakdown in

Songold plums occurred as a result of storing the fruits in sub-optimal temperature regimes (Infruitec research review, 1992).

An experiment conducted over a period of two years revealed that Songold plums planted in areas with high accumulated heat units with a long fruit growth period, had better storage quality (Infruitec research review, 1992). Breeders and researchers have continued to investigate optimum storage temperature, particularly looking at plum cultivars that have potential to withstand single temperature while in storage. This has been a cause for concern because plums travel in the same ships as grapes which travel at a single temperature regime while plums require multi-temperature storage and this compromises the quality of plums. It may seem that this kind of research is still far from being conclusive.

3.4.7 Climatic effects

Research on the detrimental effect of certain climatic conditions was also conducted. The aim was to find ways of manipulating trees both before and after the winter dormancy, so as to protect them from the adverse effects of not meeting the chilling requirements. Application of rest-breaking agents has been considered and research has focused on developing more eco-friendly chemicals. Currently, research on climatic conditions is aimed at finding ways to optimize production of fruits in specific climatic and soil conditions.

The foregoing analysis relates to plum research conducted in South Africa using South African funds. In the next section, a brief account of international plum research is given.

3.5 PLUM RESEARCH WORLDWIDE

Countries in Asia, North America, the Southern Hemisphere and Europe are actively involved in plum-breeding research. Plum-breeding programmes across the world are largely to develop cultivars that are suitable to the environment in which they are grown, are productive and resistant to pests and diseases as well as physiological disorders (Okie and Ramming, 1999). In the developing world, the cost of labour is high, so research emphasis has concentrated on changing tree architecture such that less labour is required. This has included developing new training systems and developing dwarfing rootstocks. Consumers have raised concerns about the use of chemicals for pests and diseases; this has led to research objectives changing to finding alternatives that will be eco-friendly and safe for farm workers to use.

In some countries plum breeding is conducted by private research institutes in contrast to South Africa where plum-breeding research is still predominantly carried out by the public sector. Table 3.3 below shows the distribution of research focus for the private and public breeding programmes. According to Byrne (2005) private research institutes direct 91 percent of their resources to cultivar development, mainly because they can now exploit the gains from the Intellectual Property they acquire by patenting their products. On the other hand, the public sector has an equal distribution of resources between cultivar development and germplasm enhancement. Germplasm enhancement and genetic research are, however, of relatively low importance in the private sector. In USA, the public sector has devoted more than twice as many scientific years' to research as private research institutes.

Table 3.3: Public versus Private breeding programmes in deciduous fruits and nuts in USA

Activity	Public	Private
Cultivar development	36 percent	91 percent
Germplasm enhancement	36 percent	6 percent
Genetic research	28 percent	3 percent
Total (Scientist-years) effort	73	32

Source: Byrne (2005)

In California, plum breeding was started in 1932, and the objectives have included developing late-season cultivars, with good shipping ability and eating quality. Other breeding programmes in the USA have focused primarily on developing cultivars that are resistant to diseases and have lower chilling requirements. Since 1970, breeding has moved from the public to private companies. Whilst public breeding programmes devote 60 percent of their budget and efforts to genetic research, private breeding programmes apportion a mere 10 percent of efforts in these areas (Byrne, 2005). As a result, the shift from public to private breeding programmes implied that there was a decrease in basic research as well as breeding technology in the USA. Plums bred in South Africa and in Australia, are the sources of new plums in the USA.

Although plums have been part of the economy of Chile for over 2000 years, plum programmes to develop new cultivars only began in 1913 (Carrasco, Meisel, Gebauer, Garcia-Gozales and Silva, 2013). The focus was on developing highly productive and good quality cultivars that were well adapted to diverse biotic and abiotic conditions. Since 1992, the major challenge to the Chilean plum industry has been the *plum pox virus*, which has been reported to have affected several commercial orchards (Wong, *et al*., 2010). This shifted the focus to developing disease-resistant cultivars. Currently the Chilean breeding programmes focus on meeting both consumer and producer preferences and demand, hence breeding has shifted from traditional to molecular breeding. Consumers require a particular taste and texture from plums, yet producers seek cultivars that can resist diseases, and have different harvest and high storability dates to prolong the marketing season.

In Brazil the breeding programme was aimed at developing cultivars that have low chilling requirements as well as resistance to bacterial spot. Brazil also has a challenge with leaf rust disease and developing cultivars that are resistant to this is one of the main objectives.
In Australia the plum-breeding programme only started in 1967 and the goals have been to develop large-sized early-season cultivars of high quality, that are resistant to bacterial spot and summer rainfall blemishes (Okie and Ramming, 1999). In Eastern Europe, most plums are dried and processed into brandy; therefore research objectives in this region are inclined towards developing plums with high soluble solids.

In Italy plum breeding began in 1970, with the purpose of developing large early ripening plums of high quality that are resistant to biotic and abiotic stresses (Okie and Ramming, 1999). In Germany, plum-breeding research was initiated in 1980. The main aims were to improve quality and quantity of the fruit as well as resistance to the plum pox virus. Breeding programmes in Switzerland, Sweden and Norway have similar aims. In Asia, China only started a plum-breeding programme in the late 1980s. The focus has been to develop late-ripening cultivars that will extend the marketing season, varieties that have high productivity, large fruit size, and are resistant to bacterial spot as well as other diseases. However, their programme has yielded no new cultivars thus far.

3.6 CONCLUSION

Due to the problems faced by deciduous fruit growers in South Africa, they decided to use collective action to gain government support through research, and this attempt was successful. Several institutions have been established since 1899 to represent and promote industry interests. Initially membership was voluntary, but this proved ineffective in the formative years of the industry. To better exploit market opportunities a need was identified for a more organized approach with statutory control over export marketing. With the improved access to international markets that followed from the removal of sanctions post 1994, the export market was deregulated in 1997. Producers are now free to choose through whom they market their fruit. This has also given plum growers the liberty to choose their own export destinations, and it is reasonable to argue that this was to some extent responsible for strong growth of the industry. The industry structure is continuing to evolve.

Since 1937, when the Western Province Fruit Research Station was established, a great deal of research work has been done with respect to plums. The main aim was to improve the performance of existing imported plums and to develop new and improved cultivars that would replace the poor performing ones. Various research focus areas have branched out of this. In South Africa the cost of labour is high and research has tried to find production practices that would limit labour requirements, such as tree-training systems that would have less labour needs. Plums suffer post-harvest internal disorders and are prone to diseases; researchers continue to seek optimal storage temperatures and chemicals that can reduce the occurrence of these. Biotechnology has also been used to hasten the breeding of new cultivars.

The South African plum industry has broadly the same objectives as those of other countries when it comes to plum research. The aim is to create cultivars that are suitable for the local environment and can withstand diseases whilst yielding high quality fruit. Although in some countries plum research has shifted to private breeders, in South Africa Infruitec (a public organization) is still the dominant institute responsible for plum breeding.

The next chapter provides a descriptive overview of the resource allocation to fruit and plum research in Infruitec.

CHAPTER 4

RESEARCH FUNDING AND STAFF CAPACITY

4.1 INTRODUCTION

The purpose of this chapter is to analyse the trend in historic investment in plum research. Since the records on plum investments data prior to 1994 were aggregated to the deciduous fruit industry, the basis to form a disaggregated series was determined by using trends. A complete expenditure series from 1980 was determined by extrapolation based on the data gathered from Unifruco. Staff capacity allocated to plum research will also be discussed.

4.2 FUNDING LEVELS, SOURCES AND ALLOCATION

The research expenditures reported in this study include the funds that went into Infruitec's research and those expenses used to directly support plum research. These data were obtained from the project income statements of the Department of Agricultural Technical Services publications and the Deciduous Fruit Board memoranda and minutes. This section of the chapter describes the financial documents that were examined in an attempt to estimate the cost of research at Infruitec.

4.2.1 Support from the Deciduous Fruit Board

The Deciduous Fruit Board played a pivotal role in funding fruit research at Infruitec. From the time plum-breeding research started in 1945 until 1949, the Deciduous Fruit Board used to allocate a fixed research grant of £25 000 for the whole institute (Deciduous Fruit Board memoranda). This amount was further apportioned by the institute to the different fruits' research according to the needs of each project. Farmers were charged a fee per carton received by the Board, and it was called the fruit levy. The funds collected from this levy went to the General Reserve Fund to cover the administrative expenses for the Board, and some were transferred to the Research Reserve Fund for the purpose of providing funds for special projects conducted by either the Board or outside organizations. The movements into and out of the Fruit Levy Fund were under the control of the Board, subject to particular receipts (like levy) and payments for certain purposes requiring the special approval of the Minister. The Minister was to approve all amounts which were credited to the Research Reserve Fund and he was also to give approval to the manner in which the Board dealt with any moneys in any other reserve fund. Another facet of research expenditure towards WPFRS was in the form of payments for fruit required for experimental projects and packaging material experiments.

In 1949 the Board introduced a scheme which made provision for a special levy which was to be used to finance other activities which were outside normal administrative costs of the Board, and research fell in this category. In addition to the fruit levy, farmers were charged a special levy which was much less than the fruit levy. The rates of the levies were fixed and changed when the Board saw it fit. The fruit levy was charged as a percentage of the selling price, which varied according to the place of sale; and the special levy was in the form of a unit charge on quantities exported and a different unit charge for quantities sent to local markets.

From 1947, the first post-war year in which levies were raised, up to and including 1967, the nominal aggregate levy contributions were as shown in Figure 4.1 below:

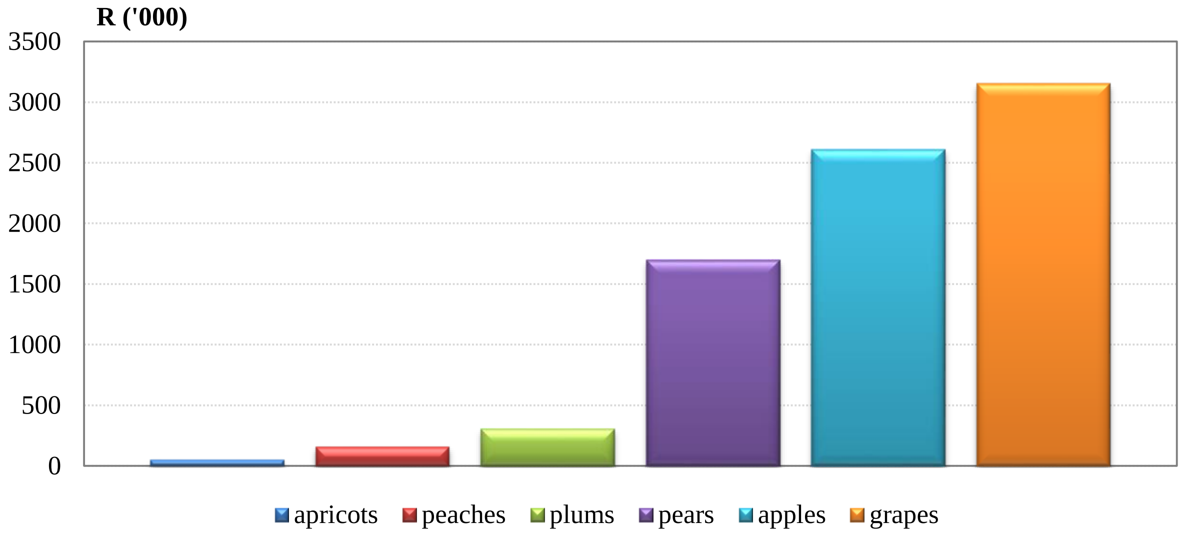

Figure 4.1: Aggregate levy contributions between 1947 and 1967

Source: Deciduous Fruit Board memorandum, 1974

The values above show that stone fruits collected the lowest levies; this could be mainly because of the lower production levels as compared to pome fruits and grapes. Among the stone fruits, plums had the highest levy contributions. In 1962 a fruit levy of 1.5 percent of the selling price realized in respect of both exports and local sales of local fruit and a 6d (£0.025) special levy were imposed on farmers. In 1983, the general levy was increased to 24–27.3 cents and the special levy for plums was between 5 and 12 cents. Expenditure on research was allocated in proportion to the aggregate levy contributions of the various categories of fruit in that particular year. But, because of the method used by the Board for fixing rates of levy, this meant that the expenditure was allocated on a package basis.

In 1967, in addition to the fixed research grant, a special grant of R25 000 was given to the research institute for urgent research projects that were to be undertaken on behalf of the Deciduous Fruit Board. This grant was intended to provide funds to the institute for urgent research work or experiments, only in instances where the facilities or equipment could not be obtained by the institute in a normal manner in time for the experiments. In 1968, plum projects were allocated a nominal amount of R2 074 by the Board. This decreased to R1 255 in 1969/70. By 1972/73 the figure fell to R800. In the season 1982/83 the funds from the Board for plum research increased to R48 000 and, in addition to that, an amount of R48 000 was allocated solely for the purchase of temperature cages and equipment for research by FFTRI on internal breakdown in plums.

4.2.2 Allocation by Unifruco

The Board was directly responsible for allocating research funds to FFTRI until 1987 when they delegated some of their tasks to Unifruco. Unifruco Research Services (URS) formally took over the task of rationalizing the development of technology for the industry and allocating as well as managing industry research funds (Carter, 1999). In the season 1987/88, the rates of the export levies increased and producers were charged a fruit levy of 47.8cents per carton and a special levy of 36.1 cents. Producers who sold in the local market were charged a much lower special levy of 22.9 cents per carton. In that season, an amount of R6 721 was allocated to FFTRI by the Board for plum research.

