An *ex-ante* Assessment of the Socio-Economic Impacts of Genetically Modified Sugarcane in the ILembe District of KwaZulu-Natal.

By

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DEDICATION

This thesis is dedicated to my mother and father, Annah and Musa Ntuli, and my son, Lwazi Ntuli, who have motivated me to persevere no matter the circumstances.

Niqhubeke njalo maBhele amahle.

DECLARATION

I, Zamandlela Ntuli, declare that:

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Dr. SRD Ferrer (Supervisor)

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ABSTRACT

The increasing prevalence of the stalk borer, *Eldana saccharina Walker* (*eldana*), and creeping grass weed, *Cynodon dactylon* (*cynodon*), in sugarcane growing regions of South Africa have caused costs associated with control of pests and diseases in sugarcane production to increase. This has contributed to a decline in the relative profitability of sugarcane farming, which has contributed to a decline in the area planted to sugarcane. The South African Sugar Research Institute (SASRI) is currently considering developing an insect-resistant (IR) and herbicide-tolerant (HT) genetically modified (GM) sugarcane cultivar to address these challenges. This GM cultivar is specifically intended to be suited to production in coastal regions of KwaZulu-Natal. The expected socio-economic impacts of introducing GM cultivars are an essential component of SASRI's decision.

A review of literature on the topic indicates that the adoption of GM crops, since the early 1990s, has generally had positive socioeconomic impacts. Farmers benefited through energy and environmentally friendly chemical control, reduced chemical cost, and improved human health owing to less handling of chemicals. However, no cultivars of GM sugarcane have yet been commercialised globally, and limited research has been done on the impact of GM perennial crops. This study, therefore, aims to fill this knowledge gap. Because the development and roll-out of a GM cultivar will take approximately ten years, this research is an *ex-ante* study.

The study was conducted in the North Coast region of KwaZulu-Natal, where *eldana* and *cynodon* are most prevalent. Commercial sugarcane farms were aggregated into two representative farms, based on different climatic conditions, cane cutting cycles, yields, and soil types. Data were collected through focus group discussions with SASRI experts and commercial farmers. Microsoft Excel was used to compile enterprise budgets of GM sugarcane and conventional sugarcane under different cutting cycles to determine the profitability of the different sugarcane cultivars. An analysis of cultivar gross margins shows that the hypothetical GM sugarcane harvested on an 18-month cutting cycle is relatively more profitable than conventional sugarcane harvested on either a 14 to 16-month cutting, or an 18-month cutting cycle on sandy and loam soils in both the Coastal and Hinterland regions of the North coast. On clay soils in coastal areas, the N59 cultivar harvested on an 18-month cutting cycle had marginally higher gross margin than the hypothetical GM cultivar.

Mathematical Linear Programming farm models that account for risk using Baumol's E-L criterion, variability in farmland resources, and SASRI's recommendations against planting one variety of sugarcane in more than 33% of the total area under sugarcane on a farm, amongst other factors, were then compiled for each of the two representative farms. The models were verified by their ability to closely simulate observed land-use decisions on the representative farms for a current scenario. Having verified the models, the likely change in land use decisions due to GM sugarcane was investigated by re-running the models for a scenario in which a hypothetical GM sugarcane cultivar is available, *ceteris paribus*. The current scenario was used as a baseline due to uncertainty about a likely scenario ten years from now when a GM sugarcane cultivar is expected to become available. The impacts of GM sugarcane were assessed by comparing yields, gross margins, farmer's production decisions, chemical applications, and employment across the two scenarios.

Results of the study are that farmers that adopt GM sugarcane cultivars are likely to benefit through savings in pest and weed chemical control and improved sugarcane yield and quality. Furthermore, the reduction in chemical requirement has indirect benefits such as less handling of chemicals leading to improved health and safety of farmers, increased management time, and less on-field traffic reducing soil compaction, which increases soil stress, increasing the prevalence of *eldana*. Based on the findings, it is recommended that information and communication of GM sugarcane be shared along the supply chain for it to be successfully produced and commercialised. Additionally, the decision on the sugarcane cultivar that will be commercialised in the first stage is crucial for the successful adoption of GM cultivars. Furthermore, training of smallholder farmers is recommended to improve the likely impacts of GM sugarcane.

Keywords: cynodon, *eldana*, genetically modified, herbicide-tolerant, insect-resistant, linear programming farm model, Sugarcane

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AATF	African Agricultural Technology Foundation
AUC	Area Under Cane
BFAP	Bureau for Food and Agricultural Policy
CBA	Cost-Benefit Analysis
CTS	Cane Testing Services
DAFF	Department of Agriculture Fishery and Forestry
DT	Drought Tolerant
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
GM	Genetically Modified
GMO	Genetically Modified Organisms
HPL	Health Promotion Levy
HT	Herbicide Tolerance
IPM	Integrated Pest Management
IR	Insect Resistance
KZN	KwaZulu-Natal
LP	Linear Programming
MOTAD	Minimisation of Total Absolute Deviation
NFI	Net Farm Income
NGO	Non-Government Organisation
NLP	Non-Linear Programming
OFAB	Open Forum on Agricultural Biotechnology
OFSP	Orange-fleshed sweet-potatoes
P&D	Pest and Disease
PPI	Producer Price Index
RV	Recoverable Value
SA	South Africa
SACGA	South African Cane Growers Association
SASA	South African Sugar Association
SASRI	South African Sugar Research Institute
TR	Total Revenue
US	United States

CHAPTER 1. INTRODUCTION

This study is part of a broader research project that investigates various aspects of the likely socio-economic impact of genetically modified sugarcane in South Africa (SA) if it is successfully developed. The focus of this component of the project is to study how the availability of GM sugarcane is likely to change farmers' land-use decisions and sugarcane production systems and the impacts thereof for returns to sugarcane farming, employment in sugarcane farming, and the use of harmful agrochemicals in sugarcane farming. The topic is investigated using sugarcane producing regions of the KwaZulu-Natal North Coast as a case study. The objective of this chapter is to present the problem statement, and to outline the research objectives, the assumptions and the limitations of the project, and to explain why the North Coast was selected as the case study region for this research project.

1.1 Background to the Study

The increase in demand for good quantity and quality of food has increased the requirements for pest and weed control in food production systems. Controlling pests and weed is one of the highest input costs on the farm, and often time-consuming (Chassy, 2007). Since 1996 crops have been genetically bred to select for traits that are desired by farmers, to be resistant to insects, to be tolerant to round-up ready chemicals that control the spread of weeds, tolerant to drought, and enhance vital nutrients, amongst other traits (James, 2015).

In the South African sugar industry, the spread of the pest *Eldana saccharina Walker* (*eldana*) and the creeping grass weed, *Cynodon dactylon* (*cynodon*), has imposed a challenge on sugarcane farmers, particularly in the coastal areas of KwaZulu-Natal, where this pest and weed are most problematic. Rutherford (2015) noted that the South African sugar industry is one of the main sugarcane producers in Africa; *eldana* and *cynodon* have caused a direct and indirect loss of sugarcane production since the early 1940s in South Africa. Factors such as drought, water stress, poor soil types for example, sandy soils and poor management practices increase the risk of *eldana*, while *cynodon* weed competes for the nutrients in the soil during drought seasons, stressing and retarding sugarcane growth (Rutherford, 2015).

Currently, research is being conducted to address this challenge and genetic modification of sugarcane cultivars is amongst one of the proposed solutions. Snyman and Rutherford (2017) indicated that the South African Sugar Research Institute (SASRI) was considering developing an *Eldana saccharina Walker* (Lepidoptera: Pyralidae) insect resistant (IR), and herbicide tolerant (HT) genetically modified (GM) sugarcane cultivar that is specifically suited to production in the coastal regions of KwaZulu-Natal, as it is the regions most affected by *eldana*.

However, no research has, as yet, considered the likely socio-economic impacts of SASRI releasing a GM cultivar of sugarcane. This study is a component of a broader study into whether or not GM sugarcane is likely to be adopted if it is made available to farmers, and the likely socio-economic impacts of GM sugarcane if it is adopted by farmers in South Africa. The broader study is considering a range of issues, investigating a range of topics, including potential economic impacts at sector level, co-existence and supply-chain impacts, export market impacts and consumer impacts. This component of the project considers the extent to which farmers are likely to adopt GM cultivars of sugarcane and the socioeconomic impacts thereof, assuming that sugarcane millers will not discriminate between GM and conventional cultivars of sugarcane.

The study is important because development of GM sugarcane cultivars may have implications for the future of the SA sugar industry. The SA sugar industry is over 150 years old and plays a significant role in employment and contributes 0.84% to the gross domestic product (GDP) of South Africa (SASA, 2016). Despite the relative importance of sugarcane production to the South African agriculture sector, over the past decade there has been a decrease in area planted under sugarcane and sugarcane yield by 13.7% and 8.7%, respectively (SACGA, 2018).

This decline in area under cane and yield of sugarcane may be explained by a range of socio-economic and socio-political factors (BFAP, 2017). However, the damage caused by *eldana* and *cynodon* and the increased costs incurred by farmers to control the spread of it are important contributing factors as it reduced revenue. Furthermore, addressing the spread of this pest and herbicide is important for the environmental and the economic sustainability of sugarcane farming, especially in the coastal areas (Ducasse *et al*, 2017). The decrease in the quality of sugarcane, measured by a decline in recoverable value as a percentage of the sugarcane mass (RV %), has also been associated with the increase in the fibre content in the stalk owing to *eldana* infestation.

SASRI has made important contributions to address pest and diseases (P&D) in the sugarcane industry, including positive contributions to the management of *eldana* and *cynodon* (Snyman & Rutherford, 2017). These contributions include the development of new agrochemicals (which are less harmful to the environment) and improved sugarcane cultivars, together with Integrated Pest Management (IPM) practices, all of wherein, have played a significant role in controlling the spread of pests and weeds (Ducasse *et al*, 2017; Rutherford, 2015; Snyman & Rutherford, 2017). Nonetheless, according to Lichakane and Zhou (2019), the spread of *eldana*, continues despite better management practices and genetic breeding for *eldana* resistance, particularly in the coastal areas.

Management of pests and weeds in the sugarcane industry contributes significantly to the cost of sugarcane production. According to Nicholson *et al* (2017) application rates of pesticides and herbicides have increased sugarcane planting costs by 13% and ratoon management costs by 18%. According to Rutherford (2015), farmers in the coastal area of KZN with relatively acid soils have also increased fertilizer application rates as part of their strategies to reduce the spread of *eldana*. Goebel & Sallam (2011) and Rutherford (2015) do, however, caution farmers against overuse and misuse of agrochemicals, amongst other farm management practices, because it can contribute to outbreaks of insects and weeds.

1.2 Problem Statement

A decline of 30% in the average net farm income due to decreased yield and planting over the past decade poses a threat as it increases uncertainty of the sustainability of the South African sugar industry (BFAP, 2017). The decrease in the production of sugarcane is mainly in the coastal regions (Northern and Southern) of KZN (Ducasse *et al*, 2017). The increase in *eldana* and *cynodon* in these areas has contributed to this significant decrease. The increase in *eldana* and *cynodon* populations has increased input costs, decreases yields and quality and profitability of sugarcane in rainfed areas significantly since the early 2000s (Nicholson *et al*, 2017). Findings from BFAP (2017) show that on average farmers' real net farm income decreased for Midlands and Coastal sugarcane farms by 26% and 54% per ha respectively from the 2000/01 to 2011/12 season.

Controlling the spread of *eldana* increases the cost of production (Rutherford, 2015). Rutherford (2015) explained that it would be inconceivable to eliminate the entire *eldana* population because it is indigenous to South Africa. He further explained that doing so would be unsafe and an expensive process. Consequently, IR, HT, GM sugarcane has been proposed as a means to address this problem in the sugar industry (Rutherford, 2015).

Considering the above problems associated with the increase of the *eldana* and *cynodon* population the following research questions are raised in the study:

- If a GM cultivar of sugarcane is developed and made available to farmers in the North Coast of KwaZulu-Natal, how will the availability of that cultivar affect;
    1. The likely adoption of GM cultivars on the farm;
    2. The use of agrochemicals (pesticides and herbicides) in sugarcane production;
    3. The profitability of the farm (through reduced costs);
    4. The area under sugarcane; and
    5. Employment in sugarcane farming.

1.3 Research Aims and Objective

This is an *ex ante* study that considers a scenario in which a GM, IR and HT sugarcane cultivar has been developed and is available for adoption by sugarcane farmers in the North Coast regions of KwaZulu-Natal. The general aim of this project is to assess the socio-economic impact of that GM sugarcane cultivar by comparing the scenario with a counterfactual scenario in which no GM sugarcane cultivars are available for adoption. It is assumed that sugar produced from GM sugarcane is perceived to be a perfect substitute for sugar produced from conventional sugarcane by sugarcane millers, consumers and other players in the sugar value chain.

The general objective of the project is to inform SASRI's technology development process about the possible socioeconomic impacts of GM sugarcane, if it is developed. The findings will be used in the consideration of the technology within the GMO regulatory process.

The specific objectives of the study are:

(a) To compile representative farm models of commercial sugarcane farms in the North Coast of KwaZulu-Natal using mathematical programming techniques;

(b) To use the representative farm models to assess the extent to which sugarcane farmers on the North Coast are likely to adopt a GM cane cultivar by comparing the results of running the models using a "with GM cane" scenario and a counterfactual;

(c) If results show that GM cane is likely to be adopted, to estimate the impact thereof on farm production decisions, and specifically with respect to the area planted to sugarcane, employment in sugarcane farming, and agrochemical use on sugarcane farms in the region.

1.4 Hypotheses

1. Farmers will be indifferent between adoption of GM sugarcane cultivars and conventional sugarcane varieties.
2. The availability of a GM sugarcane cultivar suited to sugarcane production in coastal regions of KwaZulu-Natal will have no effect on the area under sugarcane and sugarcane production decisions on sugarcane farms on the North Coast
3. Adoption of GM sugarcane will not affect employment in sugarcane farming on the North Coast.
4. Adoption of GM sugarcane will not affect agrochemical use in sugarcane farming on the North Coast.
5. The total area under sugarcane will not change with GM sugarcane.

1.5 Significance of the Study

This study is an important component of the broader research project designed to inform SASRI's decision to develop a GM sugarcane cultivar. Currently no GM cultivars of sugarcane have been developed globally. Sugarcane is an important crop in KZN with reference to both area cultivated and employment, therefore relatively small changes in agrochemical use and employment per hectare can have a large impact at a perennial level. The outcomes will assist in the regulatory assessment for commercial approval of the development of the GM sugarcane.

Literature on farm level impacts of producing GM products is scarce in South Africa. Literature found on GM crops pertains mostly to annual crops. There is a gap in the literature on farm level impact of GM crops in South Africa and the cultivation of perennial GM crops globally. This research will contribute towards knowledge creation in this area.

1.6 Scope of the project

The scope of this component of the project is limited to the likely impact of GM sugarcane at the farm level in the iLembe region of KZN. In particular the extent to which GM sugarcane is likely to be adopted by commercial sugarcane farmers, and the implications thereof for the relative profitability of sugarcane farming, use of agrochemicals and employment in sugarcane farming will be studied. Because the vast majority of sugarcane produced in the iLembe region is farmed on relatively commercial farmers, this study is focused on that category of farms. The likely impact of GM sugarcane for smallholder sugarcane farmers are an important consideration in SASRI's decisions to develop GM sugarcane cultivars, and should be investigated in a separate study.

1.7 Assumptions

The main assumption of the study is the characteristics of the GM sugarcane cultivar. The study also assumes that there are no other technological changes; hence the counterfactual is similar to a present day scenario, rather than a scenario ten years from now when a GM cane cultivar is released. Additionally, it assumes all large-scale farmers adhere to the recommendation of the SASRI guidelines, for example, the recommendation that the area planted to any cultivar of sugarcane on a farm should exceed one-third of that farm's area under cane. The study also assumes that there are no errors in the data provided by key informants. Because this study is a component of a bigger project, it is assumed that GM sugarcane is a perfect substitute for conventional sugarcane for millers, and that sugar extracted from GM sugarcane is a perfect substitute for sugar extracted from conventional sugarcane from the perspective of consumers and agro-processors and other uses of sugar. Therefore the price received by farmers per ton of RV is the same regardless of the cultivars of sugarcane, including GM cultivars.

1.8 Structure of the Dissertation

This dissertation is comprised of six chapters. Chapter One introduces the research topic and states the objectives of the study. The first part of the second chapter reviews the farm level impact of GM crops globally, in the African continent and lastly in South Africa. The second section reviews methodologies for *ex-ante* assessment of the impacts of GM crops, and identifies the methodology best suited to this particular project. Chapter Three gives a background of the sugar industry and describes sugarcane farming in the iLembe District. Chapter Four describes the methods and methodologies of the project, limitations of the model are given. Results are provided and discussed in Chapter Five. Chapter Six concludes and further research recommendations are stated.

CHAPTER 2. REVIEW OF THE FARM LEVEL IMPACT OF GENETICALLY MODIFIED CROPS

A literature review of research on the farm level impacts of genetically modified crops is presented in this chapter. The specific purpose of this review of literature is to inform this study about, (a) the socio-economic impacts of GM crops, in general, based on studies conducted in South Africa, elsewhere in Africa and internationally, and to consider whether or not there is consensus in their findings; (b) to examine the range of socio-economic impacts considered in these studies and to learn about how impacts at the farm level can be extrapolated to their impacts on society as a whole; (c) identify economic theories of farmers' decisions to adopt GM crops; and (d) to identify methodologies used to study farm level impacts of GM crops and to consider their strengths and weaknesses for conducting an *ex-ante* study of a perennial GM crop.