Figure 4.2 below shows the amount of money invested in plum research as a percentage of the total amount of money apportioned to FFTRI by URS between the years 1982 and 1992. Although the total research expenditure allocated to FFTRI for fruit research was increasing in real terms, the amount for plum research was generally decreasing. Funding was allocated according to the assessment of priorities, amount requested and the available funds. Funds were allocated based on the most important projects receiving funds until all the money is exhausted and there is none left to be allocated to any project. The decrease in the percentage allocated to plums could mean that plum projects were not regarded as important or that there were no high priorities in plum research.

As shown in Figure 4.2, in 1982, of the total R&D funds invested by URS, 93 percent was solely for plum research. This decreased by 1984 to 37 percent. In the year 1986 it further decreased to 13 percent and by 1988 it had plummeted to a mere 4 percent. In 1990 URS increased the funds it invested for plum research as compared to the previous years to 16 percent of the total institute allocated funds. In 1992, the percentage allocated to plums further decreased to a mere 2 percent.

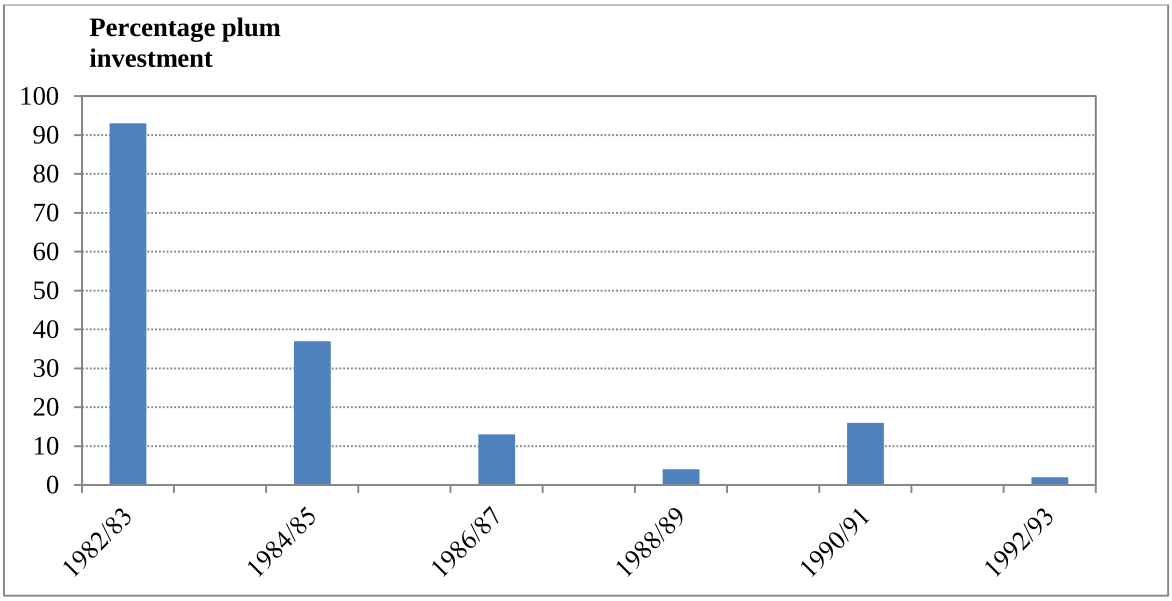

Figure 4.2: Plum investment as a percentage of total institute investment by URS 1982-1992

Source: Unifruco annual reports (1982 — 1992)

4.2.3 Research funding from the industry post-deregulation

After deregulation URS separated into two bodies. One now provides commercialized research services which were previously offered for free. Users now pay for such services as weather data, fruit size predictions, release dates and maturity indexing. The other body is Hortec which assumed the responsibility of managing the industry research budget and allocating funds to the principal research institutes including the ARC until 2002 when Hortec became independent. After the commercialization of Hortec as a stand-alone business in 2002, the Deciduous Fruit Producers Trust (DFPT) was instigated and took over the task of managing research for its shareholders who included SAAPPA, SASPA and SAT (Fruitgro[science], undated).

The DFPT only contributes a fraction of the required funds for each project. For breeding and evaluation, 35 percent is allocated to all running projects and for other projects such as pest management, plant physiology and pathology, post-harvest and technology 45 percent is allocated. All new projects are allocated 49 percent of the total cost of the project. Figure 4.3 below shows the total amount of funds invested by DFPT for plum research at Infruitec between the years 2000 and 2012. As shown by the figure above, the amount invested by DFPT in real terms on behalf of the industry has continued to increase since 2000.

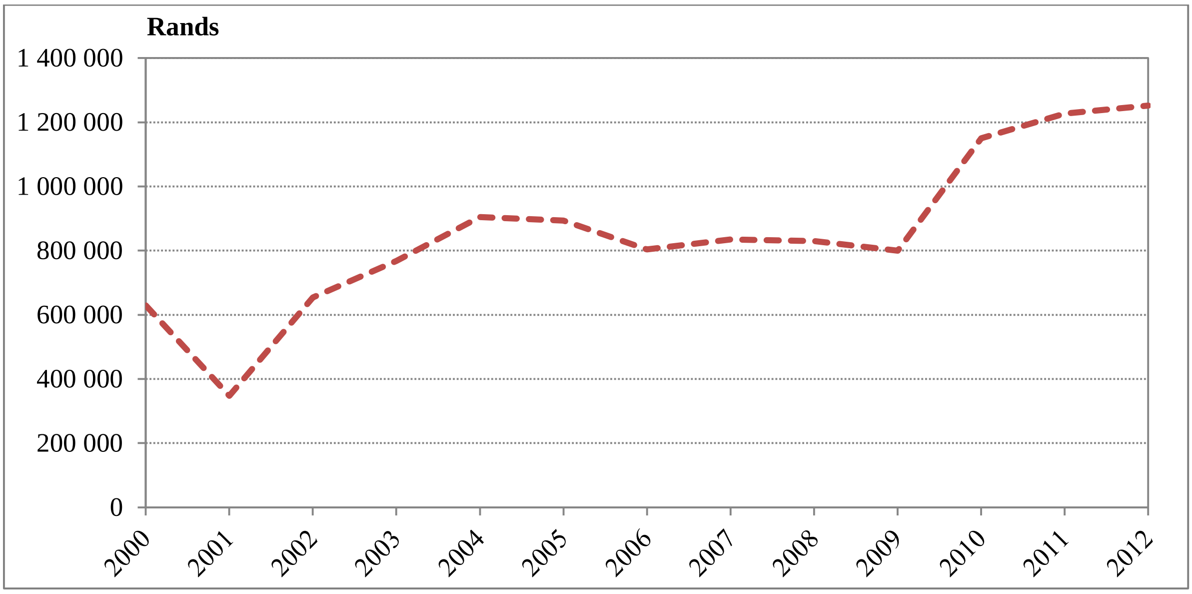

Figure 4.3: Funds allocated by DFPT to Infruitec/Nietvoorbij for plum research 2000-2012

Source: Infruitec's financial database

4.2.4 Research investment after amalgamation with the ARC

When Infruitec became part of the ARC in 1992, the government changed its funding formula from core funding dispensation to allocating parliamentary grants on a competitive basis to science councils. Infruitec now receives its investments from the baseline Parliamentary Grant (PG) of the Department of Agriculture, Forestry and Fisheries (DAFF) and the Department of Science and Technology (DST). The Parliamentary Grant has not been sufficient to cover the total salary bill of employees, and the capital expenditure allocation has not been able to cover the replacement of aging infrastructure and the acquisition of new technologies required for science and innovation (ARC annual report, 2012). Despite the reductions in funding by the government, Infruitec has continued to produce research output of high quality and has established a pool of clients, both locally and internationally.

According to its mandate, the ARC is not obliged to make any profits, but is expected to expand knowledge and contribute to economic development and growth through public investment. However, due to the gap left by government funds, the ARC has resorted to seeking external income. This is in the form of contract research and development income from local and international public and private sectors, and income from intellectual property exploits or technology transfer efforts. Infruitec also makes short-term investments from which interest is earned and this is classified under other income. These funds are primarily used to cover researchers' salaries, benefits, operating costs, administrative expenses and research and development infrastructure. The operating costs include research consumables, pest control, plants and plant/stock feeds.

Project income statements for plum breeding have been available from 1994 to 2012, this is after the formation of the Agricultural Research Council of South Africa. The parliamentary grant has followed an increasing trend although some sharp decreases were experienced. On the other hand, external income continued to increase at a smoother rate than the parliamentary grant. This increase in external income is consistent with the trend shown by Figure 4.2, which shows that the funds invested by DFPT on behalf of the industry are increasing. Figure 4.4 below shows the distributions of the parliamentary grant and external income for cultivar development projects only.

External income has exhibited an increasing trend since 1994, and by 2001 comprised 52.7 percent of Infruitec's total income. External income has not only continued to increase, but has more often than not surpassed the parliamentary grant. External earnings more than doubled from the financial year 1994/95 to 1995/96. They decreased slightly in the following years and a major decrease was experienced in 2000/01. But it soared back up in the following year. The figure decreased somewhat in the succeeding three years, but gained momentum in 2004/05 and continued to increase, although a slight decrease was experienced in 2008/09. Although there have been some decreases in the external income for funding plum research, the trend has generally been increasing. On the other hand, the parliamentary grant fluctuated vastly although it had a generally upward trend.

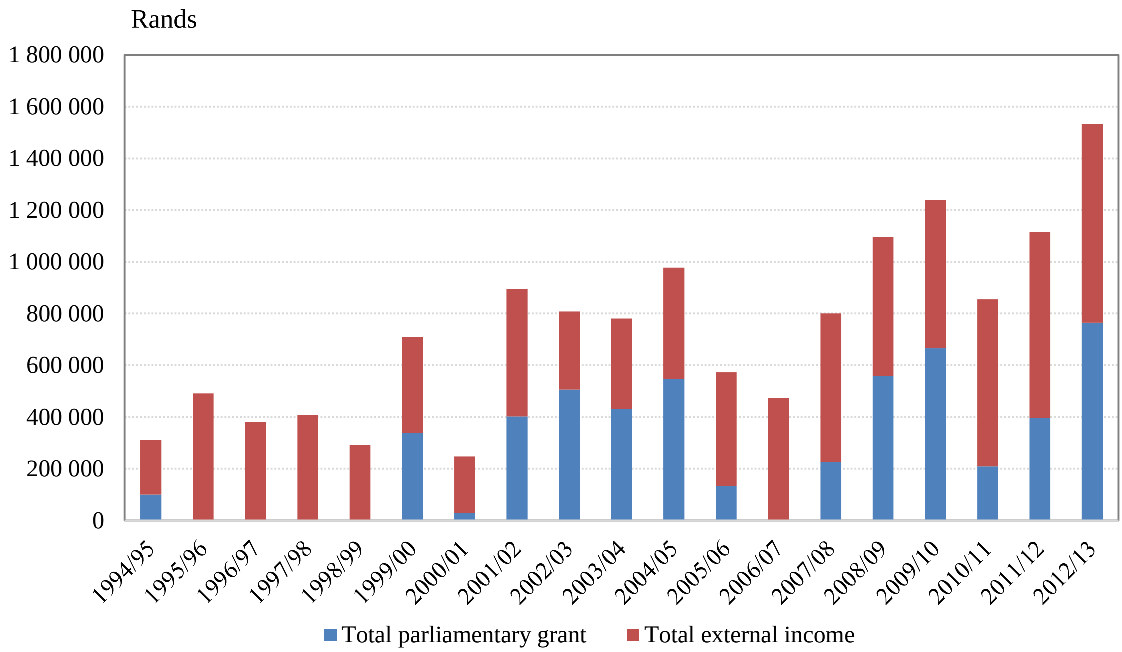

Figure 4.4: Trends in the distribution of the parliamentary grant and external income for plum breeding and evaluation, 1994-2012

Source: Author's own calculations from Infruitec's plum project income statements

Figure 4.5 below shows that the level of investment for breeding and evaluation in plums has increased from the financial years 1994/95 to 2012/13 in real terms. On the other hand, it is also shown that the real costs have continued to increase within the same period. Although both investments and costs are increasing, costs are increasing at a faster rate than investments. The overall net income from plum-breeding research alone, is shown to be positive although it is decreasing in size. In the years 2002/02 and 2003/04 the costs were negative, this is because income was allocated to resources and these resources showed a surplus and thus generated income.