The chapter is structured into 4 sections. A review of GM crops globally, on the African continent and then in South Africa is presented in Section 2.1. Then the major challenges and opportunities of GMOs are identified and discussed in Section 2.2, and followed by a review of economic theories of farmers' decisions to adopt GM crops. The last section (Section 2.4) reviews methodologies for *ex-ante* assessments of GM crops. These methodologies are discussed to identify their relative advantages, disadvantages, and limitations.

2.1 Farm Level Impacts of GM Crops

There has been an increase in adoption of genetically modified organisms (GMOs) both globally and in Africa since the early 1990s. The objective of this section is to review how adoption of GM crops has impacted farmers. This section is particularly beneficial as it highlights factors the study may focus on when analysing farmers' likely impact of adopting GM sugarcane cultivars.

In the past century, the need for improved agricultural production to provide for the growing human population and changes in preferences has led for the need for agriculturists to select desirable genes from each generation of a crop for cultivation (Chassy, 2007). Early adoption of GM crops proved that farmers benefited through cheaper labour, energy and environmentally friendly weed control chemicals (Brookes & Barfoot, 2006). Even though GM seed tends to cost more than non-GM seed, studies have shown that farmers will often prefer GM seeds because those cultivars tend to produce higher yield, reduce labour requirements, and reduce environmental harm by applying less chemical inputs (James, 2015). According to Chassy (2007), GM crops have been adopted faster than any technology in the history of the agricultural industry.

Growth in the production of GM crops globally has been significant since 1996 (Brookes & Barfoot, 2016). Literature has shown that GM crops that are most common globally are soybean, maize, cotton, and canola, accounting for 48% of all GM crops (Brookes & Barfoot, 2016). Rates of adoption of GM crops are currently highest in the United States (US) and in Canada. Dominant traits that are planted are HT soybean (39%), IR maize (21%) and IR cotton (20%) (James, 2015).

2.1.1 The Adoption of GM Crops Globally

Genetically modified crops have been approved by up to 60 countries globally since 1996. US was amongst the first country to adopt GM crops in 1996 (James, 2015). In the 2013-2014 season, 94% of total soybean crop produced in the US were GM HT cultivars (Brookes & Barfoot, 2016). The farm level impact of the GM HT soybean in the US reflected positively through reduced input costs. The rapid adoption of GM crops in other countries such as Brazil, Argentina, India, and Canada has shown that those farmers have a strong preference for GM cultivars (Areal *et al*, 2013; Klümper & Qaim, 2014). Research by Brookes & Barfoot (2016), assessing the global socio-economic and environmental impact of GM crops from 1996-2014, stated that US had the biggest share of GM crops globally (38%) closely followed by Brazil, (28%), Argentina (14%), India (7%), Canada (6%) and China (2%). More up-do-date statistics are currently not available, but it is expected that the proportions have changed with the rapid adoption of the technology.

The major on-farm benefits of adopting GM crops were realized in reduced costs of herbicides, labour and maintenance of machinery due to weed management. Despite a global increase in the price of glyphosate relative to the prices of other herbicides in the 2008-2010 season (Brookes & Barfoot, 2016), impacts on reduced costs were positive on farmers producing GM HT [1]soybean. However, James, (2015) reported that producers of GM HT soybean have experienced problems of weeds becoming resistant to glyphosate. This was addressed by using other herbicides together with glyphosate at the farm. Soybean yields have improved by up to 11% with improved GM HT cultivars (James, 2015).

[1] HT soybeans are tolerant to glyphosate, which enable farmer to use glyphosate to control weed infields of HT soybeans.

Dill *et al*, (2008) reported a similar experience with respect to GM HT soybean production in Argentina, including a significant positive impact on farm gross margins. Leguizamón (2014) reported that farmers perceived the major contribution to this positive impact was from input cost reductions. This agrees with findings of Brookes and Barfoot (2016) who found that initially there was a relatively neutral impact on yield and quality of soybean that only improved by 0.5%. The major advantage Argentina farmers had, and still have, over the US and other countries is that GM seeds are not sold at a premium price. Another positive impact of GM HT soybean is the ease, simplicity and the flexibly of weed management as it has led to the adoption of low or no tillage production systems (Brookes & Barfoot, 2016). The low or no tillage system reduced the time required for drilling and harvesting, enabling farmers to diversify. The increased soybean production has grown the Argentina economy as it is the third largest global grower and exporter of soybeans. Because of this, the economy has grown by an average of 8.6% since 1996. Similar farm level impacts were observed in Brazil, Canada and other countries (Brookes & Barfoot 2016), with Romania having the largest positive impact at the farm.

Just like GM HT soybean, Herbicide Tolerant maize has had a similar impact through improved yields, significant improvement of weed control (up to 22% efficiency), reduce costs and improve profitability at the farm level globally (Mendez *et al,* 2011; Brookes & Barfoot 2016). It is amongst the top five adopted GM crops globally (James, 2015). In the US, Canada, and Argentina the production of GM maize has been above 70% compared to conventional maize (Brookes & Barfoot, 2016). Similar benefits have been identified in GM IR maize, HT cotton, HT canola and GM HT sugar beets (Brookes & Barfoot, 2016). Impacts differed country to county and the magnitude of the benefits ranged from marginal (in the initial stages of introduction) to significant depending on the geographical barriers, climatic conditions, and resources available.

80% of sugar worldwide is produced from sugarcane (Gao *et al,* 2018) while the other 20% is produced from sugar beets. Just like other crops, the need to improve sugarcane cultivars has been significant this is because there has been an increase in demand for sustainable energy production worldwide. For the past 30 years, better agronomic practices have contributed to improved yields and additional improvements are expected from the use of GM sugarcane (Cheavegatti-Gianotto *et al,* 2011). Sugar derived from GM sugarcane has not yet been commercialised in the market globally and hence, no *ex-post* scientific articles have been published to date. However, Brazil is in the regulatory process of commercialising it. Brazil and Indonesia have approved the commercialisation of IR GM and drought resistant (DR) sugarcane respectively (Gao *et al*, 2018). The Brazilian IR GM sugarcane has traits that include increased yield, insect resistance, and herbicide tolerance and drought tolerance (Cheavegatti-Gianotto *et al*, 2011). A Reference Study for the Regulation of Genetically Modified Cultivars in Brazil, studied by Cheavegatti-Gianotto *et al* (2011) assumes that GM sugarcane can reduce environmental impact because less fertilizer and water will be required.

2.1.2 The Adoption of GM Crops in the African Continent

There has been a slow, yet steady adoption of GM crops in the African continent. African countries that have commercialized GM crops are Burkina Faso, Egypt, Kenya, Nigeria, South Africa and Uganda (James, 2015). Food insecurity is the major factor contributing to the need for improved crop cultivars through GM crops in Africa. Special emphasis has been on staple crops such as maize, cassava, sweet potatoes, and bananas. The implemented trials are focusing on traits that will overcome challenges faced by Africa such as nutritional enhancements, drought tolerance (DT) and tropical pests and diseases. Examples of the above include cassava with additional pro-vitamin A, proteins and iron in Kenya and Nigeria (James, 2015), DT maize in Kenya, South Africa and Uganda (Brookes & Barfoot 2016) and banana that has been enhanced with pro-vitamin A and iron and insect resistance in Uganda (James, 2015). A study done by Kostandini, *et al* (2015) on the impacts of adopting nitrogen-efficient maize for South Africa and Kenya showed that, on estimate, $248 Million in revenue could be generated from adopting nitrogen-efficient maize. They also showed that it could alleviate poverty on an estimate of 71 000 poor households. An *ex-ante* impact study of drought-tolerant (DT) varieties of staple crops was also conducted by Kostandini, *et al* (2011) in East Africa.

In Egypt, the development of DT GM wheat showed a 20% increase in yield compared to conventional wheat (James, 2015). Trials done on IR, HT cotton in Uganda proved that the stacked traits could double yields without expanding the area under cotton cultivation because conventional cotton had yield loss contributing to approximately 40% insect damage and 30% weeds (Brookes & Barfoot, 2016). Burkina Faso first commercialized GM IR cotton in 2008 and by 2014, it accounted for 70% of total cotton planted (Brookes & Barfoot, 2016). Studies done by

Vitale *et al* (2011) showed that GM IR improved yields by up to 20% through improved pest management which reduces input costs. Orange-fleshed sweet-potatoes (OFSP), which was produced to address vitamin A deficiency in woman and children in Uganda, benefited farmers through improved Net Farm Income (Mwanga & Ssemakula, 2011). The increase in income helped farmers with off-farm obligations such as improved household shelter, pay for children's education, medication, clothing and expand farm area (Mwanga & Ssemakula, 2011).

Government and private organisations have been working hand in hand, in research, to improve food security through enhancing crop cultivars with GM crops. The increasing number of field trials in Africa is a clear indication that GM technology is progressing and plays a vital role in food security. In addition to the research done on GM crops by governments and the private organizations such as African Agricultural Technology Foundation (AATF) efforts have been made to create awareness and educate consumers about the technology (James, 2015). An example of this is the Open Forum on Agricultural Biotechnology in Africa (OFAB). In Ghana, this forum brings stakeholders together and enables interactions between scientists, farmer groups, policymakers, civil society and journalists regularly. This provides stakeholders with the platform to discuss all aspects of GM technology and expand their knowledge base and improved informed contributions to policymakers (James, 2015). With the public-public and public-private innovation to improve the pace of research on biotechnology, the future of agriculture in the African continent will improve significantly.

2.1.3 The Adoption of GM Crops in South Africa

South Africa was the first and leading African country to accept and commercialise GM technology in 2000 (Brookes & Barfoot, 2016). Just like other African countries, South Africa uses GM technology mainly on staple foods such as maize and soybeans. South Africa is a producer of six major crops, namely maize, wheat, sunflower, potatoes, sugarcane, and grapes. From these, maize, wheat and potatoes are known to have already been commercialised to be cultivated as GM crops (Swanby, 2008). The intention of introducing GM sugarcane in this project is progressing. The main crops that have been cultivated through GM technology are HT soybeans, HT and IR maize, and IR cotton (James, 2015). Since 2000 the increase in area under these crops has been significant to a point that they compete for resources such as land (Swanby, 2008).

Genetically modified HT soybeans were commercially planted in 2001, by 2014 the adoption of GM HT soybean was up to 90% (James, 2015). Farmers benefited mostly through reduced chemical application, less ploughing and reduced labour requirements. Maize farmers have benefited from HT maize since 2003. Gouse *et al* (2012) found that smallholder farmers benefited mostly from reduced chemical costs, reduced labour cost (as hand weeding is the main form of weed control) and yield increase of up to 8%. Insect resistant maize increased yields from 5-32%, with an average of 15% (James, 2015). The cost of acquiring GM maize showed it is to be less than the average cost saved on labour, chemicals, and management (Gouse *et al*, 2012). Similar positive impacts have been identified in GM IR cotton which was first commercially planted in South Africa in 2014. Farmers interviewed by James (2015) stated that even though the cost of GM seed came at a cost, the benefits outweighed the costs.

Research done by the South African Sugar Research Institute (SASRI) shows that the adoption of GM sugarcane in Coastal regions of KwaZulu-Natal is likely to benefit farmers directly through reduced chemical application and less management of weed and indirectly as the recommended sugarcane production cycle in that region would increase from 12-14-month cycle to 16-18-month cycle (i.e., the average harvesting age of cane would return to what it was before *eldana* became prevalent in the region.) The average age at which cane was harvested was previously reduced to minimize *eldana* damage on mature sugarcane in the North Coast (Ducasse *et al*, 2017). Currently, sugarcane farmers primarily use improved chemical control and integrated pest management (IPM) practices to address the losses caused by *eldana* (Rutherford, 2015). The introduction of GM sugarcane in South Africa is expected to solve the problem on the spread of *eldana saccharina* species and control the growth of creeping grasses. Some articles have postulated that commercialising GM sugarcane will have a positive impact on social welfare as it is expected to reduce sugar prices (through providing farmers with higher yields), reduce the use of pesticides and herbicides, and increase Net Farm Income (Finger *et al*, 2011; Klümper& Qaim, 2014; Nagarajan, 2016). There appears to be a strong consensus amongst agronomists and plant breeders in the SA sugar industry that genetically modified IR and HT sugarcane is crucial for the future sustainability of growers and the sugar industry.

2.1.4 Indirect (Non-Pecuniary) Farm Level Impact of GM Crops

In addition to the quantifiable economic impact farmers benefit from in GM crops, there are broader intangible positive social and environmental impacts that GM crops have (Ducasse *et al*, 2017, Brookes & Barfoot, 2016). These impacts can include impacts on the local community, labour and households (Marra *et al*, 2002). One of the major indirect impacts of GM IR crops is that it accounts for production risk management- there is less worry among the farmers for pest damage, the reduction in crop damage also improves quality of the crop (Ismael *et al*, 2002). There is also an increase in management flexibility as less time is devoted to scouting and applying insecticides.

Farmers' safety and health are improved because there are less handling and use of pesticides- this is particularly important to smallholder farmers, where protective equipment or clothing may be limited (Hofs *et al*, 2006). Insect resistant crops have also benefited farmers through a shorter growing season, which allows farmers to plant a second crop during the season (Brookes, 2008). This is in contrast with what Ducasse *et al* (2017) predict for sugarcane farmers, but in both cases, the farmers benefit. In the shorter season crop, farmers can plant and sell twice in the season and sugarcane farmers benefit through longer production cycles resulting in increased sucrose content and yield as the sugarcane stalk ages.

Crops that have the HT gene have shown to increase management flexibility (James, 2015). This may be because post-emergent herbicides, e.g., round-up and glyphosate, are no longer necessary, and farmers may use the extra time for other farm activates or off-farm, income-earning activities. Herbicides used to control weeds post-emergent may hinder the crop from growing to its full potential (Dill *et al*, 2008), GM HT crops do not face such a challenge. Other benefits include saving on costs for labour and fuel cost, reduced soil erosion attributed to ploughing because of the no-tillage system. Just like GM IR crops, GM HT crops contribute positively to human safety as there is less handling of chemicals.

2.2 Challenges and Opportunities for GM Crops

Despite the positive farm level impact of GM crops, some countries such as Kenya and Europe have banned the use of GM crops (Nagarajan, 2016). The reason why this technology has not been introduced successfully is primarily because of health concerns and environmental reasons raised by consumers. Qaim & Zilberman (2003), stated that they were surprised to see the slow adoption of GM crops in many developing countries, and that this is explained through the reluctance of farmers (especially smallholder farmers) to adopt new technologies due to the perceived risks that are often associated with them. Another reason why some developing countries have banned the use of GM crops is because of the possibility of losing export markets where GM crops are banned (Nagarajan, 2016).

A relative lack of markets for GM crops in many developing countries is an obstacle to introducing GMO technologies in those countries. Qaim (2016), showed that the reluctance of accepting GM crops is also linked to the absence of biosafety regulation, and the problems associated with negotiating intellectual property. The perception that larger firms with proprietary rights of GM crops and well-established resources will monopolise local seed industries is a significant reason that non-governmental organisation (NGOs) actively lobby against the introduction of GM crops (Nagarajan, 2016). Even though there may be challenges on the commercialisation of GM crops in some countries, opportunities to address global issues far exceed the problems.

The Save and Grow Report (FAO, 2011) forecasts that by 2050 the world would need approximately 70% more food. This creates both pressure and great opportunities for agriculture globally. The commercialisation of genetically modified organisms (GMOs), therefore, plays a crucial role in reaching current and future goals of providing food security globally, but especially in developing countries. Research has shown that in developing countries, where there are many smallholder growers, high-input costs is one of the significant challenges that farmers face. GMOs have proven to address farmers' challenges such as high-income costs and producing sufficient, healthy, and affordable food for consumers to date (James, 2015). Based on the theory and the positive impact of GMOs thus far, the future for sustainable agriculture depends on the improvement of technology and the commercialisation of GMOs globally.

Addressing poverty continues to be a major challenge in many developing countries, especially in rural areas. James (2015) approximated that 50% of people living in poverty are smallholder farmers with limited resources, while another 20% are landless farmers who depended on agriculture for their livelihoods. This challenge can be addressed as it creates an opportunity for new technologies like GMO's to contribute to the alleviation of hunger and poverty. With the increasing population and the increasing drought in Africa, GMOs have the potential to provide healthy, affordable food to people living at the bottom of the pyramid. Global warming affects agriculture mostly in tropical and subtropical areas where drought is already a limitation to optimal crop production. Increasing climate change increases food insecurity by decreasing crop yield, which increases food prices (law of demand and supply) (FAO, 2011). The effect of global warming on agriculture will not only depend on changing climatic conditions, but also on the ability of the agricultural sector to adapt and develop crops which will withstand constraining climate change.

Genetically modified crops have already proven to contribute food, feed, and fibre security by increasing productivity and economic sustainable benefits at the farm level (Brookes & Barfoot, 2016; James, 2015; Finger *et al*, 2011). In addition to the economic benefits, because GM crops are a land saving technology, their adoption creates an opportunity to protect biodiversity and reduce deforestation as higher yields are produced on less land (James, 2015), and to reduce the negative impacts of conventional agriculture on the soil (Wood *et al*, 2006). Genetically modified crops reduce agriculture's environmental footprint by reducing pesticide application, CO_2 through less ploughing and conserves the soil and moisture by applying no-tillage practices on GM HT crops. Drought tolerance crops increase the efficiency of water usage, this trait plays a significant role in developing countries where drought is prevalent. Despite the challenges that agriculture faces globally, improved technology like GM crops create an opportunity for sustainable living.