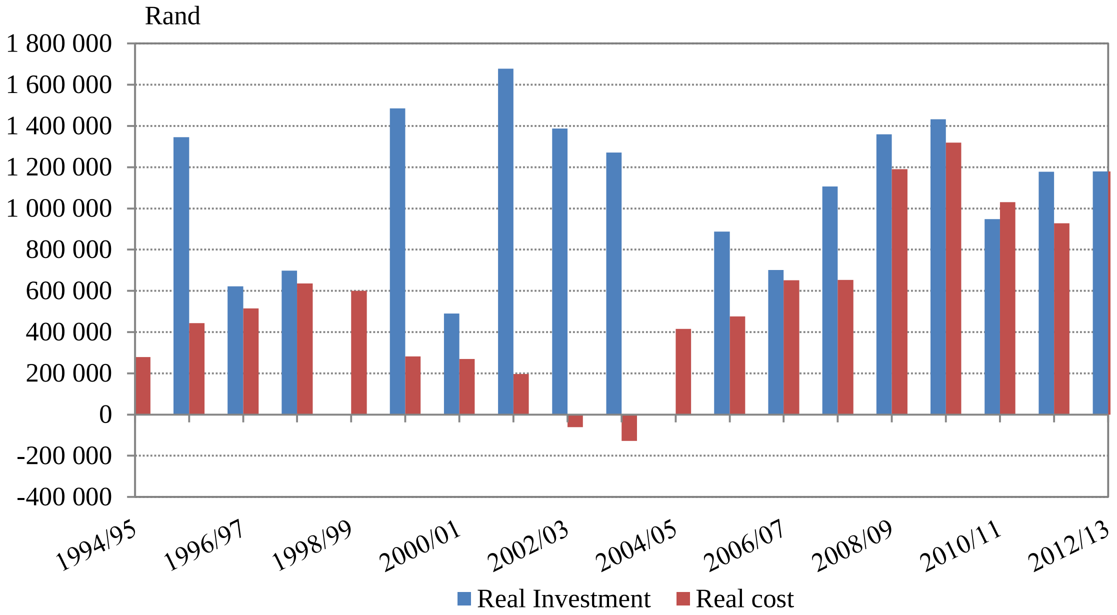

Figure 4.5: Total Investment and total cost trends for plum research at Infruitec/Nietvoorbij, 1994-2012

Source: Author's own calculations from Infruitec's plum project income statements

Although funds from the industry for all plum projects have been increasing and plum breeding and evaluation projects have had an increase in funding, the same cannot be said for the total investments for all plum projects. Figure 4.6 below shows a downward trend in funding for plum research. The estimated aggregate real plum research expenditure decreased sharply until the year 1990, and then remained fairly constant until 2012, with a few year–on–year swings. The aggregate investment on plum research is a relatively low percentage of the total value of the plum industry, which was discussed in Chapter 2.

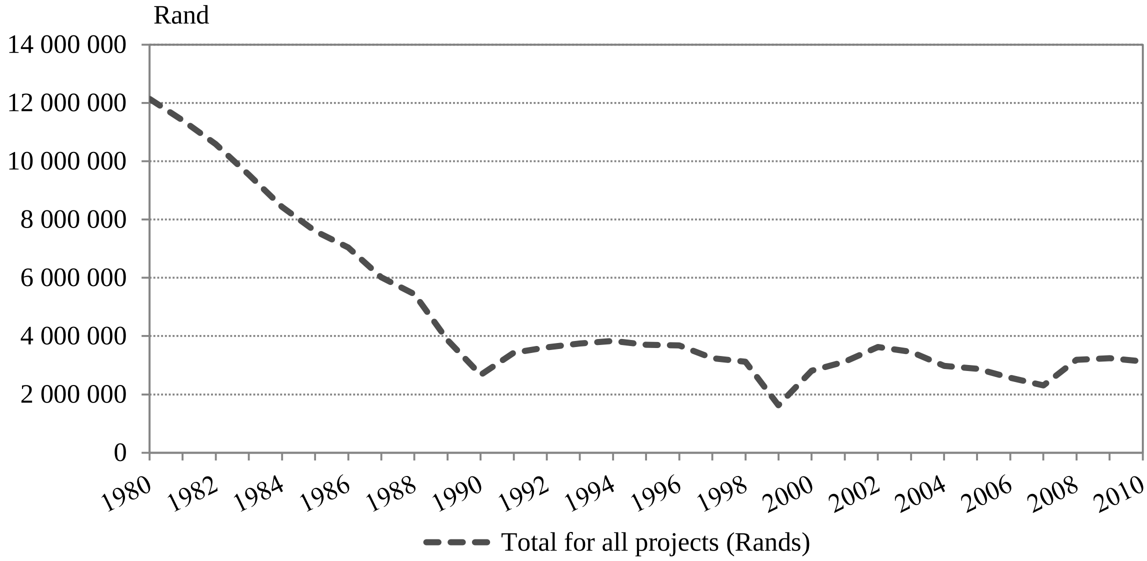

Figure 4.6: Aggregate real plum research expenditure estimates, 1980-2012

Source: Author's own extrapolation from available data using GENSTAT

4.3 SOURCES OF EXTERNAL INCOME

To alleviate financial constraints in the provision of agricultural research, two options have been found: the first is the participation of the private sector or the beneficiaries, and the second is improvement of the cost effectiveness of services in the public sector. Infruitec has been involved in both methods to expand the institute's research funds as the private sector has played a major role in the financing of plum research in South Africa.

The beneficiaries of the research, who are farmers have been a source of funding for plum research. Most farmers are willing to pay for research only if all the farmers are sharing the cost. Devising a mechanism for extracting payment was feasible for plums, since they are export commodities. A farmer-managed levy has been one of the sources of external income for plum research. The Farmer Producer Association, now SASPA, imposes a levy on farmers who will then pay according to their output. This means that the more farmers pay, the more they will benefit from research as the research conducted is demand-driven, since the plum producers determine what they want researched on. It has also become paramount to set priorities when allocating financial and human resources for plum research. Allowing farmers to influence the type of research to focus on, makes the research output more relevant and cost-effective.

SASPA funds plum research at Infruitec through the competitive bidding system. This involves research institutions competing with one another for funding by bidding for it. Infruitec has to compete with other institutes that conduct fruit research, such as the South African Plant Improvement Organization, and the University of Stellenbosch. This system allows users' real voice in the setting of priorities by allowing them to be involved in the drafting and execution of proposals and, as a result, ensures efficient and cost-effective allocation of funds. Project proposals go through a rigorous process of peer review and the best projects are then selected.

DFPT Research, later transformed to Fruitgro^{Science}, the organisation now responsible for managing the research portfolio for the deciduous fruit industry on behalf of producer associations (Fruitgro^{Science}, undated). The organisation is responsible for setting priorities for research based on the growers' associations' specific needs and funding the research projects. Due to financial pressures, Fruitgro identified five Investment Focus Areas (IFAs) which are to be given priority when considering projects to be funded (Farrell, 2011). The first IFA is *sustainable farming*, under which the integrated R&D effort should increase the marketable tons of fruit per hectare over time. The second IFA is *product integrity* through the chain, where R&D efforts are expected to increase the marketable tons of fruit delivered per ton of fruit loaded. The third IFA is *genetic pool optimization* whose aim is to ensure investment in R&D projects that seek to increase the marketable tons of fruit delivered per ton of fruit per hectare. The fourth IFA is *market alignment and sustainable supply chains*, which concentrates on R&D activities that increase the farm-gate returns per marketable ton of fruit. The final IFA is more concerned with capacity building, technology transfer and empowerment of the industry as a whole. There are several key objectives outlined under each IFA and the assessment of projects is based on these.

Different processes are followed when identifying priority research projects, selecting them and funding them. The identification and prioritization of research projects are done by the Crop Protection Technical Advisory Committee (CPTAC), and based on the IFAs. The committee first sits to discuss and assess the relevance of new project proposals submitted by the different research institutions; two months later they sit to discuss running projects' final and progress reports. The last meeting is in November/December where the committee sits to identify research needs and technology transfer opportunities. If the research proposal meets the identified research requirements, it is then funded (Farrell, 2011). However, although the industry's representatives have played a pivotal role in the funding of fruit research at the ARC, investments are slowly shifting away from the institute, mainly because of the limited number of specialized personnel at the ARC.

The advantage of this system is that it not only fosters high quality research through the rigorous screening of research proposals and monitoring of implementation, but also promotes greater accountability to the funding source (Byerlee, 2005). Another advantage of competitive bidding is that it also gives researchers an opportunity to venture into new areas as funds are easily allocated to any type of research based on its merits.

However, the downside of competitive grant funding is that the limited number of researchers may spend an immensurable amount of their time trying to draft the best proposals, maintain the research programme and manage its funds. In some instances, it was found that much more time was spent preparing the proposal than was spent actually carrying out the research (Ruttan, 1982). This may ultimately lead to a disproportionate amount of time spent on basic research and due to the short-term nature of most projects, lack of continuity in funding. The other disadvantage is that the peer-review panel may be biased towards their associates and tend to rank their proposals more highly than others, or their knowledge of a particular field may be too limited to enable them to assess a proposal objectively. Another negative effect of this system of funding is that, although it is of paramount importance to meet current challenges, there is a danger that the proverbial eye is taken off the longer-term development of the industry creating what can be called "blind spots" that potentially threaten the long-term viability of the industry (Farrell, 2011).

Another form of external funding has been by means of Infruitec's services being contracted by commercial organizations. The institute has ventured into commercialization of non-research products and services such as soil and chemical testing, diagnostic tests, sale of commercial seeds and staff consultancies. In addition to this, other revenue generating activities have also been explored; these have included selling surplus produce from experimental farms, commercial farming of surplus land or leasing it out, and revenue from publication sales.

Another source of funding for plum research has been joint ventures with the private sector. Since the establishment of Culdevco in 2006, Infruitec has formed a partnership with the organisation to commercialize their research results. This has been backed by the identification and protection of the intellectual property rights subsisting in such results, and the gains through royalties have been used to fund some of the research. Culdevco is responsible for managing the Plant Breeder's Rights both locally and in countries outside South Africa, and for the registration of Commercial Selections. In general the advantage of this source of funding has been that the revenue from commercialization goes directly to the research institute's account and not that of the general treasury (Byerlee, 2005).

4.4 POSSIBLE SOURCES OF FUNDING

Private companies could also participate in funding public research. Due to liberalization of markets, it has been easy for multinational firms to access global markets and to exploit economies of scale and scope in R&D and, as a result, they are able to conduct research independent from public sector research institutions. An example of such a firm is Monsanto. However, the same cannot be said of national private companies. These require greater interaction with and access to public sector research for them to develop their own applied R&D (Echeverría, Trigo and Byerlee, 1996). An example of such a company is Stargrow which started as a rootstock business in 1992, but now also carries out breeding and cultivar development research. Infruitec could partner with such organizations as Stargrow in meeting the challenges of limited funds for research. Echeverria (1995) proposed a feasible set-up for research funding and execution, which will be effective and allow the optimum use of resources.

Table 4.1 below shows details of the two most important sources of funds for public research institutes — the public sector agricultural budget, and international donors. Donor funding could also be an important source of financial funding for research, something not too common in South Africa. The institute could partner with international donors in conducting research of mutual benefit to farmers and the donors. Another potential source of funding plum research that could be explored is research foundations, such as Bill and Melinda Gates Foundation and the National Research Fund (NRF).

Table 4.1: Alternative means of financing and executing agricultural research at national level

Funding		**Execution** (number of asterisks indicates the potential importance)				
Source	Example	Public research Institute	University	Other non-profit and NGOs	Research Corporation	Private com-pany
Public sector agricultural budget	Public funds targeted for agriculture	***	**	*	**	*
Public sector science and technology budget	Public funds targeted to support science	**	***		**	*
Charge for services	Charges for pre-release pesticide screening	**	**		***	*
Foundation	Endowment for research	**	**	**	**	**
Internationa l donors	Grant or loan from a donor or development bank	***	***	***	*	*
Joint ventures	Market testing and development of a product developed by the public sector	**	**		***	***
Farmer financing	Levy or check-offs on commodity sales	**	**	***	***	
Charges for research products	Royalties for inbreds	**	*	**	***	***

Source: Echeverria (1995).

4.5 STAFF CAPACITY

When the Western Province Fruit Research Station was established, it had limited funds as well as a restricted number of personnel at its disposal. The challenge has always been salary scales which are not satisfactory, as a result of which, promising young scientists seek employment elsewhere. Owing to this, there is a shortage of clerical staff and junior scientists, and senior scientists have to give so much of their time to routine work that they have little time left for regular research. Another challenge has been that the continuity of specialized work is very often interrupted by transfers and promotions and, in the worst cases, resignations to accept posts elsewhere at higher salary scales, offers which research workers can for financial reasons not refuse. At some point in the 1970s, the already over-worked research workers at FFTRI were constantly called upon to offer assistance to farmers. Their willingness to assist was admirable, but their research programmes inevitably suffered. The Board then suggested the separation of research and extension agencies from civil services by using American and European agencies as models (Deciduous Fruit Board, 1974).

The research station started off with graduate scientific personnel of less than 20 in 1937. In the period between 1956 and 1960, on average 7.7 full time equivalent (fte) scientists were involved in plum research per year (FFTRI annual reports). By 1965, a total of 69 professional workers were involved in fruit research at FFTRI. Management consisted of two members and there were a total of 67 researchers. Of these, 12 had PhDs, 31 had master's degrees and 24 had a BSc degree. In the period between 1961 and 1965, the annual average fte scientists who were involved in plum research fell to 6.1. In the period between 1966 and 1970, this average increased slightly to 6.5 fte researchers. The total number of professional workers decreased to 50 in 1973 and four of these were in management positions with the number of doctoral researchers increasing to 13, master's degree holders decreasing to 18 and BSc holders decreasing to 15. Between 1971 and 1975 the number of fte scientists who did plum research further decreased to 5.7 (Department of Agricultural Technical Services, 1965–1993).

By 1976, the total number of professional workers had further decreased to 48 and management still consisted of four personnel. The number of researchers who held a PhD had increased to 16, the number of researchers holding a master's degree further decreased to 15 and BSc holders were only 13. In 1978 the total number of professional officers further decreased to 42, and the management personnel also decreased to two. Of the researchers, 12 were PhD holders, 13 had a master's degree and 15 had a BSc degree. The average fte scientists doing plum research from 1975 to 1980 was 5.1. In the 13 years between 1965 and 1978 the staff capacity at FFTRI decreased from 69 to 42, giving an annual average negative growth rate of –14.7 percent.

By 1982, the total had grown to 54 professional workers with two of these being part of management. Of the researchers, 14 held PhD degrees, 15 of them had master's degrees and 23 had a BSc degree. This decreased slightly to 53 professional workers in 1985, two of whom were part of the management team. Ten of these held a PhD, 30 had a master's degree while 13 had a BSc. From 1981 to 1985, scientists directly involved in plum research increased to 9.2 fte. In 1987, the staff was distributed as follows: 51 professional officers, 60 technicians, 21 farm managers and 25 management officials. By 1989 the number of researchers had increased to 57 with only two as management personnel, and nine of the researchers held PhDs, 28 master's degrees and 18 a BSc. Of the total researchers, 9.4 fte were directly involved in plum research. In 1991 there was a total of 65 researchers, 15 of whom held a PhD, 30 held a master's degrees and 20 had a BSc. The average fte scientists directly involved in plum research went up to 10.4 between the years 1991 and 1995. By 2002/2003 Infruitec-Nietvoorbij had staff capacity of 65 researchers and 57 technicians. In 2012, there were 58 researchers at Infruitec, and they were supported by 38 technicians.

Between the years 1970 and 2013 there has not been much change in the staff capacity working in plum breeding and evaluation only. Over the 43 years there has been an aggregate of seven researchers and fourteen technicians. Within this period there was always one researcher who worked with an average of three technicians per period. In 2012 there were three researchers, five technicians and four assistants for plum breeding. Research on cultivation and other maintenance research was done by researchers from other research units. The challenge that plum research is facing is that of limited personnel. The new employees coming straight from universities and colleges do not have practical experience and are not attracted to plum-breeding programmes, but more to the theory. Currently there are three breeders, two of whom will retire in the next four years (after 2014) and the third one retiring three years after them. Failure to find successors who will be trained by the more experienced personnel means plum breeding faces a risk.

Following the creation of the autonomous ARC, Infruitec was amalgamated with Nietvoorbij institute for Viticulture and Oenology on the 1st of May 1997 and was given the name Infruitec/Nietvoorbij. As a result of this amalgamation, the total expenditure for the institute and the staff capacity is thus not disaggregated. This explains the decrease shown in Table 4.2 in the expenditure on plum research expressed as a percentage of the institute's total R&D expenditures. Factoring in the amalgamation of the two institutes, expenditure on plum research expressed as a percentage of the Institute's R&D expenditure has continued to decrease since 1980.

Table 4.2: Overview of plum research spending and staff in full-time equivalents, 1981-2010

Period	Plum Research Expenditures (Average, nominal)	Number of Scientists (Average FTE)	Expenditures per Scientists	Expenditure as a percent of institute's total R&D expenditures
1981-85	353 709	9.2	38 446.63	17.3
1986-90	446 903	9.4	47 542.87	10.2
1991-95	427 498	10.4	41 105.58	2.4
1996-00	629 805	6.2	101 581.45	1.6
2001-05	713 764	8.7	82 041.84	1.1
2006-10	883 605	7.3	121 041.78	1.1

Source: Own compilation from FFTRI annual reports and project income statements

4.6 CONCLUSION

From the inception of the Fruit Research Station in Stellenbosch, a considerable amount of research expenditure came from the Deciduous Fruit Board. This amount was allocated by the Board in proportion to the levies collected from fruits in each year. The research expenditure from the Board on plum research, between the years 1968 and 1986, fluctuated considerably. From the year 1987 when URS took over the task of managing research funds, the portion from the industry decreased substantially. With the formation of the ARC, the institute was primarily funded by the government through the parliamentary grant. The parliamentary grant set aside for plum breeding fluctuated considerably, although it exhibited a generally increasing trend. The Institute had to rely heavily on external sources. Over the years the aggregate expenditure on plum research has continued to decrease in real terms. The number of fte researchers has also fluctuated significantly; however the general trend has been a reduction in the number of junior scientists who possess BSc degrees.

The following chapter will show the techniques used for estimating the rate of return on research for ex-post evaluations.

CHAPTER 5

METHODS AND PROCEDURES FOR ESTIMATING THE RETURNS ON RESEARCH

5.1 INTRODUCTION

There are a number of studies that have attempted to measure the return to agricultural research investment. Different methodologies have been applied for measuring the returns on agricultural research, but there are two commonly used approaches in *ex-post* evaluations. The most commonly used approach is the *economic surplus approach*, which provides a relatively simple, flexible approach to determining the value of research, by comparing the situations with and without it (Alston *et al.*, 1998; Masters *et al.*, 1996). The alternative is the *production function approach*, which expresses output as a function of inputs. It incorporates conventional inputs (e.g. rainfall, fertilizer), non-conventional inputs and the stock of knowledge (e.g. investments in R&D). The aim of this chapter is to discuss these commonly applied approaches.

5.2 WHY RATE OF RETURN STUDIES?

Since 1955, there have been hundreds of studies published reporting on what the benefits from agricultural research and development investments have been. These studies are carried out for internal and external stakeholders of the research institutes. Internal stakeholders are the researchers themselves, who require information on what the economic impact of their work has been on the targeted population so as to support their decision-making process on whether or not to adjust resource allocation across programmes. The external stakeholders include the governments and other funders of the research in order to provide accountability for the funds they invest. In the current climate of increasing competition for funding and declining funds, much effort has been put into demonstrating to the external stakeholders what the results of the research investments have been.

Rate of return studies can be classified as *ex-ante* and *ex-post* evaluations. *Ex-ante* studies are conducted before projects or programmes have been undertaken and generally make use of experimental data provided by scientists to forecast the performance of the product. On the other hand, *ex-post* evaluations are undertaken after diffusion of research has been initiated and are based on the actual data collected on the ground. *Ex-ante* studies are usually done to help the researchers in setting priorities, whilst ex-post studies generate information that is useful for the selection, planning and management of future research programmes. The approaches employed in measuring both impacts are essentially the same. This study will focus on *ex-post* economic impacts.

5.3 APPROACHES TO MEASURING EX-POST ECONOMIC IMPACTS OF PLUM RESEARCH

Ex-post economic impacts of agricultural R&D investments have been estimated using a number of methods, namely: congruence, supply response, scoring, benefit–cost analysis, total factor productivity, error correction models, economic surplus models and the production function approach. The two main approaches that are common in literature are the economic surplus approach and the production function approach. Each of these is discussed in detail below.

5.3.1 The economic surplus approach

The analytical framework of the economic surplus approach is based on three postulates by Harberger (1971):

i) The competitive demand price for a given commodity measures the value of that commodity to the demander.

ii) The competitive supply price for a given commodity measures the value of that commodity to the supplier.

iii) The net benefits or costs of a given action are accrued to each member of the relevant group without regard to the individual to whom they apply. Under these circumstances, the economic welfare resulting from research investments can be measured using the concepts of economic surplus.

According to Alston *et al.* (1998) the economic surplus approach starts by recognizing that production levels depend on the use of a wide range of inputs, such as land, labour, seeds, fertilizers and chemicals. It goes on to express the level of production as a function of price, which predicts that as the price of plums increases, the level of production will be higher. Again, the same approach is used with demand to determine the equilibrium price and quantity. In this case the function predicts that, as the price of the good increases, the quantity consumed decreases.

How will research affect this economic surplus? Research will result in the increase in the quantities produced while the prices remain the same, thus shifting the supply curve to the right and shifting the equilibrium to a lower price. This shift in the supply curve will represent the aggregate effect of farm-level yield gains due to improved technologies.

The initial price, and the quantity supplied and demanded, are represented by P and Q respectively, as shown in Figure 5.1. With the adoption of new yield-enhancing and cost-reducing improved technologies, the supply curve will shift to the right, resulting in a new equilibrium. At this new equilibrium, price and quantity will be represented by P′ and Q′ respectively. The impact of research on producers is that aggregate supply increases while costs remain the same, as a result the production costs will be reduced. This is shown in Figure 1 below as area **A** minus area **B**. Consumer surplus is the area below the demand curve and above the relevant price horizontal. The gains in consumer surplus will be depicted by area **B** plus area **C**. The impact of research on the economy as a whole is represented by area **A** plus area **C**.

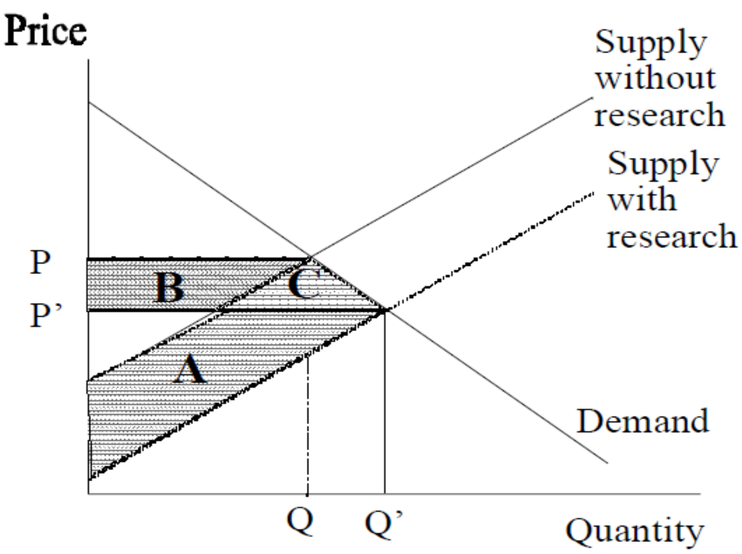

Figure 5.1: Economic surplus (producer and consumer surplus)

Source: Masters *et al.* (1996)

Seeing that South Africa is a small, open economy the appropriate model to be adopted would be that in Masters *et al*. (1996), and will be used to calculate the *ex-post* economic benefits in year *t* from a downward shift in the plum supply curve as:

$$ES_t = P_t Q_t K_t (1\text{-}0.5K_t \varepsilon) \quad (1)$$

Where *ES* will be the change in total economic surplus attributed to plum research, *K* is the supply shift as a proportion of price — measuring net unit cost reductions resulting from the adoption of improved cultivars, *P* is the real price of plums, *Q* is total plum production, and *ε* is the price elasticity of the supply of plums.

Supply shift

The research-induced supply shift parameter, *K*, is the single most important parameter influencing total economic surplus resulting from unit cost reductions. Following Alene et al. (2009) the supply shift can be estimated as

$$Kt = \left(\frac{(\Delta Y/Y)}{\varepsilon} - \frac{(\Delta C/C)}{1+(\frac{\Delta Y}{Y})}\right) \times At \quad (2)$$

Where $\Delta Y/Y$ is the average proportional plum yield increase per hectare attributable to research, $\Delta C/C$ the average proportional change in the variable costs required to attain the yield increase, and A_t the rate of adoption of improved cultivars at time *t*.

Once the value of *K*, and the demand and supply have been estimated, the total social benefit from research can be estimated. Annual estimates are made by substituting the supply function shifter *K*, the price elasticity of demand (n), the price elasticity of supply (y), the annual product price (*P′*) and the annual market product (q) into the following approximation formulae:

$$Area\ of\ C = \frac{1}{2} P'Q' \frac{[K(1+y)]2}{y+n} \quad (3)$$

$$Area\ of\ A = K\,P'Q' \quad (4)$$

$$Area\ of\ B = \frac{P'Q'K(1+Y)}{y+n} \times [1- \frac{\frac{1}{2}k(1+Y)n}{y+n} - \frac{1}{2} k\,(1+y) \quad (5)$$

The elasticity of demand and supply is estimated by a simple ordinary least squares (OLS) regression using the usual variables affecting demand and supply, for example, price of substitutes and complements and quantities demanded.

Two ways of calculating profitability can be carried out, and these are shown below, following Wander *et al.* (2004):

$$NPVt = PV(B)t - PV(C)t = \sum_{j=0} \frac{(Bi+j-Ci+j)}{(1+i)^{\wedge}2} \quad (6)$$

$$IRR = \sum_{T=0}^{t} \frac{Rt- \ Ct}{(1+Ri)} = 0 \quad (7)$$

Where R_t represents the social gains resulting from research for the respective year, C_t is the cost of research and T is the year in which research begins producing returns. If the Net Present Value (NPV) is positive, then the investments are considered to be profitable and worthwhile. Likewise, when the Internal Rate of Return (IRR) is greater than zero, the investment is considered profitable.

The economic surplus method is said to be a simple and flexible approach to estimate the benefits of research, in that it compares the situations with and without research. When using standard models little data are required, and the necessary data can in most cases be found from secondary sources. It is also commended for its ability to handle side-effects of technological changes, such as income distribution and environmental consequences. Another advantage of this method is that it can be applied to closed as well as open economies. This model can also be used in both *ex-post* and *ex-ante* analyses.

On the downside, this method ignores transaction costs and could potentially overestimate benefits in activities that incur transaction costs. The economic surplus approach has also been criticized for being a partial-equilibrium welfare analysis that disregards the complex interrelationships with other products and factor markets in the economy. Another criticism of this approach is its normative nature. The approach is based on what should be and makes use of implicit value judgments. Another major criticism of the economic surplus approach is its policy irrelevance. Arguments have been made that, although policy-makers may understand the implications of price changes, they do not understand the effects of changes in economic surplus (Alston *et. al*, 1998). In addition to these weaknesses, this method only estimates the average rate of return making it a less powerful tool than the production function method which estimates the marginal rate of return.