2.3 Economic Theories of Farmers' Decisions to Adopt GM Crops

The adoption and diffusion rate of genetically modified crops, just like many other technologies, has been gradual. Although stakeholders may have imperative information about the technology at hand, effort is needed to persuade farmers to adopt it as the adoption process is complex and influenced by both internal and external factors (Pierpaolia *et al*, 2013). It is therefore useful to understand the factors affecting the adoption of any new technology. Similarly to consumer preferences, farmers' (producers') decisions are impacted by their characteristics; risk preference, asset endowment, resource availability and education level (Bowman & Zilberman, 2013). This section serves to highlight economic, social and environmental factors that may affect farmers' decision in adopting a new technology; it further extrapolates how these factors may affect sugarcane farmers' decision to adopting genetically modified sugarcane.

2.3.1 Economic Factors Affecting Farmers' Decisions

The main factors that farmers consider when assessing economic factors that affect their decisions of adopting any new technology include profitability, and risk associated with adopting the new technology. The uncertainty associated with the anticipated outcome results in a gradual adoption, starting from the more risk-preferring, commercial farmers spreading through to the risk neutral farmers, once the technology has proved to be beneficial (Marra *et al*, 2003). According to Bowman & Zilberman (2013), economists assume that farmers' decisions are influenced by their well-being or utility. This is supported by farmers generally being willing to adopt any new technology that they expect will increase income, reduce physical and financial risk and reduce labour requirements. Farmers' expectation about the impacts of adopting a new technology may change as more becomes known subsequent to the initial stages of implementation, which may change their decision to adopt the technology, or not (Hall & Khan, 2003).

The diffusion rate of any new technology is a result of a series of different decisions based on the comparison of the expected benefits of the technology that farmers are uncertain about, and the cost associated with adopting it- and by nature the benefits are received throughout the life of the technology whereas, the costs are incurred at adoption and cannot be recovered, especially non-pecuniary cost (e.g. the cost of learning the new technology). *Ex ante*, farmers weigh the anticipated economic cost of adopting the new technology against the expected benefits, taking perceived risk into account in the economic costs (Hall & Khan, 2003). According to Marra *et al* (2003), risk is considered to be one of the major factors that contribute to low adoption rate of a new technology. The investment time lag in the diffusion rate may be contributed by the uncertainty about the future value of the investment and its sunk costs (Arrow & Fisher, 1974, cited by Marra *et al*, 2003). This gives farmers the *option value* of waiting to invest if there is uncertainty regarding use of the technology.

Generally, there is a scarcity of empirical studies that sufficiently address how risk and uncertainty impact the adoption of a new technology; this is attributed to the challenges associated with observing and measuring (Mottaleb, 2018). Economists such as Ghadim, (2000) have used the game theoretic approach, using the *option value* as a method to wait and observe earlier farmers who adopted the new technology. This approach provided the theoretical bases for studies on the role risk attitudes, credit constraints, farm size, joint distribution returns and the fixed cost of adoption between two risky technologies. Ghadim, (2000) also used the direct interview technique to investigate how farmers' perceived riskiness and risk attitude impacts their allocative decisions. He concluded that farmers used subjective yield distributions and modified them over time as they obtained more information. Farmers based their actual adoption decisions on these subjective estimates of riskiness. This explains why farmers may plant more than one cultivar of the same crop (Mottaleb, 2018).

2.3.2 Social Factors Affecting Farmers' Decisions

In the early 1900's, most decisions were taken by the head of the household. This contributed to literature focusing on the head of the household as the sole decision maker of adopting any new technology (Ramirez, 2013). Recent studies have, however, increased the social setting, where farmers' decisions are influenced by other family members, education level and age amongst other factors that influence farmers' decisions (Björklund & Jäntti, 2009).

Studies have shown that the level of education is positively correlated to the adoption of any new technology. Empirical evidence indicates that educated farmers are influential in the family and in the community, especially in small scale farming (Ramirez, 2013). This is because educated farmers can easily access information and analyse the future expected returns to their investment. Additionally, spreading information through seminars, training, extension services, field/ farmers days, demonstrations and farm visits, reduces the gap of uncertainty and between farmers' objective information and their perceptions (Doss, 2006). Emmanuel *et al* (2016) further elaborates that access to extension staff, indicating that extension services significantly increase the probability of technology adoption because they facilitate in providing easy access to information and promote farmers' perception, enhancing their productivity.

There is a positive correlation between farm size and the probability of adopting a new technology (Bjomlund *et al*, 2009). Research has shown that large farm sizes are associated with higher income and that farm size can be used as a proxy for income. This indicates that farmers with relatively larger farms can allocate more resources to covering fixed costs of accessing better information and adopting a new technology because they have greater collateral value. Similarly, land ownership influences the decision on the type of technology farmers will invest in as land owners have better financial resources (Emmanuel *et al*, 2016).

2.3.3 Environmental Factors Affecting Farmers' Decisions

The sustainable use of resources, in particular land, is one of the major key factors that contribute to farmer decisions of adopting a new technology. In recent years, there has been a drive towards sustainability and precision agriculture. The geography of the farm and the soil quality are components researchers assess when conducting an *ex-post* cost-benefit analysis (CBA), in particular ecologists. Farmers where are closer to places that information can easily flow, and farmers closer to other farmers that have already adopted any new technology have a higher probability to adopt it faster (Pierpaoli *et al*, 2013). This is contributed to easy access to first assessment of the first farmers who have adopted the technology in the first stages of initialisation. Additionally, rural farmers face challenges such as poor infrastructure and roads, lack of flow of information, low level of education and financial constraints, constraining them from adopting new technology (Akudugu *et al*, 2012).

Ex-post, the quality of the soil is crucial for the diffusion rate of any new technology; this is contributed by the fact that soil quality is positively correlated to the sustainability of agriculture (Pierpaoli *et al*, 2013). With land being the first limiting factor, it is imperative for farmers to consider environmental implications of adopting any new technology. Soil management practices is one of the factors extension staff promote, as it improves crop yield, farm profitability and decreases pest and diseases (Knowler & Brandshaw, 2007). Conserving the soil is, therefore important in the sustainability of agriculture, food security and agro-ecosystems.

2.3.4 Adoption and Diffusion of Genetically Modified Sugarcane Cultivars

In the 1980's, when *eldana* became an economic pest in the industry, the South African Sugar Research Institute (SASRI) started breeding for a trait known as *eldana* resistance (Nuss, 1991). According to Zhou (2015) breeding for *eldana* resistance proved to be highly complex, and only relatively small gains were achieved in selecting for *eldana* damage reduction. More recently, SASRI's sugarcane breeding programmes have achieved more success by using selection for *eldana* damage and family evaluation to breed for *eldana* resistant cultivars (Zhou, 2015). Genetic modification has potential to accelerate this success (Zhou, 2015).

According to Rutherford (2015), GM cultivars of sugarcane are expected to improve sugarcane yield by up to 7% owing to the IR and HT traits. Moreover, the costs of producing GM sugarcane are likely to be less than that of producing conventional sugarcane because use of agrochemicals will be reduced. This will further have benefits of reduced handling of harmful chemicals by farm workers in sugarcane production. Environmentally, better soil management practices may be implemented as there will be less time use on scouting for pests and weeds and spraying for chemicals (Naude, March 2018, *Pers.com*).

The discussion in this section indicates a high degree of consensus amongst SASRI scientists and extension staff that development of a GM sugarcane cultivar with IR and HT traits is desirable and that this would be welcomed by farmers. Nonetheless, and bearing in mind SASRI's recommendation that no sugarcane cultivar should account for more than one-third of the area under cane on a farm, the literature reviewed does not consider either the likely extent of adoption of GM cane, if it is successfully developed, or which of the existing cultivars it is likely to replace. It also fails to quantify the likely revenue gains, cost savings and reduced agro-chemical use.

2.4 Methodologies for *Ex-Ante* Assessment of Socio-Economic Impacts of GM Crops

Several analyses of the impacts of Genetically Modified (GM) crops have been conducted over the past two decades. The increasing demand for the assessment of the impact of GM crops has increased the methods used to assess the advantages and the disadvantages of introducing the GM crops in a country both *ex-ante* (an analysis for a possible future scenario rather than actual outcomes) and *ex-post* (an analysis based on actual outcomes) (Smale *et al*, 2007). This section reviews the approaches used and considers their suitability for *ex ante* assessment of the socio-economic impacts of a perennial GM crop, such as sugarcane, as it is an analysis for a possible future scenario.

2.4.1 Cost-Benefit Analysis

The Cost-Benefit Analysis (CBA) was first used in 1848 by Jules Dupuit who wanted to weigh the cost and benefits of constructing a bridge (Smale *et al*, 2007). The model involves the process of quantifying costs and benefits of a decision over a certain period and those of its alternatives (Hanley & Spash, 1993). The purpose of this type of analysis is to inform projects or public policy decisions if the project or the policy is worthwhile. CBA can be analysed at three levels, namely Private CBA, which is used mostly in private companies, economic CBA which analyses the given data from the point of view of the national economy, and the social CBA, which views the cost and the benefits from society and environmental CBA, which relates to the environment such as the deforestation and soil degradation (Hanley & Spash, 1993). The Theory of CBA involves gainers and losers (Sunstein, 2005). A project, or policy is considered beneficial if the sum of the benefits outweighs the sum of the costs in monetary value (Pasour & Rucker, 2005).

There are two types of CBA impact assessments, the *ex-ante* (anticipated) and the *ex-post* (actual) assessment (Hanley & Spash, 1993). The *ex-ante* impact assessment evaluates the potential impacts as part of the planning, design and approval process of a project (Hanley & Spash, 1993). It is based on expected assumptions (i.e., a scenario) as it informs decisions before they are implemented. *Ex-post* impact assessment identifies actual (usually environmental) impacts attributable to a project after implementation (Sunstein, 2005). *Ex-post* impact assessment is mostly conducted for accountability and feedback of the project (Sunstein, 2005). CBA may apply both *ex-ante* and *ex-post* assessments.

Cost-Benefit Analysis has been used to assess farm level impacts of GM crops by many researchers in developing countries. Research on GM cultivation, is however, limited in more developing countries (Flannery *et al*, 2004; Cartel *et al*, 2006); this may be because these countries initially lobbied against the commercialisation of GM crops. A study by Alston *et al* (2015) is an interesting reference for this study as it assesses benefits of a perennial crop. Findings in this study has shown similar trends of benefits as those of annual crops. Studies were done on BT cotton in the Makhathini Flats (KwaZulu-Natal) showed that farmers benefited through higher yields, lower chemical spray costs, and higher gross margins (Hofs *et al*, 2006, Bennett *et al*, 2004). Though these researchers used partial budgeting to address the research question, CBA is the more common approach. CBA can be used to answer questions such as, what is the potential impact of introducing GM sugarcane, both economically and socially. Using this approach would require the impact of GM sugarcane on farms in other sugarcane producing regions. Additionally, looking at the broader project CBA can be used to answer questions of consumers' willingness to accept GM sugarcane. A private CBA is not appropriate because the objective is not to consider only the costs and benefits that accrue to SASRI.

2.4.1.1 Advantages and Disadvantages of Cost-Benefit Analysis

The advantage of using the CBA to analyse a project is that it makes clear the trade-offs that decision makers face (Finger *et al*, 2011). Once the costs and benefits have been properly assigned, the model is simple to interpret. The disadvantage of using the CBA is that data may not be readily available, which will cause the data to be skewed (Finger *et al*, 2011). Comparing the differences between the gainers and the losers may not always be achievable as the monetary value of the gainers and the losers may not be the same (Pasour & Rucker, 2005). Confounding factors, just like in other economic models, complicate the impact assessment of CBA (Sunstein, 2005). Risk is difficult to incorporate in this and that would be a major limitation of using this model for the purpose of this study as risk plays a role in decision making for farmers. The majority of the disadvantages of the model is the reason for its limitations.

2.4.1.2 Limitations of Cost-Benefit Analysis

CBA looks at the impact of a project along the entire supply chain, including all stakeholders. This project is smaller than a CBA. Because GM sugarcane could become available to growers throughout the SA sugar industry, it is not sufficient to only consider the on-farm impacts of GM sugarcane on commercial farms in the iLembe district for purposes of a CBA. It has also not considered the costs and benefits that accrue to other stakeholders. This does not diminish the value of the project, as details to answers to the important questions about the extent to which GM sugarcane is likely to be adopted on farms.

This study is smaller than a CBA. Suitable methodologies for the study are:

(a) Gross margin analysis (simple comparison of gross margins for conventional and GM sugarcane cultivars to determine which is more profitable). This, however, does not consider implicit costs of risk and ignores important considerations such as recommendations against planting more than 33% of a farm to a single cultivar.

(b) Partial budgeting techniques. These are also problematic because the impact on sugarcane cultivar mix and length of production cycle is exogenously determined.

(c) Mathematical programming (e.g., LP). This has strengths that representative farm models can first be verified before being used to consider an alternative scenario in which GM sugarcane is available. It therefore goes beyond GM analysis and is preferred to partial budgeting because it endogenously determines farmers' optimal combinations of sugarcane cultivars and production cycles.

One may argue that this study is smaller than a CBA, however, it is not smaller than a private economic CBA. In fact, the decisions at farm level could be conducted by comparing the firm-level costs and benefits of adopting GM sugarcane across a range of soil types for representative farms. The advantage of the LP approach is that this is done whilst also allowing for additional considerations such as limits to the extent of adoption of GM sugarcane (33%), as well as risk considerations, which are imperative at farm level decisions.

2.4.2 Representative Farm Modelling

Representative farm modelling has been widely used to analyse and solve problems since the early 1900s (Hazell & Norton, 1986). The process of selecting/aggregating representative farms is important in order to reduce aggregation bias (Dalgaard, *et al* 2006). This process includes clustering farmers according to a selected set of subjective criteria. This model aims to develop and validate the representation of the farm population. The modelling process is mostly based on the research questions (Kostov & McErlean, 2004). Representative farm models are commonly compiled using the Linear Programming (LP) technique. The use of the linear programming model has been useful in informing decisions and helped as a planning tool in agriculture, the environment and in resource economics (Beneke & Winterboer, 1984). Subsequently, mathematical non-linear programming is used because it minimises errors and it is more common with improving technology (Hazell & Norton, 1986). Mathematical programming models are used widely for agricultural economic policy analysis, engineering and hydrological fields. Even though there have been few methodological developments since the mid-1970s (Howitt, 1995) linear programming is useful at the farm, especially for models that will incorporate risk (will be discussed in detail in Chapter 3).

Farming is a complicated business. Complicated decisions have to be made throughout the year. Decision making in any crop farm includes, how the soil should be prepared, which crop to plant, how much labour to use and the optimal time to harvest (Kaiser & Messer, 2011). The use of LP at the farm level has been useful for farm managers and those responsible for decision making at the farm. It has been applied in capital budgeting, cost minimisation solutions, profit maximisation solutions, resource allocation problems and transportation solutions (Kaiser & Messer, 2011). At an industry level, LP has been used to analyse markets, assist in policy implementations and land use planning and forest management (Howitt, 1995). Institutions such as Universities and agricultural extension programs have offered different types of LP models to farmers to help them in the decision making process.

2.4.2.1 Advantages of Representative Farm Modelling

Use of a representative farm modelling approach has various advantages. These include the fact that researchers aggregate farmers according to the desired set of characteristics in order to account for the research question (Dalgaard *et al,* 2006). Additionally it is easy to understand and insert into the LP model. Linear programming is not only used in the representative farm modelling, but it can also be used by policymakers, mathematicians, statisticians, engineers and economists (Hazell & Norton, 1986). The advantage of using linear programming is its simplicity, and that it is easy to understand (Beneke & Winterboer, 1984). This technique can be used to solve many diverse combined problems (more than one problem simultaneously). It is recommended in re-evaluation processes: linear programming helps in changing condition of the process, or system. Ben-Tal & Nemirovski (2000) showed that using linear programming was advantageous as it is adaptive and more flexible to analyse the problems and it can be used to solve many diverse combination problems.

Linear Programming has the advantage of more easily incorporating costs of risk in the analysis, compared to econometrics methods (Hazell & Norton, 1986). Models such as MOTAD (Minimisation of Total Absolute Deviations), Baumol's E-L criterion and Game theory models take risk and uncertainty into account when used as a decision-making tool. This is helpful as many business decisions have a large amount of risk and uncertainty attached to them due to unforeseen circumstances and lack of full information. Other more recent techniques such as Stochastic Programming with Recourse is a technique that can deal with uncertainty in any of the model parameters. Mean-Variance models, Focus-Loss model and Chance Constrained Programming are more recent Non-Linear Programming (NLP) models used in agriculture. Risk, and LP risk models will, however be discussed in depth in the methodology chapter (Chapter 4).

2.4.2.2 Disadvantages and Limitations of Representative Farm Modelling

One of the most challenging steps of aggregating representative farms is to decide on how to aggregate them into representative farms and to balance the trade-off of aggregation bias vs. having too many farm models as homogeneity amongst farmers is complex. The subjective nature of deciding on the parameters to be simulated is also a disadvantage to the model. Additionally, the challenge of verifying the model is time consuming – and a question on why the model should be trusted to predict farmers' decisions has to be carefully viewed. Finally, the challenge of defining the two scenarios (the "with GM" vs the "counterfactual" (without GM)) and when it may be appropriate to use the baseline as the counterfactual in the LP technique is time consuming. The most crucial part of linear programming, which can be a disadvantage, is that it only works with variables that are linear; non-linear functions cannot be solved using this model (Hazell & Norton, 1986). Although the model is said to be simple and easy to use, it may be difficult to solve some problems which have more than two variables in graphical methods (Beneke & Winterboer, 1984). The linear programming model uses a static scenario, and therefore has the disadvantage that it does not consider change and evolution of variables. Because of this, the long term objective of the management cannot be resolved with a single goal (Hazell &Norton, 1986).