5.3.2 The production function approach

In the production function approach, parameters of a single commodity are estimated. Here, agricultural research and extension are the explanatory variables. It is assumed that investment in research creates technological changes which in turn affect production and/or productivity. These changes have a considerable time lag attached to them and, therefore, time series data are required.

According to Alston *et. al* (1998), investments in agricultural research result in the production of knowledge which, in turn, results in increased productivity. The relationship between research investment and the stock of useful knowledge is known as the knowledge production function. According to this function, the benefits from research-induced changes in knowledge are: more outputs for a given expenditure of inputs, cost saving for a given quantity of output, and new and better products. Current knowledge refers to capital stock from past investments and will determine the rate of production of new knowledge. Thus, productivity in a given year does not depend on the current level of R&D investments, but rather on the stock of knowledge derived from past expenditure. This is because there is a time lag before an investment can be converted into useful knowledge that can be adopted by farmers.

The Cobb-Douglas production function approach is commonly used to estimate the rate of return, mainly because of its simplicity and straight forward transparency in which the estimated parameters can be used to quantify the economic effects of interest. This production function assumes homogeneity, unitary elasticity of substitution between inputs, and separability. In this approach, the marginal rate of return on research is estimated by using research expenditure as a variable of the production function in order to measure the impact of research on output. The basic model used in the production function approach can be expressed as:

$$Qt = A \prod_{i=1}^{m} Xit\beta \prod_{j=0}^{n} Rt\text{-}j\gamma eu \qquad (8)$$

Where:

Q_t = value of output in year t,

A = a shift factor,

X_{it} = value of i^{th} conventional input in year t,

R_{t-j} = research and extension expenditure in the $t\text{-}j^{th}$ period,

β and γ are parameters, and

u is the random error term.

The equation above is mainly used for cross-sectional data. The length and shape of the time lag of impact of research expenditure on output varies. In some cases the effects of research on productivity are seen over a period of between 12 to 15 years. The effect of research on productivity may be small in the first years, but with time more producers have access to research results for adoption, and the effect to productivity increases. However, when a longer period has elapsed, the impact of the improvement may decrease, which is known as diminished returns.

For time series data, Norton and Davis (1981) noted that:

$$P = AW\gamma E\epsilon\prod_{j=0}^{n} R\alpha t\text{-}jt\text{-}jev, \qquad (9)$$

Where P is the productivity index of agricultural output, W is a weather index, E is the education level of the farmers, and γ and ϵ are productivity coefficients for the associated inputs. The productivity index is mainly used when there is a lack of sufficient data on the important conventional input and because it helps avoid the occurrence of multicollinearity problems that are associated with time series data. Weather is included because it explains some residual errors. The education level of farmers *(E)* is used as it affects their creative and managerial abilities, as well as their abilities of rationally assessing and adopting new technologies.

The advantage of using the production function approach is that it allows the measurement of the marginal rate of return, as opposed to the economic surplus model, which only measures the average rate of return. The other advantage of the production function approach is that it assigns weights in terms of how much each input contributes towards the total return (Khan and Akbari, 1986). Another advantage of this approach is that it can be extended to include technology variables that shift the production function. It is also preferred because it is inherently difficult to measure the output of R&D directly, but when stock of knowledge is used it becomes easier to measure by means of information available in publications. Also, the knowledge produced is incorporated in new technologies, making patents another useful measure of the R&D output.

However, the production function approach is not without limitations. The major constraint of this approach is the difficulty in obtaining data on production inputs. The other limitation to this approach is it is useful only for *ex-post* analysis. The approach is also criticized for not accounting for quality adjustments when most research in agriculture also improves quality.

Another limitation of the production function is that institutional changes and policy reforms are often disregarded when they are also a significant source of production growth; this in turn results in the economic rate of return on agricultural research being biased upwards. The difficulty in choosing the appropriate functional form is another disadvantage of the production function. Yet, although this method has limitations, due to data constraints, it is the most appropriate model for this study.

5.4 MODEL SPECIFICATION

The choice of functional form is determined by the data available and the purpose for which the study is intended. The model should be able to determine the length and shape of the lag distribution to ensure that the rate of return is accurately estimated. The lag between research expenditures and financial returns is determined by the type of R&D whose rate of return is being investigated as well as the type of enterprise. A common approach of calculating the lag structure is the Almon polynomial lag. This is mainly because for long lag lengths severe multicollinearity can occur and this model helps avoid this problem. Townsend and Van Zyl (1998) use the following equation to determine the lag structure:

$$In\ Yieldt = In\alpha + In\alpha WEATHER + \sum_{i=1}^{n} \beta InRDt\text{-}1 + Ut \qquad (10)$$

Where Yield is the tonnage of produce, RD is the research expenditure and WEATHER is the weather index. β is the elasticity of R&D at various lag lengths and *n* is the maximum lag of R&D that affects yield, and U_t is the residual which accounts for variables not included in the model. To calculate the rate of return from the production function approach, the productivity coefficients above are converted to the value of marginal products. As explained by Townsend and Van Zyl (1998), each lag coefficient β_i is the output elasticity of R&D for that year and is given by:

$$Bi = \frac{\partial InOUTPUTt}{\partial InRDt-i} = \frac{\partial OUTPUTt}{\partial RDt-i} \times \frac{RDt-i}{OUTPUTt} \qquad (11)$$

Thus the marginal physical product of R&D is the elasticity multiplied by the average physical product:

$$MPPt\text{-}i = \frac{\partial InOUTPUTt}{\partial InRDt} = \beta \frac{OUTPUTt}{RDt-i} \qquad (12)$$

Replacing YIELD/RD_{t-i} by its geometric mean and changing from continuous to discrete approximations gives:

$$\frac{\Delta OUTPUTt}{\Delta RDt-i} = \beta i \frac{\overline{YIELD}}{\overline{RDt-i}} \qquad (13)$$

Then, multiplying by the increase in the value of output divided by the change in quantity converts from output change in quantity to output value. Hence the value marginal product of R&D in period t-i is given as:

$$VMPt\text{-}i = \frac{\Delta VALUEt}{\Delta RDt-i} = \beta i\,\frac{\overline{OUTPUT}}{\overline{RDt-i}} \times \frac{\Delta VALUEt}{\Delta OUTPUTt} \qquad (14)$$

Where Yield/$RD_{t\text{-}i}$ is an average, and $\Delta Value_t/\Delta Yield_t$ is calculated as the average of the last five years minus the average for the first five years, due to the fluctuations. $\Delta Value_t/\Delta Yield_t$ and Yield/$RD_{t\text{-}I}$ are constant price geometric averages. The marginal internal rate of return (MIRR) is then calculated from:

$$\sum_{i=1}^{n} \frac{VMPt-1}{(1+r)} \text{-}1 = 0 \qquad (15)$$

Where n is the lag length. By solving for r the MIRR will be obtained.

This study will make use of a modification of the model above due to data constraints. The data for this study were obtained from secondary sources. Yield data were obtained from industry sources, data on R&D were synthesized from the Infruitec financial database and data from other role players in the funding of plum research. Data on weather were obtained from the South African Weather Services. Details on the data to be used are explained in the chapter that follows.

5.5 CONCLUSION

Various methods and approaches have been used in evaluating the returns on agricultural research investments. There are two ways in which returns on research can be determined — *ex-post* and *ex-ante*. *Ex-post* studies are based on time series data which are used to put an economic value on the return on previous investments in research, whilst ex-ante studies are done prior to the diffusion of research and are based on experimental data. This study focuses on *ex-post* economic evaluations. Broadly speaking, *ex-post* rate of return studies (ROR) are based on two types of models, that is, the economic surplus approach, and the production function approach pioneered by Zvi Griliches (Griliches, 1958).

This study makes use of secondary historical data to estimate the rate of return on plum research collected from various sources. The production function approach is used as it directly derives the elasticity of R&D and also aggregates out the effect of other variables which may be attributable to changes in plum output. The chapter that follows describes the statistical model used and the results from the analysis.

CHAPTER 6

RETURNS TO PLUM RESEARCH

6.1 INTRODUCTION

The first effort of measuring the returns to research was made in 1953 by Professor Schultz(Capalbo, 1990). He evaluated the value of inputs saved as a result of improved production techniques in American agriculture. Griliches (1958) followed when he attempted to estimate the realized social rate of return in hybrid-corn research. Numerous studies have been conducted thereafter, and the evidence is unambiguous, showing that the rate of return on agricultural research is high. Most of these studies are *ex-post* and are based on secondary data. The table below shows an overview of studies on estimating the rate of return to research in South Africa.

Table 6.1: Estimated Rates of return (ROR) to agricultural research for South Africa

Study and period	**Time period**	**Annual rate of return (percent)**
Aggregate, 1993 (Thirtle, Von Bach and Van Zyl)	1955-1991	64
Agregate, 1996 (Khatri, Thirtle, Van Zyl)	1947-1991	44
Crops, 1996 (Van Zyl)	1947-1991	30
Horticulture, 1996 (Van Zyl)	1947-1991	100
Animals, 1996 (Van Zyl)	1947-1991	5
Maize, (Townsend, Van Zyl and Vink)	1950-1995	29-39
Wheat, (Thirtle, Van Zyl and Vink)	1950-1995	28-34
Sorghum, (Thirtle, Van Zyl and ink)	1950-1995	50-63
Groundnuts, 1997 (Thirtle, Townsend and Van Zyl)	1968-95	50
Tobacco, 1997 (Thirtle, Townsend and Van Zyl)	1965-1995	50-53
Sweet potatoes, 1997 (Thirtle, Van Zyl and Townsend)	1952-1994	21
Animal Production, 1998 (Townsend and Thirtle)	1947-1994	11-16
Wine grapes, 1997 (Townsend and Van Zyl)	1987-1996	40-60
Crop cover management, 1997 (Thirtle and Townsend)	1986-1997	44
Bananas, 1997 (Thirtle, Townsend and Van Zyl)	1953-1995	50
Deciduous fruits, 1997 (Thirtle, Townsend and Van Zyl)	1965-1994	78
Lachenalia, 1997 (Niederwieser, *et al.*)		6.5-12
Protea, 1997 (Wessels, *et al.*)		8

Adopted from: Thirtle, Townsend, Amandi, Lusigi and Van Zyl (1998)

Various techniques were used in the studies above, and these included the economic surplus model, error correction model, and production functions model, just to mention a few. It is evident that investment in agricultural research in South Africa has been worthwhile.

The scope of this study only covers the rate of return on plum research conducted by the Agricultural Research Council at Infruitec using data from the period 1980 to 2012. The ROR estimate will be based on a production function using regression analysis of time series data. The research expenditures included in this study will be those of Infruitec which will include projects such as cultivar breeding, rootstock breeding, cultivar evaluation, fruit quality, fruit physiology, cultivation practices, chemical thinning, pollination, climatic effects and post-harvest research of plums. As reported in the chapter on resource allocation (Chapter 4), the government has been in charge of research and its funding and therefore the recording and storage of the data on project costs have also been under the control of state bureaucracy. Following policy changes over time, the style of recording and the funding structure changed resulting in inconsistencies. These inconsistencies make it difficult to have a uniform definition for R&D expenditure.

The specific model applied in this study will be described in this chapter. The data, its sources and how it is manipulated will also be described. The time-series data to be input in the model will be given in a tabulated form. Finally, the results will be presented as well as their interpretation.

6.2 THE MODEL

The production function for plums in this study was specified as

$$Yt = f(W, F, A, RD) \qquad (16)$$

Where Y_t is the yield of plums in tons per ha, W is the weather index, F is the fertilizer price index, A is the area planted and RD is the research expenditure. The variables will be expressed in the form of natural logarithms (*ln x*), in order to have coefficients as elasticities. To have the effects of R&D expenditures lagged by up to a certain number of years. The resulting equation will be:

$$ln\ Yt = ln\beta 0 + ln\beta 1W + ln\beta 2F + ln\beta 3A\ \sum_{i=1}^{n} \beta jRD\ t\text{-}I + ut \qquad (17)$$

where n is the maximum lag length which affects the yield, and ut is the disturbance term which accounts for the variations in yield not explained by the model.

For the production function in this study, the type of data that is required are the R&D costs, and uncontrolled factors such as weather and research output. The dependent variable will be Y_t which will be the total yield of plums in tons per ha. The independent variables will include: R&D expenditure given by the real values of R&D costs in Rands, lagged, conventional inputs represented by the fertilizer price index and the area planted, and uncontrolled factors represented by the weather index W.

6.2.1 Definition of data

R&D investment data were defined as research costs, and these refer to the actual expenses that were incurred to develop the technology and for maintenance research. Actual expenses incurred in research include staff salaries and benefits, recurrent, administration and overhead expenditures, as well as provision for the depreciation of capital assets. One of the limitations was that, over the years, agricultural research funding structures and the recording mechanisms have changed markedly. Much of the data were not documented and some not retained due to policy. At the then Fruit and Fruit Technology Research Institute, the policy stipulated that financial records be discarded after every ten years; as a result specific data could not be obtained prior to 1994.

Financial data analysed were obtained from project income statements for the years 1994 to 2012 from Infruitec's finance database. Some of the data on plum investments from the industry were obtained from Unifruco Research Services financial statements between the years 1982 and 1992. Data for the missing years in between were extrapolated to determine a full series of R&D expenditure between the years 1980 and 2012. A statistical programme, GENSTAT, was used for the extrapolation.