A limitation of using linear programming modelling is that in some cases both the objective function and constraints in linear form cannot be expressed (Kaiser & Messer, 2011). Linear programming is more restrictive than non-linear programming. It is mostly used to solve single objective problems (Hazell & Norton, 1986). Not clearly defining or understanding the constraints of the model can also be a major limitation as the problem can only be solved when there is a clear representation of linear relationships between different variables. It is therefore very important to understand the model, its limits and its constraints to help analyse the outcome. Additionally, there is however a gap in literature on methods used to assess impacts of perennial crops and livestock production, compared to annual crops; these findings agree with Alston *et al* (2015).

2.5 Summary

This chapter has identified the impact GM crops have had on farmers both globally and in the African continent. Furthermore, it highlighted important factors that impacted farmers' decisions on the adoption of any new technology. Two types of methods which have been used to analyse the data collected for the impact assessment of GM crops were stated. A limitation to this section is that most methods discussed are mostly methods applied on annual crops which use a comparative static analysis and do not take time lags into account. Additionally, most assessments are ex-post. This project is an example of an *ex-ante* assessment as GM sugarcane has not yet been developed and its characteristics are therefore assumed, based on expert opinion. Outcomes will be used to inform the decisions of the SASRI regarding the adoption of GM sugarcane in South Africa.

CHAPTER 3. BACKGROUND TO THE SOUTH AFRICAN SUGAR INDUSTRY AND SUGARCANE FARMING IN ILEMBE

Having considered the options in Chapter Two and having decided that this study will use a representative farm modelling approach, the purpose of this chapter is fourfold:

(a) To briefly discuss the heterogeneity of sugarcane production within South Africa (dryland vs irrigated, coastal vs inland, small-scale vs large scale). The purpose is to show that sugarcane farms cannot be meaningfully aggregated into a few representative farm models. Consequently, it is more appropriate to conduct a case study of one sugarcane producing region, and in this regard it makes sense to select a region where (a) *eldana* and *cynodon* are most prevalent, and (b) a region where SASRI intends the GM cultivar to be well suited.

(b) Having selected the case study region, it is important to provide background on that region, because it is relevant to compiling representative farm models for that region. This includes the climate, availability of water for irrigation, soil types, potential land uses, sugarcane production systems, small-scale vs large-scale, etc.

(c) Relevant background on *eldana* and *cynodon* and methods of controlling these pests in sugarcane farming in iLembe. This includes a discussion of sugarcane stalk anatomy and the biology of *eldana* to explain why *eldana* reduces RV yield and why it is so challenging to control.

(d) To identify socio-economic impacts of sugarcane farming over and above returns to farming, e.g., employment, environmental impacts, etc.

All of this information is important background for compilation of the representative farm models in the next chapter.

3.1 Sugarcane Farming in ILembe

Sugarcane farming has contributed significantly to the national to economic development in rural townships such as Tongaat in KwaZulu Natal, where many businesses have been established owing to the presence of sugarcane farming in the area (SASA, 2018). This industry provides direct and indirect employment, training and education, and research in science and technology. The agricultural sector is vital to the nation as it creates employment, alleviates poverty and ensures food security, including the iLembe district. Despite challenges of land distribution, minimum wage rate, cheap imports and changing climatic conditions the sector faces, the sugar industry continues to be the main source of economic development in rural sugarcane producing areas (Hussain & Khattak, 2011).

As is evident from Figure 3.1, the iLembe district is situated between Durban and Richards Bay, the two busiest ports in Africa. Despite its good economic position, allowing easy access to local and international markets, the district continues to face a number of economic challenges such as poverty in the hinterland regions, contrasting the development in the coastal regions. Major activities in the iLembe district include but are not limited to tourism, manufacturing, trade and accommodation, retail and agriculture. Agriculture is the primary use of land, with sugarcane being the dominant crop cultivated (Zulu *et al,* 2019). Other farming activities include fruit and vegetable farming and forestry. Diversification in the district is highly recommended as the decline in sugar production may pose a treat. The South African Sugar Association statistics show that there has been a decline in sugar production over the past decade. This has been attributed to changing climatic conditions, introduction of sugar tax, cheap imports and industrialisation (BFAP, 2017).

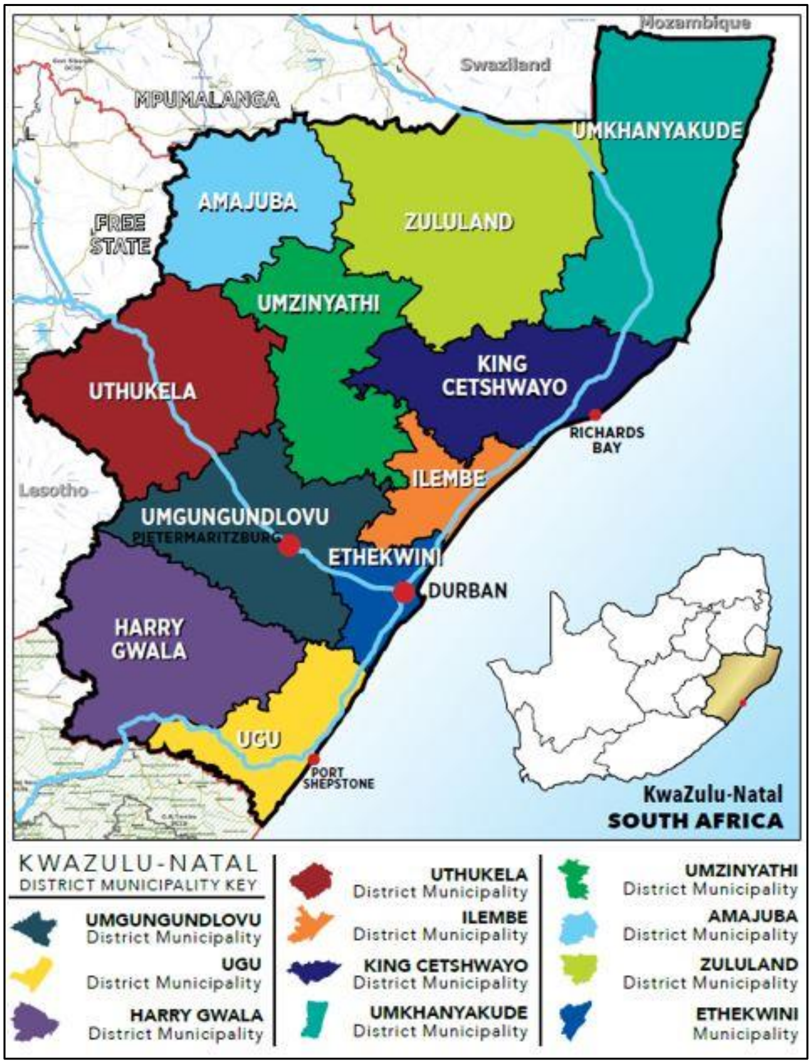


Figure 3.1 KwaZulu-Natal Map Showing ILembe District (Google Maps, 07 May 2018)

Even though sugarcane production and profitability is currently diminishing, the mills in the iLembe district continues to be feasible. Alternative uses of sugarcane such as ethanol and electricity production and animal feed (molasses) are currently being investigated (SASA, 2018). There are two mills in the iLembe district, namely Darnall and Amatikulu, producing Tongaat Hulett sugar. These mills have already started generating bagasse to generate steam and electricity.

3.2 Study Area Description

In this study the relative profitability of sugarcane cultivars, including a GM cultivar, are compared for farms in predominantly rain-fed, sugarcane growing regions of KwaZulu-Natal, i.e., the regions where *eldana* and creeping grasses are currently most problematic. The *eldana* population tends to increase with increasing average temperatures and humid areas such as the North Coast (Rutherford, 2015). Nonetheless, *eldana* has severely affected some inland regions, such as Eston, where its population is positively correlated to the occurrence of drought. Many farmers have adopted Pest Management Control practices to reduce populations of *eldana* on their farms (Nicholson *et al*, 2017), and regional chemical control of *eldana* was conducted as an attempt to address the rapid spread of *eldana* in 2016 (Botha, March 2018, *Pers.com*). This research is conducted on the North Coast, iLembe district of KwaZulu-Natal. Farmers who supply to the Gledhow Mill, which is situated Latitude: -29º21'21.96; Longitude: 31º17'36.96, are studied.

Common creeping grasses in the Gledhow cane supply areas are *Cynodon dactylon* and *Cynodon plectostachyus* (SACGA, 2018). Even though various weed management practices have been employed, the weeds are still prevalent in the sugarcane fields (Landrey *et al*, 1993). Commercial farmers eradicate this weed by cover spray, using the Glyphosate chemical, "Round-up" before they plant. However, the waiting period of four months before they can re-plant sugarcane delays their production (Naude, March 2018, *Pers.Com*), and hence reduces returns to sugarcane farming. The sugarcane production cycle differs between coastal and hinterland regions.

Farmers' preference for various sugarcane cultivars in the Gledhow cane supply area is investigated using two representative farm models: one for the coastal regions and one for more relatively inland regions of the coastal belt (hereafter referred to as the hinterland). The two sub-regions differ significantly by climate. Because the optimal cultivar of sugarcane is partly determined by soil, topography and micro-climate, for each representative farm the arable area suitable for sugarcane production was categorised into three of four 'land categories'. Table 3.1. presents a summary of the land resources for the two representative farms.

Historically, farmers in the region adopted relatively early maturing sugarcane cultivars in response to the increasing prevalence of *eldana* in the region, reducing the production cycle from 18-20 months to 12-14 months. More recently the availability of chemical control regimes to combat *eldana* has led to an increasing proportion of sugarcane in the region being produced on an 18-20 month cycle (Nicholson *et al*, 2017).

<u>Table 3.1 The arable land resources of the representative farms in the Gledhow cane supply area</u>

		Coastal farms	Hinterland farms
Sandy Soils	Proportion of arable Land	35%	10%
	Cane production cycle	13 -16 months	14-20 months
	Commonly produced cane cultivars	N41, N51, N52, N55, N58	N16, N31, N39, N41, N52, N54
	Opportunity cost of producing sugarcane	Macadamia nuts	Macadamia nuts
Loamy Soils	Proportion of arable Land	35%	90%
	Cane production cycle	14-18 months	14-20 months
	Commonly produced cane cultivars	N41, N51, N52, N55, N58, N59	N31, N41, N52, N54, N59
	Opportunity cost of producing sugarcane	Macadamia nuts/ Bananas	Bananas
Clay	Proportion of arable Land	30%	
	Cane production cycle	14-18 months	
	Commonly produced cane cultivars	N41, N48, N51, N54, N58, N59, N60	
	Opportunity cost of producing sugarcane	Macadamia nuts/ Bananas	

Source: (Adapted from Naude, 2018, *Pers.com,* March 2018).

3.2.1 The Opportunity Cost of Land

In addition to sugarcane, common opportunity costs (the next best alternative use) of land among farmers are macadamia nuts and bananas; other less common land uses are litchis and game ranching (Table 3.1). Farmers have stated that although the softer fruits like bananas and litchis may be profitable, they are generally not preferred to sugarcane partly due to risks of crop loss due to monkeys and birds, which tend to be a problem in the area, especially in the coastal area. Macadamia nuts are a high risk, high return crop. Many farmers perceive macadamias to be a good option to diversify their enterprises, but tend to plant less than 20% of their land to macadamia nuts. Once the macadamia nuts are established, the returns improve the liquidity of the farm business, which often enables improved management practices in sugarcane (Naude, 2018, *Pers.com*, March 2018), increasing yields and the profitability of the sugarcane enterprise.

3.2.2 Topography and Soil Types

One of the major benefits for sugarcane production in the North Coast is the excellent soils. The North coast has a variety of soil types, namely, the sandy beach soils which are highly acidic (mainly in the coastal areas), red loamy Hutton soils which are a mixture of sandy soils and clay (rich in iron-oxide), these soils have good water retention and are well drained. The third soil type is the dark Nomanci clay. Application of lime and gypsum at planting in this area can be as high as 25 tons/ha to address the high acidity depending on the area and the soil type (Naude, 2018, *Pers.com,* March 2018). According to Naude (2018, *Pers. com*. March 2018) some farmers add lime to a zero percent soil acidity (as opposed to the 20% that is recommended by SASRI guidelines) in order to reduce the susceptibility of the crop to *eldana* and to achieve higher yields.

Land categories vary from flat land compartments to more steep compartments with approximately 30-40 degree slopes. The flatter compartment is best suited for sugarcane production. While some farmers may produce sugarcane on the steeper soils, they are more suitable for orchard plantations as the soil is shallow and relatively more susceptible to being eroded. Because of this, some of the steeper, sandy soils land compartments are left idle.

3.3 The Sugarcane Stalk Anatomy and the Biology of *Eldana*

Sugarcane, scientifically known as *Saccharum officinarum*, is a tall, perennial grass that is adapted to warm, tropical and sub-tropical areas (DAFF, 2014). Sugarcane belongs to the Poaceae family and can grow up to four meters high (Kwenda, 2015). Sugarcane cultivars vary with respect to height, colour, hardness, and quality of sugarcane stalks (Tejera *et al*, 2007). The difference in stalk anatomy is a factor that makes sugarcane cultivars relatively more susceptible to *eldana*, while other cane cultivars are relatively more resistant to *eldana* (Rutherford, 2015).

A sugarcane stalk is divided by nodes, this is the point where leaves are attached, and internodes extend to the nodes (Kwenda, 2015). *Eldana* deposits its eggs between the dead leaves attached to the node and the mature sugarcane stalk (Walton & Conlong, 2016). Figure 3.2 illustrates where the *eldana* eggs are laid and the larvae hatch and spread in the stalk. The larvae then penetrate the waxed hard epidermal layer into the soft parenchyma cells, illustrated in figure 3.3, where it feeds (Rutherford, 2015). The larvae can extend to other internodes feeding on the sucrose content and thus decreasing RV% (Recoverable Value, a measure of sugar content) and increasing the fibre content of the stalk (Leslie & Keeping, 1996).

Figure 3.2 *Eldana* Egg Hatch and Disperse (Rutherford, 2015).

Figure 3.3 *Eldana* Larvae in Damaged Stalk (Rutherford, 2015).

Other similar borer species affecting the sugarcane industry include *Chilo partellus*, commonly known as the spotted stem borer, *Chilo sacchariphagus*, commonly known as the sugarcane internode borer and *Sesamia calamistic* (Sesamia) (Walton & Conlong, 2016). Conducting surveys and scouting for insects is advised by SASRI experts as it is advantageous, and information found can be used in decisions such as time of harvest, time to plough out and selecting sugarcane cultivars. This improves management practices as it increases insect activity awareness, provides up-to-date information on stalk damage levels and detects any problems early (Rutherford, 2015).

A background of the South African sugar industry was provided. Furthermore, farming in the iLembe district was described, highlighting sugarcane farming and the challenges of it. The study area was outlined. The anatomy of the sugarcane stalk and the biology of *eldana* were described, and other common pests that are problematic in the iLembe district were given. Chapters Two and Three are used as a base to develop the research methodology used for this study. This methodology is presented in the next chapter.

CHAPTER 4. RESEARCH METHODOLOGY

Having selected iLembe as a case study region and having provided relevant background on that region in the previous chapter, the objectives of this chapter are to present the methodology for compiling one or more representative farm models for sugarcane farming areas of iLembe, and then to explain how those representative farm models can be used to determine the impacts of GM cane. The chapter starts with a brief introduction to farm decisions under risk and how this may be modified using linear programming.

Because this is an *ex-ante* study, findings of a GM sugarcane scenario need to be compared against those of a counterfactual (a scenario without GM sugarcane). In order to estimate either scenario, a mathematical programming model must be compiled for that purpose. Importantly, the model must be verified to provide confidence in the outcomes projected for the GM sugarcane and counterfactual scenarios. An approach to model verification is to optimise the model for a current or recent scenario and then, in conjunction with farmers and SASRI extension staff, to compare the outcomes predicted using the model with actual outcomes. The model is verified if it predicts current and/or recent scenarios accurately, and may then be used to predict outcomes in other scenarios.

The first section of this chapter provides background to the study area and the data collection process. A discussion of the compilation of the LP model, including its assumptions and limitations, is presented thereafter.

4.1 Data Collection and Description of Participants

The first step in compiling the model was to select a case study area for the study and then to gain familiarity with the case study location with the objective of aggregating farms that are similar with respect to characteristics such as farm size, location (climate), technology available and soils. The purpose of this was to identify a relatively small number of representative farm types that account for the majority of sugarcane producing farms in the area. The method of this aggregation process first entailed meetings with various experts on *eldana*, *cynodon* and plant breeders, as well as stakeholders and their representatives (e.g., SASRI and the South African Canegrowers'

Association (SACGA)) to introduce the project, to understand the nature of the *eldana* and *cynodon* problems in sugarcane farming, and to identify a suitable case study region for the study. The outcome of this process, as indicated in the previous chapter, was to select the iLembe Region as the case study locality. The next step involved meetings with SASRI and SACGA staff in the iLembe region to identify relatively homogeneous groupings of sugarcane producing farms in the region. The identification of two groupings (the coastal regions and the hinterland) is discussed in the previous chapter. This was followed with further discussions with the SASRI and SACGA regional staff to identify and invite a cohort of farmers from each of the two regions to participate in focus group discussions used to elicit information to compile and verity representative farm models for each of the two regions. A purposive non-probability sampling technique was used to identify seven (7) commercial sugarcane growers to represent each of the coastal and hinterland regions. Characteristics that guided the farmers' selection included record keeping, diversification, growing of different cultivars and willingness to disclose information. The attributes of the focus group discussion included:

- A group of 7-10 individuals per representative farm,
- The individuals have farms with similar characteristics, e.g, size, resource base, and climatic zone,
- A discussion of 45-90 minutes per section,
- The discussion was recorded by means of audio-tape,
- The discussion focused on the general consensus, rather than on individual perspectives of the individuals, and
- Participants were given time to reflect on the discussion topics, and opportunities to present their opinions, and to respond to the comments of other group members.

The project initially aimed to include both smallholder, medium scale, and commercial farmers for the study. Limitations to the study included; the lack of willingness of some farmers to participate owing to the shift in the structure of the industry and management in the North Coast area. There was a sense of uncertainty and unease among farmers. The data collection period was in the peak of the harvesting season, which also decreased interest for farmers to participate.

Because of the characteristics that guided the farmers' selection for the focus group discussion, smallholder and medium scale farmers could not be included in the study. SACGA staff highlighted challenges such as lack of knowledge on bookkeeping and financial and management techniques (Naude, 2018, *Pers.com,* March 2018) on smallholder and medium scale farmers. Even though smallholders may benefit the most through this project, there are other challenges that require immediate attention and further research.

In the 2016/17 season, 2 752 183tons of sugarcane were delivered to the mills in the North Coast, from this 2 090 206 tons were delivered by commercial farmers. This accounts for 75,95% of the total sugarcane that was delivered to the mills in that season, while 24,05% was delivered by smallholder and medium scale farmers. The project, therefore, focussed on commercial farmers for the purpose of this study as they deliver the majority of sugarcane to the mill. The outcome of the study is sufficient to inform SASRI.

4.2 Background of the Model

Risk is an important factor to include in the model because producers do not have perfect information. Because of this they bear income risk resulting from variable yields and prices (Hazell & Norton, 1986). Studies by Ferrer *et al* (1997) and Mac Nicol *et al* (2007) have found that the majority of commercial sugarcane farmers in South Africa are risk averse, confirming that accounting for risk and risk preferences in decision-making is important when analysing production decisions on commercial sugarcane farms. Risk-averse farmers maximise utility producing portfolios of enterprises for which the returns are not highly correlated and/ or by adopting other production, marketing, and financial studies to manage their business and financial risks (Barry *et al,* 2000).

Baumol's E-L criterion, which assumes that decision-makers aim to maximise their utility (L), is suitable for this purpose and it enables "fine-tuning" of representative farm models (Hazell & Norton, 1986). It accounts for risk and uncertainty by estimating the standard deviation of the farm gross margin from historical enterprise gross margins, and weighting this by a risk aversion coefficient (ϴ) to estimate the cost of risk taking for the farm plan, where higher values of ϴ indicate relatively more risk averse behaviour. The model is optimised to find the farm plan with the greatest value of L, where L is the expected farm gross margin less its cost of risk. Because ϴ is not known with certainty, minor adjustments may be made to the coefficient to improve the accuracy with which the model predicts the outcomes of a known scenario, i.e., to “fine-tune” it (Kaiser & Messer, 2011; Hazell & Norton, 1986; Beneke & Winterboer, 1984).

4.3 Description and Compilation of Enterprise Budgets

North Coast planting cost, ratoon management and harvesting costs (Appendix 1, 2 and 3) were extracted from the SACGA website and modified in the focus group discussions with farmers (as described in section 4.3) to compile enterprise budgets that are a reflection of farmers in the Gledhow milling area. Additionally, an *eldana* cost schedule was compiled through focus group discussions. The costs of chemical control of *eldana* were accounted for using the costs of applying Coragen Chlorantraniliprole, because it is currently the most common method of chemical control of *eldana* in the Gledhow area. For the purpose of analysis of the cost value, it is assumed that a GM sugarcane cultivar with IR and HT traits, is hypothetically available. Scenarios were developed to analyse the difference between chemical costs of conventional sugarcane (Scenario 1) and GM sugarcane (Scenario 2) in Table 4.2. This scenario has been done for a hypothetical farm in the Gledhow milling area firstly to analyse the total cost of *eldana* control and secondly, the results are used in the enterprise budgets, where gross margins are analysed, for different production cycles (Table 4.3). A similar approach is used to compile herbicide costs using the normal spraying program based on the South African Canegrowers’ Association planting and ratoon management cost for the 2017/2018 season (SACGA, 2018). For conventional sugarcane, the cost is calculated to be R2589 per hectare, while for the GM cultivar the cost is R1851 per hectare at planting. At ratoon, these costs are calculated to be R731 per hectare for conventional sugarcane, and R182 per hectare for GM sugarcane (Appendix 4).

The same control agent is used for both scenarios, the major difference is in the application rate. An area that has a high population E-count (a measure of *eldana* population) is sprayed three (3) times on average annually (Naude, 2018, *Pers.com*). With the IR trait on the GM cultivar, it is assumed that *eldana* would be chemically controlled once annually if need be. Scouting of *eldana* is done approximately 15 hours annually, in a field that has low *eldana* population (GM sugarcane field); scouting may be reduced owing to less *eldana* population

Table 4.1 Comparison of *eldana* Chemical Control Scenarios

	Normal Spraying Programme										
Scenario One	**Chemical**						**Labour Cost**			**Total Cost**	**Total Cost/Yr**
	Operation	*Eldana* Control Agent	Application Rate (L/ha)	Herbicide Cost (R/L)	Frequency	Herbicide Cost (R/ha)	Labour Cost (R/hr)	Mandays (hr/ha)	Labour Cost (R/ha)	(R/ha)	
	General Spray	Coragen Chlorantraniliprole	0.2	2300	2	920	16.25	2	65	985	2955
	Scouting	5 labourers@ 3hours					Scouting is done by Ext Staff at no additional Cost.				

	GM Cane										
Scenario Two	**Chemical**						**Labour Cost**			**Total Cost**	**Total Cost/Yr**
	Operation	*Eldana* Control Agent	Application Rate (L/ha)	Herbicide Cost (R/L)	Frequency	Herbicide Cost (R/ha)	Labour Cost (R/day)	Mandays (Days/ha)	Labour Cost (R/ha)	(R/ha)	
	General Spray	Coragen Chlorantraniliprole	0.2	2300	2	920	16.25	2	65	985	985
	Scouting	5 labourers @2hours					Scouting is done by Ext Staff at no additional Cost.				

Source: (Adapted from Gledhow Commercial Farmers, 2018, *Pers.com*).

Appendix 1, 2, 3 and 4, including results obtained in Table 4.1, are used to compile an enterprise budget for each sugarcane cultivar under each production cycle. These results are used in a production cycle sensitivity analysis (on Excel) to extrapolate the results over a sugarcane production cycle from planting, through numerous ratoons, to plough out. The sugarcane production cycle used in the analysis is the 14-16 month cycle and the 18-month cycle. The assumed months are based on the effect *eldana* has had on the North Coast sugarcane farmers (refer to Chapter 2). This analysis is done in order to identify potential net gains per hectare under cane for each production cycle, and including that of a GM cultivar. Following recommendations by SASRI biotechnologists, for the purpose of this study, N52 is hypothetically modified as GM sugarcane by assuming a cultivar of sugarcane that is similar to N52 but also has the IR and HT traits. N51 is a secondary cultivar selected and hypothetically modified with IR and HT traits as it is a cultivar suitable for the coastal area. It is assumed that in the Gledhow cane supply region these cultivars will be produced on an 18-month cycle.

A description of a possible GM cultivar of sugarcane that has both the IR and HT traits, including how its production is expected to differ from production of conventional cultivars (e.g. a change in application of chemicals to control pests), and its expected performance (yield distribution) across various categories of arable land on each of the representative farms is compiled. The IR and HT traits are expected to improve the cane yield by 5% and 2%, respectively above that of the conventional cultivars to which full chemical *eldana* and conventional weed control are applied. Additionally, RV% is assumed to increase by 1 unit for the GM cultivar due to superior *eldana* control (Rutherford 2018, Pers. Com). N52 cultivar is therefore modified with these traits in the different subject fields. Table 4.2 compares gross margins of N52 on 14-16 month and 18-month production cycles with the GM cultivar on a typical farm in the Gledhow area.

Table 4.2 Example of an enterprise budget prepared for the coastal representative farm in the Gledhow cane supply region.

	Cane cultivars	N52[1]	N52[2]	GM[2]
	% area under cane /annum:			
a	Area harvested	75,00%	66,67%	66,67%
b	Area planted	10,00%	11,11%	11,11%
c	Area ploughed out	10,00%	11,11%	11,11%
d	Area green manured	7,50%	8,33%	8,33%
e	Area Ratooned	63,75%	55,56%	55,56%
f	RV price per ton	4502,98	4502,98	4502,98
g	Average yield cane (Tons/Ha harvested)	67	78	83,46
h	RV%	0,121	0,123	0,133
i	**Gross Income/ha under cane (a*f*g*h)**	**27 379,21**	**28 801,03**	**33 322,59**
	Planting costs per ha planted			
j	Land preparation	3253	3253	3253
k	Hand planting	3463	3463	3463
l	Seed cane	8520	8520	8520
m	Fertiliser and lime	4042	4042	4042
n	Weed control	2588,97	2588,97	1850,49
o	Sundries and contingencies	3354	3354	3354
p	**Total (j+k+l+m+n+o)**	25220,97	25220,97	24482,49
q	**Planting costs/ha under cane (b*p)**	**2522**	**2802,33**	**2720,28**
	Harvesting costs per ha harvested			
r	Cutting of burnt cane	3937,59	4584,06	4904,94
s	Infield-cane haulage	1693,76	1971,84	2109,87
t	Loading and transhipment of burnt cane	939,34	1093,56	1170,11
u	**Total (r+s+t)**	6570,69	7649,46	8184,92
v	**Harvesting costs/ ha under cane (a*u)**	**4928,02**	**5099,64**	**5456,61**
	Ratoon management (RM) costs: Dryland cane early harvest			
	Field management	528.28	528.28	528.28
x	Fertilizer	3232,97	3233,00	3233,00
y	Weed control	730,97	671,07	181,52
z	**Total (w+x+y)**	4492,22	4492,25	3942,80
aa	**RM costs/ ha under cane (e*z)**	**2863,79**	**2495,69**	**2190,45**
ab	Green manuring (Gm)	3106,87	3106,87	3106,87
ac	**Gm/ ha under cane (d*ab)**	233,01	258,91	258,91
ad	***Eldana* control/ ha under cane**	1970	2955	985
ae	**Total Costs/ ha under cane**	13502	13612	11611
	Gross margin per hectare (i-ae)	**14862**	**15223**	**21711**

[1]14-16 month cutting cycle

[2]18 month cutting cycle

The analysis was extended to include additional sugarcane cultivars, as advised by SASRI extension staff in each of the two representative farms. The findings are summarized in Table 4.3, which reports the performance of the best two cultivars and a hypothetical GM cultivar in different soil types. A detailed enterprise budget comparing cultivars which are used in Linear Programming farm models is attached in the Appendix List (Appendix 5).

Table 4.3 Comparison between the gross margins of GM cultivars against the best performing conventional cultivars in Gledhow on an 18-month production cycle.

Locality		Land Category	Expected Gross Margin of GM cultivar	Best performing non-GM cultivar	Second best non-GM cultivar
			Gross Margins in R/Ha under cane		
Gledhow	Coastal Area	Sandy Soils	**GM: R 20 452**	N52: R15 145	N41: R14 542
		Loamy Soils	**GM: R 21 711**	N52: R15 223	N41: R14 152
		Clay Soils	GM: R 21 015	**N59: R21 125**	N52: R15 124
	hinterland	Sandy Soils	**GM: R 20 458**	N52: R16 246	N41: R14 528
		Loamy Soils	**GM: R 21 895**	N52: R17 056	N59: R15 562

Source: (Adapted from Gledhow Commercial Farmers, 2018, *Pers.com*).

4.4 Compiling the Linear Programming Model

Section 2.4 highlights the useful planning methods used for representative farm modelling and the usefulness of the Linear Programming technique. Linear programming models consist of different elements which together allow users to formulate results.

4.4.1 The Objective Function

The objective of the model, i.e., what will be optimised subject to various constraints, must be clearly identified. In this study it is assumed that the primary objective of commercial sugarcane farmers is to maximise their utility from sugarcane farming, where utility is positively related to the farm gross margin, but negatively related to variation in the farm gross margin (risk) if farmers are averse to risk taking. Baumol's E-L criterion model maximises farm gross margin less a premium for risk taking that is, in part, determined by a risk aversion coefficient (Θ). Risk is treated as a cost in the objective function by weighting the standard deviation of farm gross income, the risk aversion coefficient, Θ. It is therefore suitable for stating the objective function of the representative farm models in this study. The mathematics of how the standard deviation of farm gross income is computed is explained in Section 4.4.4.

4.4.2 Identification of farm Activities

The primary objective of a representative farm planning model is to identify the optimal use of resources of a typical or representative farm. In particular, the allocation of the farm's most binding resources (e.g., land) to land uses (i.e., enterprises) is important. Therefore, activities of the model will include enterprise production activities. Understanding these enterprise production activities, including the selling and accounting activities is important for building representative farm linear programming models (Hazell & Norton, 1986). For example, correct specification of the activities and their timing in the production cycle is important, not only for estimating the costs of production, but also for correctly specifying the resource constraints. Because the timing of production activities, costs of production and yields will differ for the same cultivar of sugarcane produced on a 16-month harvesting cycle versus an 18-month harvesting cycle, or produced on different land categories, the various production options must be specified as different production activities. In this study, the sugarcane production activities of particular interest are those that are expected to be different for sugarcane farming with GM cultivars relative to farming sugarcane using conventional cultivars. These include the length of production cycle and activities related to the control of weeds and *eldana*. The enterprise budgets presented in Table 4.2, for example, show sizable differences in costs of production of conventional and GM sugarcane due to differences in the costs of weed and *eldana* control.

Other activities are also included in the model. The values of some of these are mathematically derived from the values of the land use activities, e.g., the number of tons of GM sugarcane sold is a function of the number of hectares of land planted to GM sugarcane cultivars. Other activities are accounting activities that do not impact on the objective function of the model, but their values provide useful information, e.g., the number of hectares of sugarcane land that are subjected to chemical control of *eldana* or weeds.

4.4.3 Setting Farm Constraints

Unless resources are limited, or restricted, Linear Programming problems would not exist (Kaiser & Messer, 2011). Constraints represent the limited resources (inputs) in the farm taking into account the activities which are used to optimise the objective function. Constraints can be subjected to inequalities such as maximum amount (≤), a minimum amount (≥), or a linear function (=) (Hazell & Norton. 1986). Land is the main limiting resource for sugarcane farmers in the Gledhow milling area. It is assumed that capital is not constraining, and that additional labour may be hired when required. Land quality varies, so farmland is divided into various categories each with its own constraint, as shown in Table 4.4 (Hazell & Norton, 1986). While fixed resources such as land and labour may be considered the main constraints of a model, there are subjective and institutional constraints (Kaiser & Messer, 2011). Taking into account the Local Pest, Disease & Variety Control Committee Rules from SASRI, a constraint stating that no single cultivar should be more than 30% of the total area planted to sugarcane was added to the model. According to Gledhow Commercial Farmers (2018, *Pers.com* March 2018), although the rule is not enforced, farmers in the region tend to adhere to it as a "recommendation". Additionally, the high returns on macadamia nuts and banana production have led to constraining the opportunity cost to 20% of total arable land. According to Gledhow Commercial Farmers (2018, *Pers.com*, March 2018), most farmers in the area tend to limit the area planted to macadamias to less than 20% of their arable land because it is perceived to be risky owing to the relatively lengthy payback period for investments in macadamia orchards and uncertainty about the export market price for macadamia nuts in the medium- to long-term. Farmers agree with this constraint, as they stated that it would be risky to decrease area under cane (AUC) to macadamia owing to the future uncertainty of the export market because that is their target market.

Table 4.4 Mini –Tableau for land use in the hinterland of the Gledhow milling area, 2018.

	Activities												
	Cultivars on S.S[2]	Cultivars on L.S[3]	Cultivars on C.S[4]	GM cultivars on S.S	GM cultivars on L.S	GM cultivars on C.S	SS Macs	LS Macs	LS Banana	Clay Macs	Clay Banana	…	RHS
Sandy soil (ha)	1			1			1						L100
Loamy soils (ha)		1			1			1	1				L120
Clay soils (ha)			1			1				1	1		L180
⋮													⋮
Gross Margin (R)	(14 766.82)	(14 781.41)	(14 798.51)	(13 518.47)	(14 798.51)	(13 518.47)	14 577.18	20 747.19	2 266.55	23 087.80	2 266.55	…	MAX!

[2] Sandy Soils
[3] Loamy Soils
[4] Clay Soils

Land is the most limiting factor on sugarcane farms. An average commercial farm is approximately 400ha (SACGA, 2018; Naude, 2018, *Pers.com*, March 2018). Farmers are expected to allocate enterprises to each category of farmland with the objective of maximising their utility, where utility is assumed to be positively related to expected returns and negatively related to variability in returns. In this regard, production of the same cultivar of sugarcane on two different categories of land is considered to be separate activities, and production of two different categories of sugarcane on the same land category are considered to be different activities. The approach used for including this in a LP model is shown in Table 4.4. Each category of land may be allocated to particular activities (production of sugarcane cultivars or other land uses). The RHS values for the various categories of farmland in Table 4.4. are computed from the average farm size of 400ha and the proportion of arable land categories for a typical coastal farm indicated in Table 3.1 .