Weather is also one of the important variables affecting yield and production of crops. Researchers have employed different approaches when attributing changes in output to changes in weather. Some of the methods have included total yearly rainfall, rainfall at critical times in the growth of the plant, rainfall and temperatures and indices computed from experimental data. To account for the variations in yield or output in this study, the annual average rainfall for plum producing regions was indexed and included as one of the independent variables. Raw weather data were collected from the South African Weather Service. This data recorded the average yearly rainfall for the plum-producing regions in the Western Cape of South Africa. This variable is included so that the effects of weather on yields and production are accounted for and the changes due to R&D can be easily identified. Rainfall is thus used as single proxy variable for all weather variables.

Output data were obtained from the Deciduous Fruit Board annual reports and *Key deciduous fruit statistics*. To obtain yield, the quantity of plums produced was divided by the total area used for plum production. Because there is no data on fertilizer use, the price was used as a proxy for conventional inputs use. Fertilizer data were obtained from the South African Wine Industry Information & Systems NPC (SAWIS). An assumption was made that plum fertilizer requirements do not differ from those of vineyards, and the data were used as a proxy in constructing the fertilizer index. The area data, also a conventional input were collected from various annual reports of the Deciduous Fruit Board and from Key Deciduous Fruit Statistics.

6.2.2 Data manipulations

The R&D variable was adjusted for inflation to 2012 values to give real expenditure. Inflation adjustment to give real figures is calculated as follows:

$$Real\ value2012prices = Nominal\ value * CPI2012/CPInominal\ year$$

CPI values were obtained from Quantec.

The first assumption made in this study is that all plum farmers have access to the same technology and have the same quality and quantity of natural endowments available because they produce plums in the same region.

6.2.3 Data series

Table 6.2 below shows the actual data that will be input in the model. All values are adjusted for inflation and expressed in 2012 terms.

Table 6.2: Data series used in the analysis

Year	W Index	A Hectares	F Price index	RD Rands	Q Tons
1980	100.0	1 455	8	750 000	9 539
1981	138.7	1 657	9	800 000	12 966
1982	162.5	1 840	10	875 000	17 294
1983	109.7	1 769	11	925 000	14 963
1984	98.2	1 780	15	955 641	12 616
1985	123.1	1 659	16	1 000 000	14 400
1986	76.8	1 614	18	1 050 000	15 259
1987	110.2	1 413	21	1 100 000	16 841
1988	112.2	1 412	24	1 150 000	17 180
1989	98.2	1 570	28	1 125 000	16 938
1990	85.9	1 874	30	1 161 283	19 376
1991	115.0	2 237	33	955 641	18 151
1992	67.9	2 280	38	750 000	18 583
1993	156.0	2 237	41	1 058 462	27 862
1994	76.0	2 250	55	1 212 693	29 417
1995	120.6	2 300	63	1 366 924	33 640
1996	125.3	2 350	63	1 500 000	36 317
1997	71.5	2 500	78	1 575 000	37 011
1998	94.9	2 750	93	1 675 000	47 282
1999	101.4	2 800	100	1 550 000	32 832
2000	125.7	3 000	110	1 572 565	38 235
2001	99.2	3 400	109	869 735	38 728
2002	76.1	3 410	118	1 634 630	58 336
2003	79.8	3 500	123	1 920 725	59 867
2004	126.9	3 800	129	2 261 540	55 221
2005	82.9	4 071	130	2 235 418	39 018
2006	153.9	4 017	128	2 008 984	54 908
2007	86.5	4 081	130	2 086 977	62 720
2008	99.0	4 227	131	2 073 850	59 961
2009	93.2	4 466	134	1 998 863	56 009
2010	93.8	4 708	140	2 876 384	67 087
2011	114.2	4 814	142	3 068 050	66 736
2012	86.4	4 900	144	3 129 023	81 419

Source: Own compilation

6.3 THE OUTPUT MODELS

The variation in plum production is explained by changes in weather, fertilizer prizes, area planted and investment in R&D. Equation 3 was used to determine the lag structure. The lag coefficients were estimated using the polynomial functional form (lag structure). The Ordinary Least Squares regression was performed on Eviews 8 software. The R&D variable was not stationary and in order to make it stationary, it was differenced once. A second degree polynomial with both near and far end of the distribution constrained to zero, was fitted at various lag lengths from 4 to 26. The 10th lag was selected as it appeared to be reliable due to its superior t, F and Durbin-Watson statistics.

Table 6.3: Ten-year R&D Polynomial Distribution Lag model (PDL)

Variable	**Coefficient**	**t-Statistic**
C	-12.58254	-2.187053
LW	0.039151	0.291647
LA	2.097594	2.550751
LF	0.874211	4.933014
RD	0.09839	3.14244
RD_{t-1}	0.17889	3.14244
RD_{t-2}	0.24151	3.14244
RD_{t-3}	0.28623	3.14244
RD_{t-4}	0.31307	3.14244
RD_{t-5}	0.32201	3.14244
RD_{t-6}	0.31307	3.14244
RD_{t-7}	0.28623	3.14244
RD_{t-8}	0.24151	3.14244
RD_{t-9}	0.17889	3.14244
RD_{t-10}	0.09839	3.14244
Sum (RD)	2.55819	3.14244
Adjusted R-squared	0.872912	
Durbin-Watson stat	1.975912	

Source: Eviews output

Table 4 shows that there is no lead time with R&D having an impact in the current year. This may reflect the direct effect of maintenance research conducted at Infruitec/Nietvoorbij. As mentioned in the preceding paragraph there are a number of research projects that may immediately affect output. These include the control of pests and diseases, and other research mentioned in Chapter 3. Because the ordinary least squares (OLS) assumptions were met, the sum of the lag coefficients is an unbiased estimate of the total elasticity. The adjusted R-squared value shows that 87 percent of the variation in plum production can be explained by the changes in the independent variables. The Durbin-Watson statistic of 1.98 indicates that the model has a limited degree of positive autocorrelation. Recall that the price of fertilizer was used as a proxy for conversional inputs, which were found to have a significant effect on the industry's output: such that a one percent increase in the use of conventional inputs was found to result in a 0.87 percent increase in industry output. The model suggests that there is a positive relationship between the area planted and plum output. A one percent increase in the area planted will increase the industry output by 2.0976 percent.

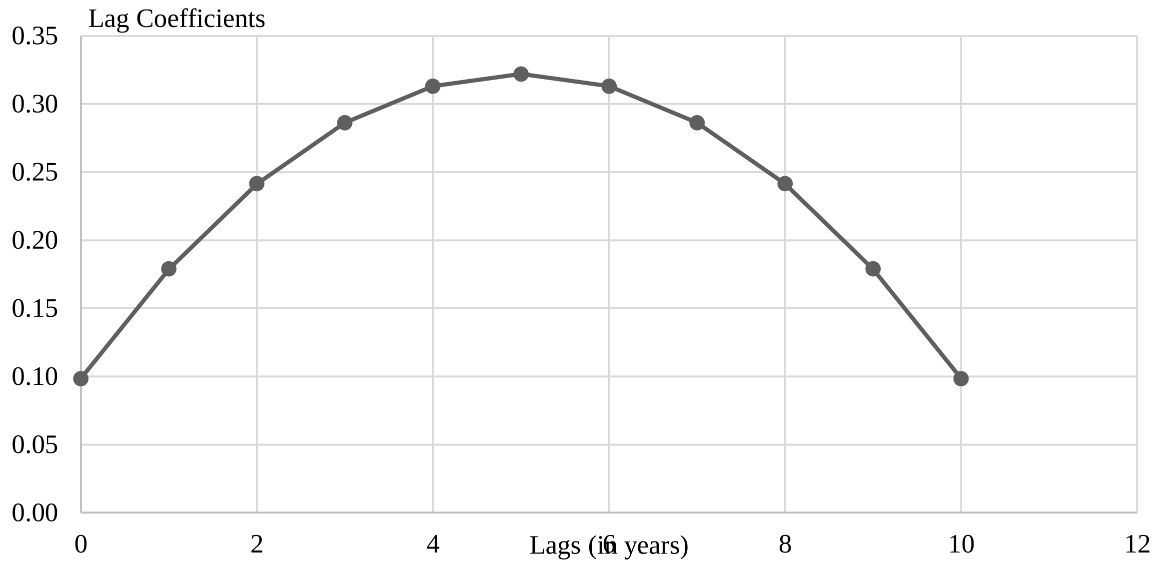

Figure 6.1: Lag structure of RD effects on plum output

Source: Eviews output

The spread of the effects of Research and Development are illustrated by Fig. 6.1 above. RD expenditures affect industry output positively in the same year as the investments and its benefits are felt over a period of ten years, with the maximum benefit experienced in the fifth year after the research investment after which it declines. This decline relates to the expenditure in year zero.

In order to convert the output quantity into output value, the elasticities were converted into value of marginal products. After discounting the benefits to allow for the long lag between the outlays and results, this gave a marginal internal rate of return of 14.23 percent. This figure suggests that for every R100 increase in R&D investment, industry output increases by R14.23.

6.4 CONCLUSION

The polynomial distribution lag is a good fit, as was shown by the high adjusted R-squared value. There is a 10-year lag between R&D and output. This lag is seen to give a rate of return of 14.23 percent. The peak effect of R&D investments in year zero is experienced at year five. However, this period may be too short because plums are perennial crops. But given the broad nature of research initiatives at ARC-Infruitec, this conclusion is plausible. This short lag is made possible by the maintenance research conducted, for example short projects such as cultivation research and physiological research, whose effects can be seen shortly after investments are made. The relationship between conventional inputs, area planted and weather in the PDL model is as expected, showing a positive relationship between production output and the independent variables.

CHAPTER 7

SUMMARY, RESULTS AND LIMITATIONS

7.1 SUMMARY

The South African deciduous fruit industry has undergone several institutional changes since it came into being in South Africa. The industry was brought to life in 1652 by Jan van Riebeeck when he planted the first orchards in the Cape. However, the industry failed to grow until 1870 when it was stimulated by the discovery and mining of diamond which resulted in the railway lines and cities being built. This brought with it the creation of a market for fruits and eliminated the transport constraints that had contributed to the decline of the deciduous fruit industry. Since then, plum production volumes as well as exports have continued to increase, and this has resulted in increasing export earnings. When comparing the history of the deciduous fruit industry in South Africa to its competitors such as Chile, the industry has shown poor growth. In 1983, the South African industry was twice the size of the Chilean industry and was among the top two exporters of plums to the European market. By 1989, Chile had superseded South Africa and was the leader in the European market. This has been attributed to the market oriented national system of research and a strong technology transfer system in Chile.

Deciduous fruit farmers encountered several challenges before the industry was fully functional and in 1899 producers came together and formed the Western Province Fruit Exporters' Association to meet the challenges of refrigeration they faced. Owing to this representation, refrigeration services and export levels and coordination of exports improved. The Fruit Growers' Cooperation was established in 1922 with the aim to improve prices received by fruit farmers through coordinated exports. This organization represented deciduous fruit, citrus and pineapple producers. To complement this body, the Perishable Products Export Control Board was formed in 1925. In 1926 the deciduous fruit industry and the citrus industry separated and two separate bodies were formed: the Deciduous Fruit Exchange and the Citrus Fruit Exchange. Although the Cooperation Exchange brought with it many improvements, the deciduous fruit industry still faced major challenges. This resulted in the formation of the Deciduous Fruit Board in 1939. The Board was granted extensive control over the export and the selling and buying of all deciduous fruits, until the industry was deregulated in 1997. All fruit was sold though the same channel, Unifruco.

However, even with the formation of the Board, deciduous fruit producers still faced challenges which the Board thought would be addressed by research. Owing to this, the Western Province Fruit Research Station was established to conduct all research for all fruit producers in the winter rainfall region. From research, it was established that the cultivars that were used at the time were not suitable for the South African environment. As a result of this, breeding and cultivar development in plums was started in 1945. Many successful cultivars have been birthed from the programme, but it is difficult to deal with problems of pests and diseases by conventional breeding only. Biotechnology-assisted breeding was then adopted which allows for the identification and isolation of genes which are kept at a gene bank and can be accessed by scientists and breeders worldwide.

The Board appointed Unifruco Research Services to allocate funding for research on its behalf. Since deregulation, fruit producers have had the liberty to choose the channel to market their produce. Following deregulation a new industry structure evolved, which has resulted in the Deciduous Fruit Producers Trust (DFPT), a non-statutory body, which is now the cohesive umbrella organisation for various branches of the industry. The body is funded by farmer levies and is responsible for financing and coordinating industry activities. The DFPT also formed its research body which took over the task of managing research for producer organizations after deregulation. In 2002, DFPT Research changed its name to Fruitgro^{Science} and still maintained its responsibility of raising research funds and allocating them appropriately to research needs across the board.

Research funds are distributed to the main fruit research institutes, namely: South African Plant Improvement Organization, Stellenbosch University, and Infruitec. The allocation of funds across these institutions is driven by farmer referendums and based on merit of the research proposals. Fruitgro^{Science} identified five key Investment Focus Areas which are used when considering which project to fund. However, should a research proposal be selected for funding, Fruitgro^{Science} does not fund the project in its totality. Running projects in breeding and evaluation are awarded 35 percent, whilst other maintenance research projects are awarded 45 percent and all new projects are granted 49 percent.