Table 4.5 is a mini tableau showing how labour requirements and the costs of *eldana* control and weeding are included in the model. Importantly, the costs of *eldana* control and weeding costs are separated out from the enterprise gross margins in the objective function in order to estimate these cost items separately. The purpose of doing this is to analyse the change in these costs in a GM sugarcane scenario relative to a non-GM sugarcane counterfactual scenario. The cost of *eldana* chemical and physical (scouting) control is shown in Scenarios 1 and 2 of Table 4.1. The differences in the conventional weeding control and GM weed control mainly attributes to the HT trait in GM sugarcane. On conventional sugarcane, herbicides are applied at planting, pre-emergence, post-emergence and spot spraying and hand weeding when required. On GM sugarcane herbicides are applied at planting and spot spraying when required (refer to appendix 4). This is one of the reasons that the costs of sugarcane production vary by sugarcane cultivar in Table 4.4. The full matrix shown in Appendix 6 shows how each sugarcane cultivar performs in each land category. Table 4.5 uses an average of all gross margins of common cultivars used in the North Coast from appendix 5. Total revenue (TR) of the alternative crops have been inserted in the objective function because the main focus of the study is sugarcane.

Sugarcane production requires an average of 370 hours of labour per year for conventional cultivars and 300 hours per annum for GM cultivars. The decrease in labour requirements are attributable to less time spent scouting and spraying for *eldana*, and less time spent on manual or chemical weed control. These tasks are typically conducted by permanent workers. Additional labour is commonly hired at peak season (harvesting and planting).

Table 4.5 Mini –Tableau presenting labour, *eldana* and weeding of sugarcane cultivars for hinterland representative farm, 2018.

	Activities									
Constraints	Cane cultivars including GM grown/ha			Labour hire (days)	Chemical control (R/ha/Yr)	Chemical control GM (R/ha/Yr)	scouting (hours/ha)	Weeding conventional (R/Yr)	Weeding in GM cane (R/Yr)	RHS
	Conventional Sugarcane	GM sugarcane	….							
Labour (hours)	370	300		-1						E0
Eldana Chemical Control (R)	2955				-1					E0
Eldana Chemical Control GM (R)		985				-1				E0
Eldana physical control: scouting	15	10					-1			L1000
Weeding Conventional (R)	5534.36							-1		E0
Weeding GM (R)		2458.63							-1	E0
⋮										⋮
Gross Margin (R)	(15 142.50)	(21 711.)			-1	-1		-1	-1	Max!

The selling activity (transfer rows) allows the output of one activity (e.g. the growing of sugarcane) to be transferred into another activity (e.g. selling sugarcane at RV price) (Beneke & Winterboer, 1984). Transfer rows are used to link production and selling activities. Table 4.6 shows how transfer rows are used to determine the total tonnages of conventional and GM sugarcane produced on the farm. For example, one hectare of conventional sugarcane is assumed to yield an average of 62.17t of sugarcane each year. These activities are accounting columns as they do not have a value in the objective function. Revenue from sugarcane is accounted for by determining the total Recoverable Value (RV) tonnage from sugarcane production. RV produced using conventional sugarcane cultivars is not differentiated from RV produced from GM cultivars as it is assumed that sugarcane millers are indifferent between conventional sugarcane and GM sugarcane, and that both are paid according to its RV content.

Since 2000, South African sugarcane farmers have been remunerated for their sugarcane according to the Recoverable Value (RV) Cane Payments system (SAGCA, 2018). The RV payment system was adopted to create an incentive for farmers to produce better sugarcane quality i.e. to maximise sucrose content while minimising fibre and non-sucrose content. Due to the RV payment system, harvested tons of sugarcane is transferred to RV tons using an RV% (approximately 12.5%) extracted from Cane Testing Services (CTS) data. There has been a gradual increase in RV price per ton for most seasons since the implementation of the new payment system until the 2015/2016 season. However, in the 2017/2018 season, the RV price sharply decreased (SAGCA, 2018). The decrease of the RV price is due to exogenous factors such as increased imports, distorting local sales, and the implementation of Health Promotion Levy (HPL), reducing the demand for sugar. Endogenous factors include decreased sugarcane quality owing to *eldana* infestation poor farm management, and weeds competing for nutrients in the soil (Rutherford, 2015). Following the fluctuating price trends of RV, real RV price average was used in the objective function of the model as shown in Table 4.6.

Table 4.6 Mini –Tableau for transfers of sugarcane and its opportunity cost of land, on hinterland representative farm, 2018.

	Activities										
Constraints	Cane variety grown/ha		Macs (ha)	Banana (ha)	…	Conventional sugarcane (t)	GM sugarcane (t)	RV Sales (t)	Macs (t)	Banana (t)	RHS
	Conventional Sugarcane	GM sugarcane									
Conventional transfer (t)	-62.17					1					E0
GM cane Transfer (t)		-66.54					1				E0
Cane: RV Conversion (t)	-8.3	-8.92						1			E0
Macadamia nuts transfer (t)			-6						1		E0
Banana transfer (t)				-23						1	E0
⋮											⋮
Gross Margin (R)								4583.48			Max!

SASRI's recommendation is that no single cultivar of sugarcane should account for more than 30% of the area under sugarcane on a farm. Table 4.7 is a mini-tableau that shows how this constraint is incorporated into the model. It shows that a separate constraint is included for each sugarcane cultivar. For example, the N52 constraint in Table 4.7 indicates that the area under all other sugarcane varieties must exceed twice the area under N52. In other words, the N52 cultivar cannot exceed 33.3% of the area under sugarcane. Likewise, the GM N52 Constraint specifies that the GM N52 cultivar cannot exceed 33.3% of the area under sugarcane.

The mini-tableau in Table 4.7 also shows how the constraint that the area under the opportunity cost of land (bananas or macadamias) cannot exceed 20% of the area planted. For example, the Macs Constraint specifies that 0.8 times the area under macadamias must be less than a quarter of the area under all other land uses, i.e., no more than 20% of the area farmed may be planted to macadamias.

Table 4.7 Mini –Tableau for crop constraints planted in a Coastal representative farm, 2018.

	Activities							
	Sandy soils			Clay soils				
Constraints	SS N51	SS N52	SS GM N52	CL N52	CL N59	CL GM N52	Macadamias	RHS
N51 Constraint	-2	1	1	1	1	1		G0
N52 Constraint	1	-2	1	-2	1	1		G0
GM N52 Constraint	1	1	-2	1	1	-2		G0
Macs Constraint	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	0.8	L0

4.4.4 Baumol's Model

Table 4.8 is a mini-tableau that shows how risk and risk preferences are included in the model using Baumol's Criterion. Farming is a risky business because producers do not have perfect foresight information, because of this they bear income risk resulting from variable yields and prices (Hazell & Norton, 1986). In a perfect market process, those that better anticipate the future conditions such as drought, changes in government policies and regulations, and input and output prices, minimise uncertainty and risk (Hardaker *et al*, 2015; Pasour & Rucker, 2005). A study by Mac Nicol *et al* (2007), analysing the perceptions of key business and financial risks by commercial sugarcane farmers in KwaZulu-Natal, identified risk factors including the threat of land reform, minimum wage legislation and the variability of the sugar price as being key risk factors affecting farmers. Risk-averse farmers maximise utility producing portfolios of enterprises for which the returns are not highly correlated and/or by adopting other production, marketing, and financial approaches to manage their business and financial risks (Barry *et al*, 2000).

Historical data on yield and price are required to construct the risk component of Baumol's model. Using the producer price index (PPI) for agricultural products, real prices (gross margins) were calculated to 2018 values. PPI was used because its primary use is to deflate income streams, which helps measure the growth of outputs. Real prices were calculated using Equation 1 as follow:

- Real price per ton produced = Nominal Price $_{current}$ *(PPI $_{base}$/PPI $_{current}$)………(1)

  Where the base year is 2018

The PPI for agricultural products was used for price comparison purposes amongst sugarcane, banana and macadamia nuts. Deviations in the gross margins per sugarcane cultivar using data for six seasons are presented (Season 2012/2013-Season 2017/2018). These years were chosen considering factors that can affect production such as drought, inflation, and opportunity cost**.** Six seasons were used to minimise understating or overstating risk impacts. Using data for the past six seasons constitutes a better representation of the probability distribution of risk.

Table 4.8 presents the risk component of Baumol's model. T1-T6 are the time periods, while D1-D6 measures deviations in the time period. Deviations are calculated by subtracting the real average gross margins from the real current time period. For example, to calculate D1, an average gross margin of six years would be calculated. The average would be subtracted from the gross margin of the first year to get D1. “F”, the conversion factor is used to convert 0.5TAD to the standard deviation (Hazell & Norton, 1986). A conversion factor of 0.26 is included in the model and is, calculated using Equation 2, below:

- $F = 2\Delta^{0.5}/T$ ………………………………………………………………………….(2)

  Where $\Delta = \pi T/2(T-1)$

  and T=Number of years

Generally, farmers are risk-averse, as a consequence, they always strive to minimise risk. The risk aversion coefficient, Ɵ, is not known by advisers beforehand. Instead, farmers are asked to choose a farming plan from a risk-efficient farm planning set, thereby revealing their risk preferences (Hazell & Norton, 1986). Risk aversion coefficient will vary with each management decision. Baumol’s model treats risk as a cost that is weighted by Ɵ, therefore, the larger Ɵ, the heavier the weight attached to risk and the less risky the farm plan will be. Using the Statistics t-table, the probability of the favourable outcome is estimated at 85%, giving Gledhow farmers the risk aversion coefficient of 1.036 (shown in Table 4.8).

Table 4.8 Mini –Tableau accounting for risk of adopting GM sugarcane on hinterland representative farm, 2018.

	Activities								
Constraints	Production per ha			…	D1 (R)	D2 (R)	0.5TAD (R)	SD (R)	RHS
	SS N51	SS GM N51	LS Macs						
GM deviations									
T1 (R)	1053.23	952.54	-4388.82		1				G0
T2 (R)	-438.24	-534.33	-115.48			1			G0
T3 (R)	-1470.96	-1386.15	182.25				1		G0
⋮									⋮
Sum (R)					-1	-1	-1		E0
Conv (R)							-0.26	1	E0
OBJ: L= E[GM]-θσ	-14759.5	-13297.37	20747.19	…				-1.036	MAX!

Finally, Table 4.9 is a mini-tableau that shows how a constraint is included in the model to allow selection of GM sugarcane cultivars when its RHS is set to “greater than or equal to zero” and disallows selection of GM sugarcane cultivars when its RHS is set to “equals zero”. The purpose of this constraint is to include GM cultivars for a with GM cane scenario, but to exclude GM cultivars for the counterfactual scenario.

4.5 Verification of the Model

Model verification is an important step in a study as it gives confidence in the results. This is a process of ensuring that the model is designed with adequate accuracy and is able to demonstrate that it is representative of the ‘real world’ (Robinson, 1997). Although one can argue that a perfect accuracy is not possible to achieve when simulating a model, the purpose of verifying is to be as accurate as possible, ensuring that clear, and easy to understand. According to Robinson (1997), model verification includes four steps, namely, conceptual model validation, data validation, white-box and black-box validation.

Conceptual verification includes ensuring that the model restrains all required details to meet the objective of the study. In this step, the scope of work and assumptions of the study are clearly stated (Pidd, 1996). Data verification is ensuring that the data required to build the model is valid and sufficiently accurate (Robinson, 1997). White-box verification is a step where the study is validated at a micro level; each component of the model is validated against the ‘real world’ scenario. While black box determines the accuracy of the overall model (Robinson, 1997). If the model cannot be verified, further modification and improvement are required until it meets the required level.

The analysis of this study is verified in three major ways. The first step included comparing the dominant sugarcane cultivars from raw sugarcane data in the CTS against the cultivars the model picked in the two representative farms. This was done to verify the model, ‘without the GM’ scenario. Furthermore, a focus group discussion was held with the commercial farmers to validate the findings of the model. Lastly, a sensitivity analysis was run to test the stability of the key variables.

To determine the accuracy of the model, a comparison between baseline scenarios, where GM sugarcane is not included in the model is run using the constraint in Table 4.9. The mini-matrix shows how a constraint is included in the model to exclude adoption of GM sugarcane cultivars. Running the model for the second time removing the constraint includes the GM sugarcane cultivars in the solution. Because not enough is known about the likely "with" and "without" GM sugarcane scenarios ten years from now, when GM sugarcane will become available, the analysis is based on a "current scenario with baseline scenario is used as the "without GM sugarcane" scenario, and a "baseline plus GM sugarcane" for the "with GM sugarcane scenario".

Both the representative farm models in the Coastal and Hinterland of the Gledhow milling area depicted the current scenarios of the sugarcane cultivar distribution (Naude, 2018, *Pers.com*, March 2018). There is however slight variation in the proportions of each cultivar planted in hectares, due to the limited cultivars used in the model. Only sugarcane cultivars that were common amongst farmers were used in the model. The representative farm models were then run including the GM sugarcane cultivar, excluding the "without GM" constraint. The full LP matrix of the representative farms are presented in Appendix 6 and 7.

Table 4.9 Mini-Tableau for GM sugarcane cultivar constraint to verify the model.

	Activities			
Constraints	grown/ha			
	Conventional sugarcane	GM sugarcane	Opportunity cost	RHS
Without GM		1		E0

4.6 Limitations and Assumptions of the Model

The primary limitation of this study is that the cultivar of sugarcane that will be used to develop a GM cultivar had not been decided at the time the study was conducted. Consequently, the traits of the GM sugarcane cultivar have been assumed based on discussions with various experts.

Another important limitation to the study is that the development and roll-out of a GM sugarcane cultivar will take approximately 10 years. It is likely that within this period there will be various advancements in pest management control, the rollout of new conventional sugarcane cultivars, and new pests in sugarcane production, amongst other possible changes. These are currently unknown, so the scenario for which the profitability of GM sugarcane is compared to that of other sugarcane varieties in this study is largely based on a ‘current scenario’.

Data used on the gross incomes of bananas and macadamia nuts are also a limit to the study. Contrary to sugarcane, data collected on the alternative crop was not easily accessible, and data that was used is not a good presentation of Gledhow farmers’. Additionally, Baumol's model only accounts for price and yield risk. Even though risk of sugarcane is well accounted for in the data incorporated in the model, risk such as future market uncertainty, and losses due to theft and monkeys, for the alternative crop is not accounted for. Due to this, risk for the opportunity cost may be understated.

Additionally, there are other non-pecuniary factors farmers are likely to consider that may not be accounted for in this study. These include the differences in time management between each cultivar owing to its different traits, and the differences in soil management practices for each cultivar that are not included in the model.

4.7 Summary

The study was conducted in two regions in the Gledhow milling areas (Coastal and Hinterland farmers), in the KwaZulu-Natal province, South Africa. This chapter has provided background information about these study areas and justified their selection. Data were collected from seven commercial sugarcane farmers using a purposive non-probability sampling technique. The data were collected using focus group discussions with commercial farmers and SASRI extension staff. The focus group discussion questions utilised to collect data were guided by the conceptual framework designed for this study to ensure that all the required information was obtained. The data was analysed using Mathematical Linear Programming, Baumol’s model, which incorporated risk. The next chapter presents the empirical results and discussions of the findings.

CHAPTER 5. RESULTS AND DISCUSSIONS

The LP models developed in the previous chapter were subsequently optimised for both -GM cane scenarios and counterfactuals. The optimal solutions for the two scenarios were then compared to determine the on-farm level impacts of making GM sugarcane cultivars available to farmers in the iLembe region. The results of the analysis are verified and reported in this chapter.

The objectives of the study are analysed and discussed. The baseline results are verified through focus group discussions and analysed how these differ once the GM sugarcane cultivars are included in the model, and how this can impact farmers' decisions of adopting GM sugarcane.

5.1 Determining the Profitability (gross margin) of the Farm

The primary measure of farmers' success is usually determined by the farm profitability. For farmers' (or a business) to stay in business, it is vital that the farm makes a profit or the farms total cost of production it less than the total revenue received from sales. For both the representative farms, gross margins are compared with a baseline scenario where GM sugarcane is not included in the model and one where GM sugarcane is included in the model.

Table 5.1 presented below, is a table extracted from the answer sheets of coastal and hinterland area representative farm baseline scenarios and a scenario with hypothetical GM cultivars (Appendix 6). The model perceives that by adopting GM sugarcane, Gledhow Coastal farmers' may increase gross margins by up to 30% annually. Similarly, hinterland farmers may increase gross margins by up to 41% *ceteris paribus*. The large increase in farmers' gross margins is mainly due to the reduction of weed and *eldana* chemical control costs by 13% and 33% respectively.

Table 5.1 Gross margin comparison of the baseline scenario and with hypothetical GM cultivars in Gledhow representative farms, 2018.