When URS Research was still responsible for distributing research funds on behalf of the industry, the amounts allocated to Infruitec solely for plum research were decreasing as a proportion of the total apportioned to the whole industry. After the formation of DFPT, funds allocated for plum research at Infruitec increased with a few fluctuations. Despite the increase in research funding from the industry, public funding towards agricultural research and plum research has been decreasing at Infruitec. This has resulted in the Institute resorting to other sources of income.

Ironically, it is no mystery that publicly funded research is responsible for the growth in agricultural productivity by improving the quality of conventional inputs or their prices. The theory is that, not only does investment in agricultural research improve inputs and production levels, but producers and consumers also benefit from the changes in prices. Several general studies have proved this before, but no such study has been done for plums specifically. This study makes an effort to investigate the relationship between research investments and production in the specific case of the South African plum industry for the period from 1980 to 2012. The main objective of this study was to evaluate the rate of return on plum research in South Africa. To address this aim, several specific objectives were formulated and these included identifying the plum research projects in order to come up with the total cost that goes into plum research, and to determine how trends in output, exports and export earnings have changed over time.

Various *ex-post* methods and approaches have been used, ranging in scope and depth depending on the available data and the objectives of the evaluation. For the purpose of this study and due to available data, simple regression analysis based on the production function approach was applied. Due policy changes, data limitations were encountered in this study and as a result much of the data was extrapolated from trends in the available data. Secondary data were collected from Infruitec and industry archives to provide more insight into R&D investments and production output. Other data used were collected from Abstract of Agricultural Statistics and some from the Key Deciduous Fruit Statistics. Some data were obtained from unpublished publications of the Deciduous Fruit Board. All the financial data were adjusted for inflation and expressed in 2012 terms. Weather related data were obtained from the South African Weather Services. The model in this study provides the yield for plums, which is the dependent variable. The independent variables were: (a) R&D

expenditure which was estimated by extrapolation of the missing data from the available time-series, and (b) the weather index which used rainfall as a proxy for weather conditions.

7.2 RESULTS AND IMPLICATIONS

Since the inception of the plum research programme at Infruitec, over 23 varieties have been released and several crop management recommendations have been made. Like all *ex-post* evaluations, the accuracy of the rate of return on these technological developments will be determined by the quality and accuracy of the data.

A time series regression analysis of the data was done using Eviews 8 software. The data were changed into natural logarithmic form so that they could be expressed as percentages. The R&D variable was also differenced once to stationarize it and make sure that no ordinary least squares assumptions were violated. A second order polynomial lag was estimated with zboth near and far end of the distribution constrained to zero. This is viewed as an appropriate model to use when estimating the lag that exists from the time when research and development investments are made to the time when the effects are felt. The polynomial distribution lag demonstrated that the effects of R&D investments are felt immediately and the highest returns are experienced in the fifth year. In a 10 year lag, significant relationships between R&D investments and output were in all the years. These relationships were significant at a confidence level of 95 percent. The price of fertilizer, and the area planted had significant and positive effects on changes in output. These relationships were found to be significant at a 99 percent confidence level. The model is a good fit and this is shown by the high R-squared value, meaning that 87 percent of the variation in industry output is explained by changes in area planted, fertilizer prices, and R&D investments.

The estimated marginal internal rate of return for plum R&D investment in South Africa is 14.53 percent. The results of this study imply that research and development efforts for plums were beneficial, and this is in line with the hypothesis made in Chapter 1. A lesson that can be learned from this study is that investing in profitable technologies can improve agricultural productivity. Given the nature of the industry and the benefits from research, it makes economic sense for the beneficiaries to be funding the R&D efforts, thus reducing the reliance on public funds (Townsend and van Zyl, 2007).

7.3 LIMITATIONS AND FUTURE RESEARCH

There were a few limiting factors experienced in this study. The major limitation was the lack of detailed data on research expenditure for plums, although some figures in the R&D expenditure were calculated accurately, the others were close estimates from statistical extrapolation. This was mainly due to the institutional and policy changes. In future, data should not be discarded but kept where there is exclusive access. Since there is a full expenditure series from 1994, this data and the data for the following years could be gathered systematically into an appropriate series. This will allow for a more reliable analysis in another study that can be done in future based on more comprehensive and accurate data as opposed to anecdotal data. Another study could also be done looking not only at the economic effect, but also64 the socio-cultural impacts, spill-over effects and intermediate effects. Another limitation of this study is that, over the years, there have been several policy challenges that directly and indirectly affected the plum industry. The effects of these changes were not explicitly captured in this study, and could be considered in another study. Despite these limitations, the results indicate that the rate of return on past investments for plum research, was attractive enough to warrant future investments.

LIST OF REFERENCES

Alene, A. D., Menkir, A., Ajala, S.O., Badu-Apraku, B. Olanrewaju, A. S., Manyong, V. M. & Ndiaye, A. 2009. The economic and poverty impacts of maize research in West and Central Africa. *Agricultural Economics,* (40): 535-550

Alston, J. M., Beddow, J.M. and Pardey, P.G. 2009. Agricultural research, productivity and food prices in the long run. *Science*, (325)4:1209-1210

Alston, J. M., Norton, G. W.; and Pardey, P. J. 1998. Science under scarcity: Principles and practise for agricultural research evaluation and priority setting. Ithaca and London: Cornell University Press, ISBN 0-8014-2937-4

Anonymous. 1929. A spraying programme for Natal. *Farming in South Africa,* July 1929

Anonymous. 1978. Plums. *The Deciduous Fruit Grower,* 28(6):195-202

Anonymous. 1981. *Deciduous Fruit Grower*, November 1981.

Anonymous. 2008. Plums. Department of Agriculture. [Online] Available from: http://www.daff.gov.za/docs/Brochures/plum.pdf [Accessed 2013-04-27]

ARC (Agricultural Research Council). 2012. *ARC and Culdevco release fourteen new stone fruit cultivars*. Press statement issued on Wednesday, 23 May 2012. [Online] Available from: http://www.arc.agric.za/arc-infruitec-nietvoorbij/Presspercent20Releasepercent20Library/ARCpercent20andpercent20Culdevcopercent20releasepercent20fourteenpercent20newpercent20stonepercent20fruitpercent20cultivars,percent2023percent20Maypercent202012.pdf [Accessed 2013-04-18]

Argenta, L. C., Krammes, J.G., Megguer, C. A., Amarante, C. V. T. & Mattheis, J. 2003. Ripening and quality of 'Laeticia' plums following harvest and cold storage as affected by inhibition of ethylene action. *Pesq. Agropec. Bras., Brasilia*, 38(10): 1139-1148

Assistant General Manager, 1954. Economic considerations for the future of the deciduous fruit industry. *The deciduous fruit grower,* 4(1):4-8

Baard, N. and Kotzé, M. 2013. SA Stone Fruit Newsletter. Plums: Week 12 (2012/2013)

Barnes, B. N. & Venter, J. H. 2006. 'The South African Fruit Fly action plan-Area wide suppression and exotic species surveillance', *Fruit Flies of Economic Importance: From Basic to Applied Knowledge: proceedings from the 7th International Symposium on fruit flies of economic importance*, Salvador, Brazil, pp. 271-283

Barrientos, S. and Visser, M. 2012. South African horticulture: opportunities and challenges for economic and social upgrading in value chains. Capturing the gains working paper. [Online] Available from: http://r4d.dfid.gov.uk/PDF/Outputs/TradePolicy/ctg-wp-2012-12.pdf [Accessed 2013-06-24]

Bergh, O. 1981. A proposed palmette system for vigorously growing plum cultivars. Deciduous Fruit Grower 31(8): 294-300.

Bester, C.W.J. 1985. Release of a locally bred plum cultivar, Laetitia. Fruit and Fruit Technology Research Institute, Stellenbosch (South Africa). *Issue 536 of Information bulletin*

Black, M. W. 1952. The deciduous fruit industry in South Africa. *Farming in South Africa*

Byerlee, D. 1998. Financing the National Agricultural Research Institutes. In: Guidelines for developing new organization and funding ways for agricultural and agro-industrial innovation systems in the Southern Cone. Montevideo, Uruguay: Mayo. 31-52

Byerlee, D. 2005. Competitive funding of agricultural research in the World Bank: Lessons and challenges. [Online] Available from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.195.9643&rep=rep1&type=pdf [Accessed 2014-01-09]

Byrne, D. 2005. Trends in stone fruit cultivar development. *HortTechnology*, 15(3): 494-500

Candan, A. P., Graell, J., Crisosto, C. and Larrigaudiére, C. 2006. Improvement of storability and shelf-life of 'Blackamber' plums treated with 1-methylcyclopropene. *Food Sci Tech Int*, 15(2):437-444

Capalbo, S. M. 1990. Technical change in agriculture: An overview of the effects of public policies. Technology and agricultural policy: Proceedings of a Symposium. National Academy Press. Washington D.C. 107-121

Carrasco, B., Meisel, L., Gebauer, M., Garcia-Gonzales, R. and Silva, H. 2013. Breeding peach, cherry and plum: from a tissue culture, genetic, transcriptomic and genomic perspective. *Biological Research*, 46(3):219-230

Carter, J. 1999. Estimating the economics rate of return to research in the South African deciduous fruit industry. Unpublished master's thesis. Stellenbosch: University of Stellenbosch

Cass, F. 1996. The Agrarian Question in South Africa. In: Henry Bernstein (ed). *South Africa's Agrarian Question: Extreme and Exceptional?* Great Britain: Redwood Books Ltd, Trowbridge, Wits

Chambers, K. 1996. Industry foot a larger part of the research bill. *Deciduous Fruit Grower*, 46(9): 314-315

Cockwell, G. L. Undated. Historical background of deciduous fruit industry and family tree of industry bodies and dates of foundation. Unpublished thesis. Stellenbosch: University of Stellenbosch.

Crosse, J. E. 1974. Report on research problems on bacterial and fungal diseases of deciduous fruits in South Africa. Deciduous Fruit Board Report.

Culdevco. *Welcome to Culdevco: Culdevco's background and aim.* [Online] Available from: http://www.culdevco.co.za/ [Accessed: 2013-09-29]

De Beer, G.; Paterson, A. and Olivier, H. 2003. 160 Years of export. The History of the Perishable Products Export Control Board. [Online] Available from: http://www.ppecb.com/index.php/doc_download/77-160-years-of-export.html [Accessed 2013-07-08]

De Kock, A. and Taylor, M. 2010. Quantum advances in the cold storage maintenance of plum fruit quality using Smartfresh^{TM} combined with other handling and packaging changes. *SA Fruit Journal* 9(6): 45-48

De Kock, A. and Taylor, M. 2012. Cold storage of plums for the South African Market. *ExperiCo Fruit Technology Solutions.* [Online] Available from: www.hortgro.co.za/...fruit/5.1.2.cold_storage_of_plums_pdf [Accessed 2013-08-21]

De Swardt, S. J. 1947. Review of agricultural production and prices in the union from 1939. *Farming in South Africa*, 22(251): 188-213

Deciduous Fruit Board annual reports, 1945-1990

Deciduous Fruit Board memoranda and minutes, 1937-1995

Deciduous Fruit Board, undated. Various unpublished reports

Deciduous Fruit Grower. 1976-2002. Cape Town: Deciduous Fruit Board

Deciduous Fruit Producers Trust, 2005. *Key deciduous fruit statistics.* Paarl

Deciduous Fruit Producers Trust. 2008. *Key deciduous fruit statistics*. Paarl

Du Preez, J. 2012. Pear production in South Africa. [Online] Available from: http://www.conerpo.com/apoc./shared/res/companies/-3529329303360169978/attach/TOLprod/Inerpera-2012/Dupercent20preez_Interpera2012.pdf [Accessed 2013-04-18]

Du Toit, A.S. (1981). *The South African Deciduous Fruit Industry -'Quo Vadis?'*. Percy. Stellenbosch: Fruit and Fruit Technology Research Institute

Du Toit, H.S. 1929. Cedara School of Agriculture. Its history and development. *Farming in South Africa*. May 1929: 67-69

Echeverría, R. G., Trigo, E. J. and Byerlee, D. 1996. Institutional change and effective financing of agricultural research in Latin America. World Bank Technical Paper No. 330

Esterhuizen, D. & Van Rooyen, C.J. (1999). How Competitive is Agribusiness in the South African Agro-Food Commodity Chain. *Agrekon*, 38 (4): 744-752

Fan, S. 2000. Research investment and the economic returns to Chinese agricultural research. *Journal of productivity analysis*, 14: 163-182

FAO (Food and Agriculture Organisation) statistics. [Online] Available from: http://faostat.fao.org/site/342/default.aspx [Accessed 2013-06-06]

Farrell, D. 2011. A strategic investment framework for Fruitgro[Science™] for pome and stone fruit. Unpublished internal report

FFTRI (Fruit and Food Technology Research Institute). 1965. Annual report for the year July 1964 to June 1965. Department of Agricultural Technical Services, Republic of South Africa

FFTRI (Fruit and Food Technology Research Institute). 1968. Annual report for the period 1st July, 1966 to 30th of June 1968. Department of Agricultural Technical Services, Republic of South Africa

FFTRI (Fruit and Fruit Technology Research Institute). 1974. World production of and trade in peaches, plums and apricots during 1961 to 1970. *Information bulletin number 239*

FFTRI (Fruit and Fruit Technology Research Institute).1976. Annual report for 1975/76

FFTRI (Fruit and Fruit Technology Research Institute).1978. Annual report for 1977/78. Department of Agricultural and Technical Services