	Coastal	Hinterlands
Baseline	R 6 688 513.37	R 4 818 310.18
With GM	R 8 663 753.35	R 6 802 370.08

Costs of pesticides and weedicides have increased over the past two decades owing to the increasing population of weeds and *eldana* (Nicholas *et al*, 2017). Results in Table 5.1 indicate that hinterland farmers gain more than coastal farmers. This can be attributed to the longer production cycle in hinterland farm. *Eldana* population increases with increasing age of sugarcane as the sucrose content increases (Rutherford, 2015). At longer production cycle, *eldana* chemical cost is lower owing to the presence of IR trait in the GM cultivars. Carried over sugarcane increases seasonally, therefore the cost savings associated with less pesticide application of the GM cultivar accumulates. These results concur with results stated by Nicholson *et al* (2017), who discovered that the gains from GM cultivars were greater in the longer production cycle (16 and 18-month cycle) when compared to the shorter production cycle (12-month cycle).

Additionally, benefits can be attained by analysing a scenario of moving from a shorter production cycle to a longer production cycle, given that the GM cultivars enhance resistance to *eldana*. This makes it possible for coastal farmers to move from a 12-14-month production cycle (where a majority of smallholder and medium scale farmers are producing) to an 18-month cycle. Farmers have agreed with this, stating that with improved, *eldana* resistant cultivars, better management practices, and chemical controls, there is already a trend of moving from a 12-14-month to a 14-16-month production cycle. With the IR trait in the GM cultivars, the production cycle can move back to the optimal 18-month production cycle. For illustrative purposes, a sensitivity analysis of Microsoft Excel was used to examine the gains of moving to a longer production cycle. The gains are summarised in Table 5.2.

Table 5.2 Comparison of gross margin gains in different production cycles.

Production cycle	**% area Ratooned**	**Gross Margins**	**% gains**
14-16 month	63.75%	R 14 862, 00	46%
18 month	55.56%	R 15 223, 00	43%
18 month GM	55.56%	R 21 711, 00	

Shifting from a 14-16 month production cycle to an 18-month production cycle not only increases gross margins per AUC but also decreases the proportion of the percentage ratooned. This increases carry-over sugarcane as highlighted earlier. A discussion with commercial farmers proved that this would be highly beneficial. It was however highlighted that farmers with liquidity challenges (Smallholder and medium scale farmers) may increase cash flow in the short term, acting as a disincentive to extending the production cycle. However, the overall profitability of extending to a longer production cycle is higher for all farmers in the long run. Ducasse *et al* (2017) in his study on, "Estimating the potential economic benefit of extending the harvesting cycle of dryland coastal cane by chemically suppressing *eldana* levels," reported similar results. With increasing the production cycle of sugarcane and the IR and HT traits in GM sugarcane, the yield and quality of the sugarcane will increase, which can be attributed to the one (1) unit increase stated by Rutherford (2015).

Adopting GM sugarcane would be highly beneficial to iLembe sugarcane farmers. The profitability of farmers may increase owing to decreased cost of chemical control, increase in production cycle, increase in yield and increase in quality of sugarcane. Additionally, there may be unquantifiable benefits of the above discussed such as, decrease population in creeping grass weeds such as *cynodon*, due to the longer canopy period. Furthermore, with the increase in production cycle leading to a decrease in area harvested and ratooned seasonally, there may be a reduction in on-farm traffic, thus improving soil health and reducing soil compaction, which is a factor that increases the susceptibility of the *eldana* population (Rutherford, 2015).

5.2 Evaluate employment in sugarcane farming

Understanding how the adoption of GM sugarcane has the potential to impact farmers and those rural dwellers who are directly dependant is of high importance. As discussed in earlier chapters, the sugarcane industry is crucial in providing on farm employment, which is particularly important for less skilled workers whose livelihoods are improved owing to the farms. Figure 5.1 compares hours scouters will spend scouting for *eldana* infestation. The graph shows that more hours will be spent on conventional sugarcane than sugarcane that is genetically modified to have IR and HT traits. This is not surprising as the insect resistant trait reduces *eldana* infestation allowing scouters to do other activities in the farm.

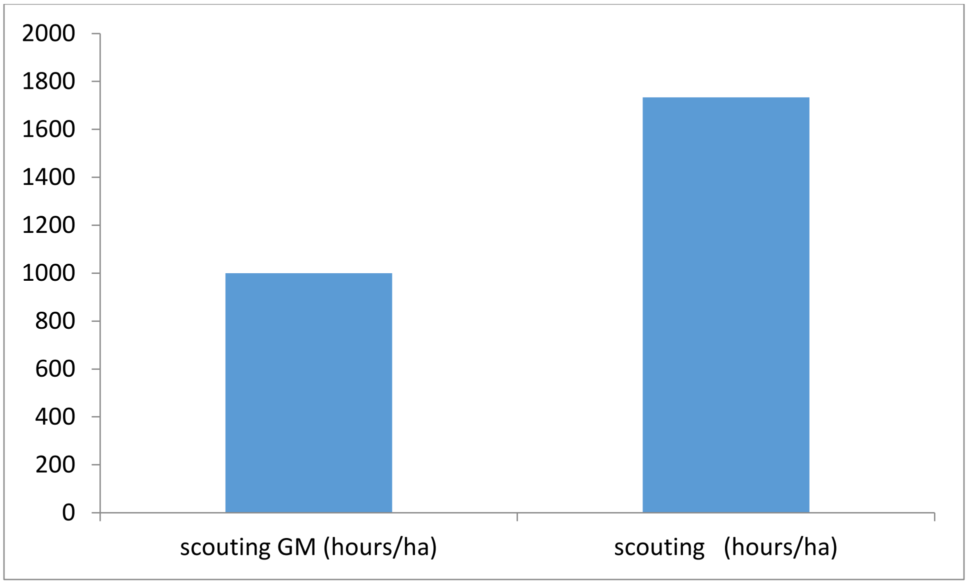


Figure 5.1 Comparison of hours spent scouting for *eldana*

Although authors such as Brookes & Barfoot (2016) and Dill *et al* (2008) have identified GM crops to decrease labour on the farm, these finding suggest that there is more time for farm workers to do other farm activities rather than decrease labour. This becomes particularly important in the iLembe district where the alternative use of land is macadamia nuts which require more time. Additionally if less time is spent on sugarcane production, while still increasing output, this may allow more time for farmers to acquire more skills through training, increasing their livelihoods. Furthermore, the less contact time with chemicals for *eldana* control, the better as there is less handling of chemicals which improves their health (This will be further discussed in section 5.4 which highlights the impact of GM on the use of agrochemicals).

Other important factors to consider that are not accounted for in this study is how each sugarcane cultivar has different characteristics. Even though GM traits may decrease time needed to directly work on the planted sugarcane, the differences in the cultivars may require more attention due to other factors such as lodging, or proneness to other pests and diseases.

5.3 Changes in Production Decisions

Farmers' use market research to guide their production decisions; this technique reduces the level of uncertainty when making production and management decisions. For example, SASRI conducts research and develops new sugarcane cultivars for farmers to improve productivity. The decision on which sugarcane cultivar to plant is critical, especially for a new cultivar, because the expected performance of that cultivar is based mainly on research.

The selection of sugarcane cultivars, by the farmers, is partially dependent on the landscape and soil type. Common cultivars amongst farmers were selected from Table 3.1 for the baseline model. The newer cultivars such as N55, N58 and N60 are only common amongst a few of the commercial growers, and Cane Testing Services (CTS) previous data on these cultivars were not available; for this reason, these cultivars were not included in the model. Similarly, the older cultivars (N16, N31, N39) are being removed for the more recent, better cultivars that are more profitable, and resistant to *eldana*. After a discussion with farmers and SASRI extension staff, it was decided not to use these cultivars in the model. Cultivars that are selected for the model are shown in the full LP Matrix in Appendix 6 and 7. Figure 5.2 presents the baseline scenario of cultivars that have been selected in the model to maximise its objective function in the coastal area.

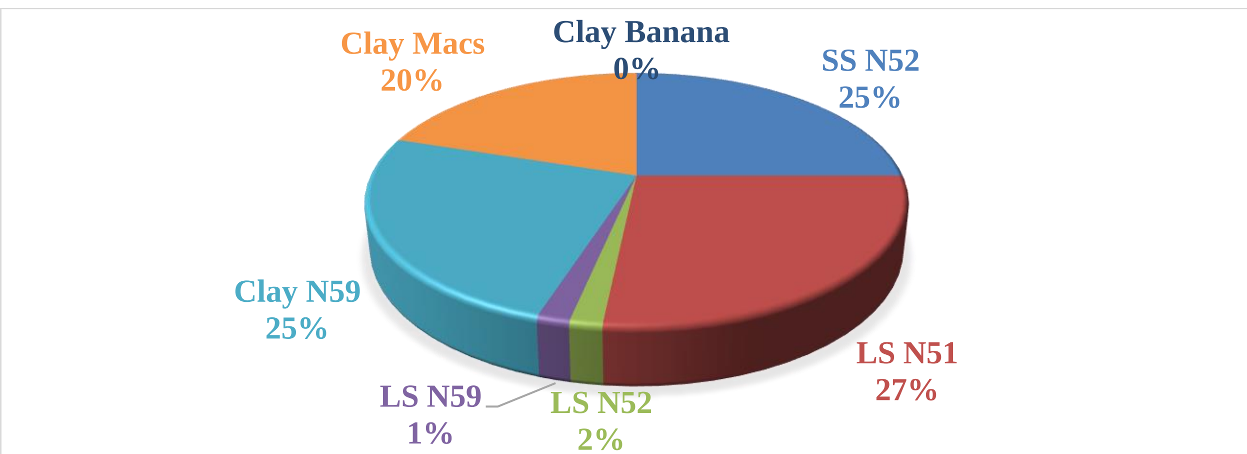


Figure 5.2 Coastal area baseline cultivar and opportunity cost distribution of land.

On sandy soil, (poor soil type) all of the land is allocated to N52, which is not surprising as SASRI information sheet has stated that this cultivar has high RV yields on sandy and humic soils. Farmers have been especially impressed with its ability to regrow after drought, as opposed to other cultivars that become stagnant once it rains again. On loamy soils, the land is mostly allocated on N51. This cultivar has a good RV yield and performs well on average and good soil types. Farmers have stated that this is a cultivar that is well preferred only in the coastal and hinterland areas. Farmers that are more inland, such as Midland farmers would select cultivars like N48 and N50 when compared to N51. N59 and macadamia nuts are selected on clay soils. Similarly to N51 and N52, N59 has a high sugarcane and RV yield, it is also disease and *eldana* resistance. Between Macadamia nuts and bananas, the model has selected macadamia nuts. This concurs to discussions with farmers as they have stated that between macadamia nuts and the softer fruits such as bananas and litchis, macadamias would be more profitable and they are not susceptible to being eaten by monkeys. Macadamia nuts are an ideal alternative for North coast farmers because it is an orchard that helps limit soil erosion on sandy soils and breaks down particles in hard clay soils where sugarcane cultivars do not grow optimally (Naude, 2018, *Pers.com,* March 2018).

All these cultivars, including the opportunity costs of land, have been subjected to their constraints. A discussion to verify results with the extension staff of the Gledhow milling area revealed that the cultivar selection was an accurate representation of the current baseline scenario to farmers' production decisions. It was added that the SASRI cultivar recommendation constraint is however not a good representation to farmers as they must relax the constraint on the cultivars that perform optimally on the soil type. Results presented in Figure 5.3 show the distribution of land once the hypothetical GM cultivars N51 and N52 have been included in the model.

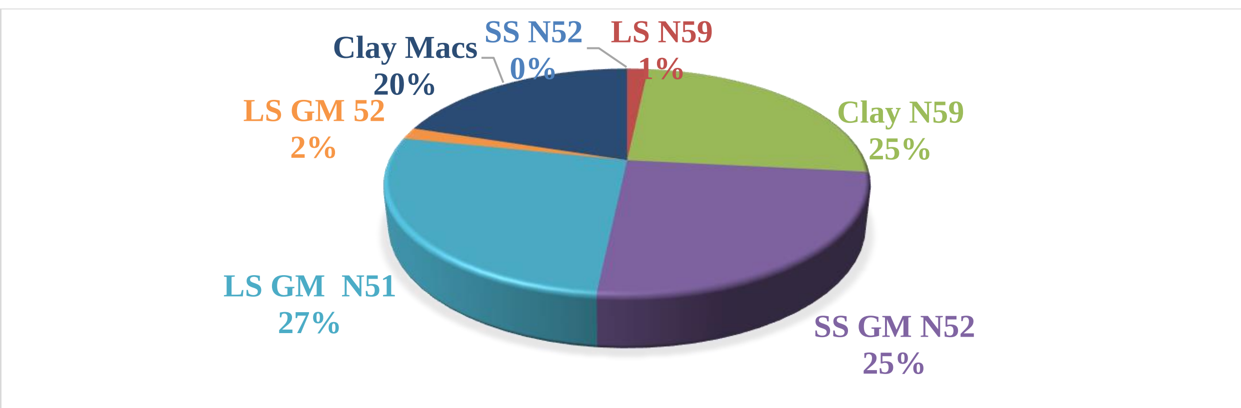


Figure 5.3 Coastal area cultivar and opportunity cost distribution of land with GM cultivars.

On sandy soil, land allocation shifts from conventional N52 to GM N52. Similarly, for loamy soil, there is a shift from conventional N51 to GM N51. This is expected as the genetically modified cultivars have similar traits to that of the conventional cultivars. Except, the GM cultivars have been modified with the IR and HT trait, making these cultivars superior to conventional cultivars. However, on clay soil, N59 and macadamia nuts are still selected by the model. As mentioned above, N59 is a high yielding and disease resistant cultivar, even when compared to the hypothetical GM cultivars. A similar illustration is displayed in Table 4.3 of the previous chapter, where N59 slightly outcompetes GM 52 when gross margins are compared. The nature of the new cultivars is cultivated to be high cane and RV yielding and to be resistant to diseases and *eldana* (Naude, 2018, *Pers.com*, March 20218; SACGA, 2018). This comparison is an example of how cultivar performances improve with time. Highlighting the limitation stated in Chapter 4. Once the GM cultivars have been developed, trails and further research need to be done when compared to conventional cultivars.

Production decisions in the hinterland area are equivalent to results in the coastal area. However, the opportunity cost constraint is evenly distributed between bananas and macadamia nuts. Bananas are allocated on loamy soil and macadamia nuts on sandy soils as opposed to the clay soil. Soil erosion is common in the hinterland area, especially on the hills and valleys. The production of macadamia nuts is therefore preferred by farmers in this land category to hold the soil as opposed to planting sugarcane. Banana grows optimally when planted on rich, well-drained soils, namely, loamy soil. Loamy soil is mostly for sugarcane cultivation as the primary production is sugarcane amongst these farmers. Figure 5.4 and 5.5 show results of how farmer's production decisions would change once GM sugarcane is produced by Gledhow hinterland farmers.

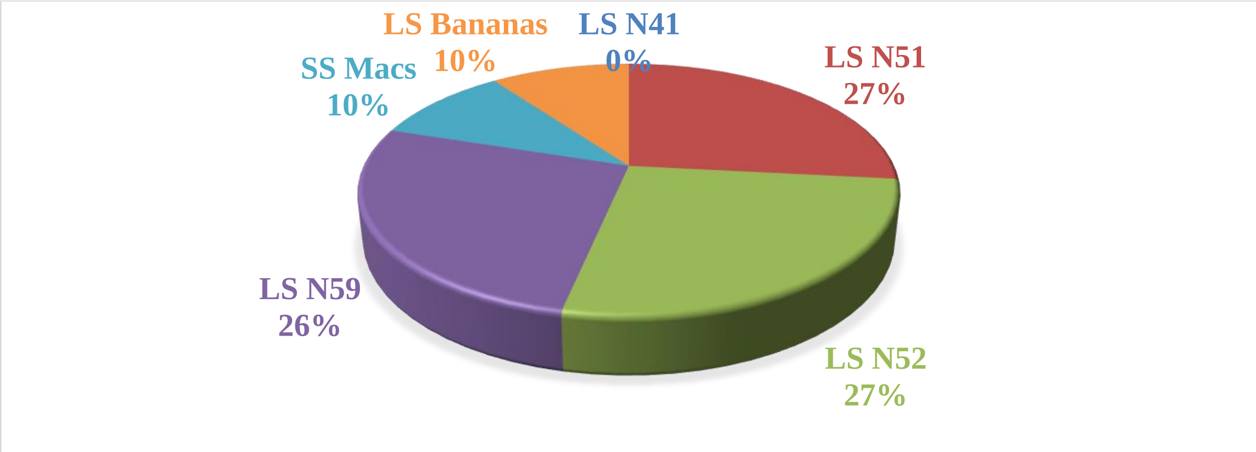


Figure 5.4 Hinterland area cultivar and opportunity cost distribution of land.

The three common cultivars, N51, N52 and N59 are selected by the model. N41 is selected by the model, (0%) but shows that very little land is allocated to it. These results are not alarming as currently, this cultivar is being replaced with N52 by most commercial farmers. Currently, these cultivars complete for land and with the high yields from N52 and its ability to resist *eldana*, it has become more profitable when compared to N41.