FFTRI (Fruit and Fruit Technology Research Institute).1986. Annual report for 1985/86. Department of Agriculture and Water Supply

FFTRI (Fruit and Fruit Technology Research Institute).1991. Annual report for 1990/91. Department of Agricultural and Technical Services

Fourie, J. 2013. Postharvest decay on stone fruit-what, when, and how to reduce. Part 2: Pre- and postharvest control measures to reduce decay development. *Experico*. [Online] Available from: http://www.experico.co.za/wp-content/uploads/2013/08/PUB-3-13-Part-2.pdf [Accessed: 2013-04-17]

FRUITFLYAFRICA [Online] Available from: http://www.fruitfly.co.za/ [Accessed: 2013-10-05]

Fruitgro[Science]. Undated. DFPT Research Transforms into Fruitgro[science]. Press statement. [Online] Available from: http://www.agriworldsa.com/article-archive/deciduous-fruit/Fruitgropercent20Science.pdf [Accessed: 2013-11-17]

Ginsburg, L., Eksteen, G. & Stubbings, W.A.K. 1976. Requirements of the industry in respect of stone fruits. *The Deciduous Fruit Grower*, 26(4): 147-150

Griliches, Z. 1958. Research costs and social returns: Hybrid corn and related innovations. *Journal of Political Economy*, (66)5:419-431

Halgryn, P.J., Smith, C., Von Mollendorff, L., & Labuschagné. 2000. Breeding and cultivar development for the South African deciduous fruit industry with special reference to African Carmine™ apple, Rosemarie pear and the yellow plums Sun Kiss™ and Sundew™. *Acta Horticulturae*, 538:207-211

Harberger, A. C. 1971. Three basic postulates for applied welfare economics: An interpretive essay. *Journal of Economic Literature*, (9)3: 785-197

Hennicke, L. 2010. USDA Foreign Agricultural Service. Chile, Stone fruit annual: Apricot, Plums Peach and Nectarines and Cherry Report

HORTGRO. 2012. *Key Deciduous Fruit Statistics*. Paarl: Hortgro South Africa

HORTGRO. *SA Stone Fruit Producers' Association (SASPA).* [Online] Available from: http://www.hortgro.co.za/portfolio/saspa/ [Accessed: 2013-08-04]

Hurter, N. & Stadler, J.D. 1979. Release of a Late Midseason Plum Cultivar Redgold. *Issue 424 of Information bulletin*. Fruit and Fruit Technology Research Institute, South Africa.

Hurter, N. & Van Tonder, M. J. 1975. Plum breeding in South Africa. *The deciduous fruit grower*, 25(2):37-39

Hurter, N. & Van Tonder, M.J. 1975. A preliminary report on plum rootstock breeding. *Issue 287 of Information Bulletin.* Fruit and Fruit Technology Research Institute, South Africa

Hurter, N. & Van Tonder, M.J. 1982. The breeding of improved Japanese plum cultivars. *Issue 486 of Information Bulletin.* Fruit and Fruit Technology Research Institute, South Africa

Hurter, N. 1972. Release of a locally bred mid-season plum cultivar Harry Pickstone. *Issue 109 of Information bulletin.* Fruit and Fruit Technology Research Institute, South Africa

Hurter, N. 1972. Release of the First Locally Bred Plum Cultivar Songold. *Issue 67 of Information bulletin.* Fruit and Fruit Technology Research Institute, South Africa

Hurter, N. 1974. Bien Donné experimental farm. *Issue number 243 of Information Bulletin.* Fruit and Fruit Technology Research Institute, South Africa

Hurter, N. 1977. Release of an early midseason plum cultivar Reubennel. *Issue 379 of Information bulletin.* Fruit and Fruit Technology Research Institute, South Africa

Hurter, N. 1978. Plums. *The Deciduous Fruit Grower*, 28(6):195-202

Infruitec (Stellenbosch Institute for Fruit Technology). 1992–1995. *Research reviews*, 1992-1996

Khan, M. H. & Akbari, A. H. Impact of agricultural research and extension on crop productivity in Pakistan: A production function approach. *World Development*, 14(6): 757-762

Kirsten, J.; Edwards, L. and Vink, N. 2007. Distortions to Agricultural Incentives in South Africa. World Bank Development Research Group. Working Paper 38

Kirsten, K. 2001. Gardening with Keith Kirsten. [Online] Available from: http://books.google.co.za/books?id=B1sqtRz50ToC&pg=PA231&lpg=PA231&dq=pruning+deciduous+fruit+trees+in+south+africa&source=bl&ots=lXT3UQMDs8&sig=Lpx296i9OvhiHko3KU63PCzzfoY&hl=en&sa=X&ei=WvmBU7GoOIeh7AbNgYHoDQ&ved=0CF8Q6AEwBQ#v=onepage&q=pruningpercent20deciduouspercent20fruitpercent20treespercent20inpercent20southpercent20africa&f=false [Accessed: 2013-07-13]

Kotzé, M. 2014. Verbal communication with the author on 10 March. Paarl.

Larue, J. H. and Johnson R.S. 1989. Peaches, plums and nectarines. Growing and handling for fresh market. Cooperative extension, University of California Division Agriculture and Natural Resources. Publication 3331

Liebenberg, F. 2013. The South African agricultural production, productivity and research performance in the 20th century. Unpublished doctoral thesis: Pretoria: University of Pretoria

Liebenberg, F., Pardey, P.G. & Kahn, M. 2011. South African agricultural R&D investments: Sources, structure and trends, 1910-2007. *Agrekon*, (50)2:1-26

Mabiya, T.C., Mansvelt, E. L., Ferreira, S. J. & Ndimba, B.N. *Ploidy of Prunus rootstocks*. Poster presented at the Combined Congress, Grahamstown, 20-23 January. [Online] Available from: http://www.combinedcongress.org.za/abstract_view_public.aspx?Id=774 [Accessed: 2014-05-23]

Marloth, R. H. 1933. Ethylene colouring and ripening of fruits and vegetables. Extending the marketing period. *Farming in South Africa*, Jan 1933:17-18

Mashabela, T. E. 2007. Measuring the relative competitiveness of global deciduous fruit supply chains: South Africa versus Chile. Unpublished master's thesis. Stellenbosch: University of Stellenbosch

Masters, W. A., Coulibaly, B., Sanogo, D., Sidibe, M., Williams, A., Sanders, J. H., and Lowenberg-Deboer, J. 1996. The economic impact of agricultural research: A practical guide. Department of Agricultural Economics, Purdue University, West Lafayette, IN.

Miller, E. P., Andersen, P.C., Williamson, J.G., Ferguson, J.J. & Bitter, J. 2005. Growing plums in Florida. University of Florida, IFAS Extension. [Online] Available from: http://edis.ifas.ufl.edu/pdffiles/HS/HS25000.pdf [Accessed 2013-11-01]

Moelich, D. 2013. Certification of plum packaging formats for export of South African fruit to markets that accept eradication in combination with insect barrier bags, as mitigation treatment. [Online] Available from: http://www.postharvestinnovation.org.za/projects-2/packaging-formats-for-certification-in-export-fruit-irradiation/ [Accessed: 2013-10-13]

Neveling, C. H. 1947. A new year's message: Light on the Horizon. *Farming in South Africa* (22) 250: 5-6

Norton, G. W. & Davis, J.S. 1981. Evaluating returns to agricultural research: A review. *American Journal of Agricultural Economics*, 63(4):685-699

Nyhondo, B., Nakana, E., Phahlane, H. & Kotzé, L. 2010. South Africa and Chile: Agricultural trade relationships. Paper presented at the Joint 3rd African Association of Agricultural Economists (AAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, 19-23 September

Okie, W.R. & Ramming, D. W. 1999. Plum breeding worldwide. *HortTechnology,* 9(2): 162-176

Oosthuizen, M. A. & Stadler, J.D. 1989. Release of the late plum cultivar Celebration. Fruit and Fruit Technology Research Institute, Stellenbosch (South Africa). *Issue 585 of Information bulletin*

Oosthuizen, M.A., Barnard, F.J. & Smith, W.J.C. 1993. Release of the plum cultivar Souvenir. *Issue 623 of Infruitec Info*

Oosthuizen, M.A., Visagie, T.R. & Smith, c. 1992. The release of the early plum cultivar Sapphire. *Issue 621 of Infruitec Info*

Pardey, P.G. Alston, J. M. & Chan-Kang, C. 2012. Agricultural production, productivity and R&D over the past half century: An emerging new world order. Staff paper: University of Minnesota. [Online] Available from: http://ageconsearch.umn.edu/bitstream/133745/2/SP12_7_2012Pardey.pdf [Accessed: 2014-05-11]

Pickstone, H. E. V. 1917. The Cape Fruit Industry. Journal of the Royal African Society, Vol 16, No. 64

QUANTEC. 2011. *Value of production, income and expenditure of the farm sector: Gross of agricultural production: Horticulture*. [Online] Available from: http://www.easydata.co.za/data/timeseries/AGR-T078S002/ [Accessed: 2013-04-25]

Reyneke, J. The keeping quality of fruit. *Farming in South Africa*, Jan 1933: 19-21

Ruttan, V. W. Agricultural Research Policy. 1982. University of Minnesota Press. Minneapolis

Smith, C. 2010. *Cultivars Development chain at the ARC.* Presentation to the Mozambique Delegation, 29 July

Smith, C. 2013. Verbal communication with the author on 27 May. Stellenbosch. (Transcript/notes in possession of author).

Steenkamp, M. and Gevers, W. 2010. Optimising fruit production choices: Mathematically modelling techniques show that choosing the right cultivar mix for deciduous fruit production units can drastically improve profitability. *USB LEADERS LAB* (4) 2:28-30

Strang, J. 2012. *Plums*. UK Cooperative extension services. University of Kentucky-College of Agriculture. [Online] Available from: https://www.uky.edu/Ag/CDBREC/introsheets/plums.pdf [Accessed 2014-01-14]

Taylor, N. & Gush, M. 2010. The water use of fruit trees and orchard crops in South Africa – a knowledge review. A paper submitted to the Water Research Commission-Project K5/1770. [Online] Available from: http://fred.csir.co.za/extra/project/fruittrees/deliverables/Deliv1K5_1770KnowledgeReview_Final.pdf [Accessed 2013-12-04]

Thirtle, C., Townsend, R. F., Amadi, J., Lusigi, A. & Van Zyl, J. 1998. The rate of return on expenditures of the South African Agricultural Research Council (ARC). *Agrekon,* 37(4): 612-622

Tinley, J. M. 1954. *South African Food and Agriculture in World War II*. California: Stanford University Press

Tomlinson, D. & Van Wyk, G.P. 1934. An economic study of deciduous fruit farming in the Western Cape Province 1931-1934. Stellenbosch-Elsenburg College of Agriculture of the University of Stellenbosch, Stellenbosch

Townsend, R. & Van Zyl, J. 2001. 'The rate of return to wine grape research and technology development in South Africa', In: Anandajayasekeram, P., Rukuni, M., Babu, S., Liebenberg, F. and Keswani, C. L. *ed. Impact of Science on African Agriculture and Food Security.* Cab International: London, pp. 161-169

Townsend, R., & van Zyl, J. 1998. Estimation of the rate of return to wine grape research and technology development expenditures in South Africa. *Agrekon,*37(4): 188-210

Turyomurugyendo, L., Boffa, J.M., and Hakiza, J.J. 2004. Introduction of deciduous fruit tree growing in the tropical highlands of Kabale, Uganda. *Uganda Journal of Agricultural Sciences,* (9): 470-480

UNIFRUCO annual reports, 1982-1992

University of California. 2001. Fruit trees: Thinning young fruit. *Publication 8047*. [Online] Available from: http://homeorchard.ucdavis.edu/8047.pdf [Accessed: 2013-10-29]

Valdes, A. 2008. Small holder adjustment in Chile and the role of INDAP. Paper presented at the OECD Global Forum on Agriculture, 20-21 November. [Online] Available from: http://www.oecd.org/tad/agricultural-policies/41687424.pdf [Accessed: 2013-04-06]

Van der Byl, P.A. 1937. Serving the winter-rainfall area with agricultural education and advice. Annual report of the Stellenbosch-Elsenburg College of Agriculture of the University of Stellenbosch. *Farming in South Africa,* December 1937: 587-588

Viljoen, P. R. 1939. A review of the Union's Agricultural Industry. *Farming South Africa*, December 1939:488-501

Vorster, D. J. & STADLER, J. D. 1976. A new approach to the cultivation of plums. *The deciduous fruit grower,* 26(6):222-224

Wander, A. E., Magalhães, M. A., Vedovoto, G. L. & Martins, E.C. 2004. Using the economic surplus method to assess economic impacts of new technologies: Case studies of Embrapa. Paper presented at the Conference on International Agricultural Research for Development, Berlin, 5-7 October

Watson, A. 1996. The price of research: Understanding the economics of charging for research. Conference proceedings: Global Agricultural Science Policy for the Twenty-first Century. Melbourne, Australia

Wong, W., Barba, P., Àlvarez, C., Castro, À., Acuña, M. Zamora, P., Rosales, M., Dell`orto, Moynihan, M.R., Scorza, R. & Prieto, H. Evaluation of the resistance of transgenic C5 plums (*Prunus domestica* L.) against four Chilean *Plum pox virus* isolates through micro-grafting. *Chilean Journal of Agricultural Research,* 70(3):372-380