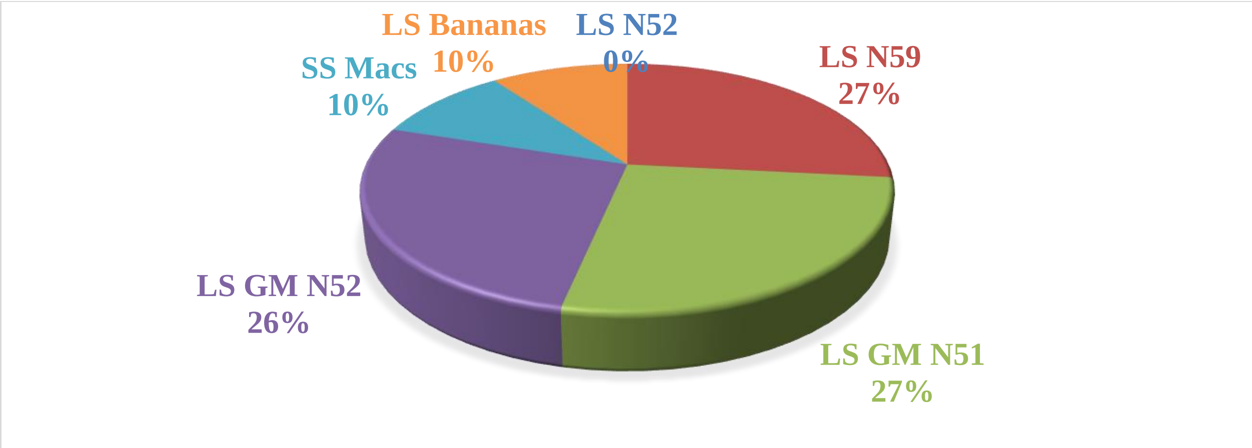
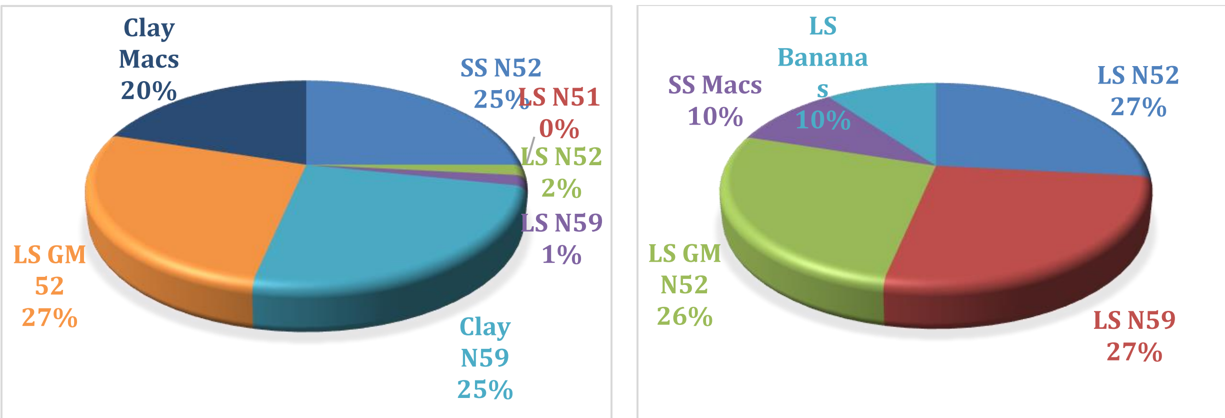


Figure 5.5 Hinterland area cultivar and opportunity cost distribution of land with GM cultivars.

Figure 5.5 illustrates how conventional N51 and N52 cultivars are replaced by hypothetical GM N51 and N52 cultivars. As Highlighted in the coastal representative farm scenario, this is not surprising as the GM cultivars are superior when compared to conventional cultivars. For both representative farms, the majority of the land is allocated to GM cultivars when it is included in the model.

Assuming that the SASRI constraint does not only apply on a per cultivar basis, but also on the GM cultivars stating that GM cultivars may not be greater than a third of the farm to avoid mutation of *eldana*. This constraint may be included in the first stage when only one or two GM cultivars are available in the market. A scenario with the GM constraint is used in the model to illustrate how this will affect farmers' decisions and is presented below (Figure 5.6).



<u>Figure 5.6 Land allocation with GM Constraint on Gledhow representative farms.</u>

Figure 5.6 represents a scenario where different GM cultivars are not viewed as individual cultivars but are grouped together as "one" GM cultivar. The one-third constraint on the GM cultivars is removed and a single constraint, constraining GM cultivar as a whole replaces it. For both representative farms, nearly 30% of the total area under sugarcane is allocated to the GM N52 cultivar. The 26% that was previously allocated to GM N51 is allocated back to conventional N52. The model allocates the next best cultivar on the land that would have been used by the GM cultivar. Not surprisingly, the N52 cultivar is selected.

The SASRI 30% constraint is a way of minimising risk through cultivar diversification, as discussed in Chapter 4. However, one may argue that this recommendation would be over constraining to smallholder farmers. Table 5.3 presents a hypothetical scenario where all the sugarcane constraints are removed. The results show that given a choice between Conventional and GM sugarcane cultivars, it would be more beneficial to farmers to adopt GM cultivars.

Table 5.3 Land allocation of cultivars without constraints on Gledhow representative farms.

Land category	Coastal	Hinterland
Sandy soil (ha)	GM N52: 100	Macs: 40
Loamy soil (ha)	GM N52: 120	GM N52: 320
		Banana: 40
Clay soil (ha)	GM N51: 97	
	GM N52: 3	
	Macs: 80	

Table 5.3 illustrates the significance of the IR, HT GM sugarcane cultivars. It demonstrates how, especially for smallholder farmers', farmers cultivar decisions may change once the GM cultivar is approved. However, for commercial farmers, it is vital to adhere to the 30% constraint. An example of this is highlighted by Naude, *Pers.com* (2018) who referenced that in the North Coast, SASRI implemented the eradication of the NCO376 cultivar by the year 2023. For farmers that have not adhered to the 30% cultivar constraint, this is a challenge as the rate of replanting will be slower than the rate of plough out disturbing the farm net cash flow.

Genetically modified cultivar in both representative farms takes up a larger portion of the total area planted to sugarcane (60-65%). In the first stages of GM implementation, this will not be the case owing to the SASRI constraint. It will, therefore, be important to use conventional chemical control as a compliment with GM cultivars to address the *cynodon* and *eldana* population. Additionally, there will be other insects and weeds that farmers have to spray for. Farmers are not to assume GM cultivars are exempt from chemical spraying. These cultivars will continue being scouted as for the conventional sugarcane, and if necessary, they will also be spot sprayed for weeds and *eldana*.

Profitability due to advantages in GM cultivars may aid in farmers production decisions once it has been approved. Results clearly highlight the advantages GM cultivars would have when compared to conventional cultivars. However, even though GM sugarcane cultivars may be highly beneficial to farmers, the nature of farmers is that only a few 'risk-taking' commercial farmers will initially adopt it. Once results from first and second ratoon are seen by neighbouring farmers, only then will the adoption gradually increase. This steady increase is also seen on other GM crops in South Africa, particularly maize (Gouse *et al*, 2005)

5.4 The Impacts of Chemicals

In the sugarcane industry, chemical control, in particular, the cost associated with managing pests and weeds has increased in the past decade owing to increases in *eldana* and *cynodon* weeds. High input cost is not limited to the sugarcane industry, but in the agricultural sector globally. Research has proven that modifying crops to be genetically resistant to pests and diseases, and tolerance to herbicides, addresses the challenges of high input costs. Literature (Chapter 2) has reviewed impacts GM crops have had on input costs globally, and evidence has been given, that GM crops can decrease high input costs. The impact GM sugarcane will have on input cost is investigated in this study.

Table 4.1, in the previous chapter, stipulates the significant cost savings that can be made by growers when you compare conventional and GM sugarcane. Similarly, the example of the enterprise budget in Table 4.2 shows that major differences between conventional and GM sugarcane are in the yields, and *eldana* and chemical cost. When comparing the 14-16-month and the 18-month production cycle, there is a larger proportion of AUC carried over in the 18-month production cycle resulting in higher *eldana* cost. These costs are however outweighed by savings attained through the reduced area being ratooned and replanted annually. The cost of weed control at planting may be the same for conventional sugarcane, however at ratoon for cultivars at a longer production cycle (18 months) there are cost savings owing to the sugarcane's ability to canopy well at an older age.

The answer reports of the LP matrix for both representative farms indicate that there may be cost savings of up to 12% and 33% for herbicides and *eldana* chemical costs respectively. These costs are directly associated with the decrease in the number of prays owing to the IR and HT traits in GM. Furthermore, the ability to lengthen the production cycle further enhances farm return and quality due to increased sucrose content. The advantages of sugarcane quality will be discussed in detail in section 5.3.

In addition to the direct quantifiable benefits of decreased number of sprays, saving costs, there are unquantifiable benefits. The decreased number of sprays means there will be less farmer to chemical contact at the farm, leading to an improvement in safety and health. One may argue that farmers are equipped with safety precautions and protective clothing when handling herbicides and pesticides, but this becomes imperative when regarding smallholder farmers as protective equipment or clothing may be limited (Hofs *et al*, 2006). Additionally, the GM sugarcane cultivar HT trait allows farmers to spray a cover spray pre-planting and not have to wait for another three to four months (for chemical residues to dissolve) before planting. A study done by Rutherford *et al* (2017) indicates that GM cultivars may not be affected by the chemical residues in the soil and planting can occur immediately. This further decreases the need for herbicides because sugarcane will be able to establish itself and canopy before competition from weeds increase. The reduction in chemical spray sustains the soil, conserving soil nutrients. Genetically Modified cultivars' ability to withstand chemical residue at planting may, however, have a long term negative impact by developing resistance to the mode of action affecting plough-out (Nicholson *et al*, 2017). Other cost-saving benefits include reduced on-farm traffic as previously discussed in section 5.1 amongst other things.

Sugarcane farmers, particularly smallholder farmers, are faced with the challenge of high input cost owing to *cynodon* and *eldana*. Genetically modified sugarcane with IR and HT traits have proven to address these challenges by directly decreasing the number of sprays needed. This has positive unqualifiable consequences of improving farmers' health and safety and conserves soils due to fewer chemicals and infield traffic. Furthermore, these traits allow for a longer closed canopy, limiting competition from weed and enhancing the absorption of soil nutrients, which will in return increase sugarcane quality.

5.5 Evaluation of Total Area Planted to Sugarcane

Sugarcane farmers have decreased the total area planted to sugarcane by up to 13% in the past decade (SACGA, 2018). Even though there are other socio-economic, and socio-political factors contributing to this, farmers strategies to address these challenges are to spread the risk through diversification, amongst other strategies. Macadamia nuts have increased in production in the North coast, as these farmers take advantage of the high returns of macadamias to address the high input cost owing to increases in weed and *eldana* population affecting sugarcane production. This has been crucial for farmers as controlling the spread of this pest and diseases is important for the environmental and the economic sustainability of sugarcane farming, especially in the coastal areas.

It is difficult to extrapolate whether GM sugarcane will increase the area planted to sugarcane because *eldana* and *cynodon* are not the sole reasons for decreasing sugarcane production. Additionally, the model used in this study is not able to quantify this objective. However, this question was one of the agendas in the focus group discussions. It was highlighted that SASRI staff anticipate an increase in yield and quality of sugarcane. An example of smallholder farmers was provided where it was stated that with GM sugarcane, there will be an increase in volume and quality of sugarcane sent to the mill on the same land, as farmers will be able to produce sugarcane to its optimal. Already this is seen on commercial farmers who use returns from macadamia nuts to adopt better management practices for sugarcane, increasing its productivity on the same land.

Even though evidence may not anticipate the impact GM sugarcane will have to the total area planted to sugarcane, there is clear evidence of increasing productivity of sugarcane on the same land. This is evidence that GM sugarcane will benefit farmers even if the total area planted to sugarcane does not increase. If farmers are able to increase productivity on the same land allocated to sugarcane and minimise risk by diversifying with other high-income crops this increases farm profitability, which is beneficial to farmers.

5.6 Summary of Findings

This chapter used descriptive analysis to produce and discuss the results of the study. Using the Mathematical Linear Programming, Baumol’s model in Chapter 4, the study analysed the socio-economic impacts GM sugarcane would have on iLembe farmers. The results showed that farmers could benefit from the increase in farmers’ net farm income owing to decreased pesticides and herbicides application. The IR and HT traits in GM cultivars would make it possible for farmers to shift back to an 18-month production cycle. The increase in the cultivars’ production cycle benefits farmers by an increase in carry-over sugarcane, which decreases on-field traffic. Additionally, the decrease in chemical requirements enhances farmers’ safety and health as less chemicals are used and soil nutrients are conserved. It is important to note that these benefits are not mutually exclusive, but rather have a ripple effect on each other. Chapter 6 presents the conclusions and recommendations for future research based on the limitations and results of the study.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

6.1 Summary of Contributions

South African sugarcane farmers are facing challenges of increasing input cost and low profitability due to *cynodon* and *eldana*. SASRI, in its effort to address these challenges, is currently developing an *eldana* saccharina Walker (Lepidoptera: Pyralidae) IR, HT GM sugarcane cultivar. For the successful implementation of GM sugarcane, a study was conducted to assess the likely socio-economic impact of IR and HT GM sugarcane at a farm level. Taking into account that GMO's are not supported by many countries due to health concerns and environmental reasons, it is assumed that millers accept GM sugarcane and that consumers will be willing and able to consume sugar derived from GM sugarcane.

Although there is substantial literature on farm level impact of GM annual crops globally, there is insufficient research on the impact perennial crops would have on farmers. Additionally, GM sugarcane has not been commercialised globally. Hence, the general objective was to conduct an *ex-ante* study to assess the potential impacts of introducing the GM IR and HT sugarcane at the farm level in order to inform SASRI's technology development process and to be used in the consideration of the technology within the GMO regulatory process. The specific objectives of the study were to: (i) investigate the potential impact GM will have on Net Farm Income, (ii) evaluate the socio-economic impact on less skilled employees at the farm, (iii) analyse the change in production decisions, (iv) analyse whether GM will be used in complement with pesticides and herbicides and (v) to evaluate the total area under sugarcane.

The study focused on commercial, iLembe farmers as *eldana* and *cynodon* are most prevalent in this area- smallholder and medium scale farmers were excluded because of the lack of record keeping. Two representative farms were selected based on different climatic conditions, cane production cycles, yields, and soil types to conduct a Mathematical Linear programming farm model that accounts for risk. Using Baumol's E-L criterion, the likely impact of GM sugarcane by comparing a baseline scenario (no GM sugarcane) to a scenario including a GM cultivar was conducted. While previous studies conducted *post-post* studies using field trials and cost-benefit analysis, this study was unique as it is an *ex-ante* study using farm representative models. Additionally, this study accounted for risk as a cost to the business, acknowledging that farmers, just like any business do not have the foresight of future conditions and are affected by uncertainty. This was the overall contribution of the study to the existing body of knowledge.

6.2 Conclusions

The findings obtained in this study were similar to those of previous studies. This confirms that GM sugarcane, with IR and HT traits, would have a positive socio-economic impact at a farm level. With the current challenges that are faced by the South Africa sugar industry, looking at a technology that has the potential to increase yields, decrease cost and improve soil quality by decreasing yields could be highly beneficial for both the farmers and the industry. Furthermore, the results indicate that there is a potential for North Coast farmers to extend their sugarcane production cycle back to an 18-month cycle owing to the enhancement of the IR trait in the GM cultivars. These results are obtained from both direct, quantifiable benefits such as cost savings, gains from revenue owing to improved sugarcane yield and quality and indirect, unquantifiable benefits, including safety and health improvement of farm workers owing to less handling of chemicals. There is a reduction in risk management as there is less concern about crop damage. There is also an increase in management flexibility as less time is devoted to scouting and applying insecticides. Additionally, soil is conserved by less on-field traffic at the farm, indirectly decreasing the cost of fuel used at the farm. Even though in reality, there will be other pesticides and herbicides on the market, and there will be cultivars that are resistant to *eldana*, by the time GM sugarcane is commercially available, this study shows that GM sugarcane will, directly and indirectly, benefit farmers and the South African sugar industry through increased production.

The choice of the cultivar that will initially be modified to have the GM traits is crucial for the South African sugarcane industry. Even though this study focused on rain fed, coastal farmers, decisions such as, the production cycle of the cultivar, will it be an early maturing or late maturing cultivar, will it be suitable for both rainfed and irrigating farmers and the soil type it will produce optimally in, need to be considered when it is produced. The selection of two cultivars for the representative farms conveyed this. A wrong selection of cultivar choice could lead to farmers not accepting GM cultivars due to its failure to compete with conventional cultivars in that specific area.

Even though smallholder farmers may benefit the most from GM sugarcane, there are other challenges that require immediate attention. They still do not have resources, technologies and some lack basic education that will help them improve their agricultural productivity. Additionally, record keeping is still a challenge to the majority of them. Currently, they do not purchase certified sugarcane and lack the finances to abide by better management practices as advised by SASRI staff. Even though government funding is readily available to them, some lack the knowledge of how to acquire the funding. Insight of this, some may initially rebel against GM cultivar given the short term liquidity constraint of moving to a longer production cycle. The research and development of GM sugarcane is essential for the survival of the sugar industry as it is currently facing a number of challenges both domestically and globally.

6.3 Limitations of the Study and Recommendations for Future Research

Due to logistical, resource and time limitations, the research was a one-time cross-sectional study conducted on two representative North Coast farms. Future research should try and expand the study to include other provinces like Mpumalanga and Eastern Cape where there are different climatic and production conditions, and sugarcane is predominantly irrigated. These results will be more comprehensive and comparable across the geographical barriers in South Africa. Resources permitting, future similar studies should also seek to compare time series studies. This approach will allow for more accurate predictions and conclusions of the model and will capture the issue of heterogeneity amongst farmers better.

The limitation of the study to exclude smallholder and medium scale farmers has led to a knowledge gap how, and to what magnitude they will benefit from GM sugarcane. It is therefore recommended that smallholder farmers receive proper training on bookkeeping, financial and pest management techniques. Additionally, it is recommended that further research be conducted of smallholder farmers. There is a stigma in society towards GMOs, therefore, educating stakeholders is necessary. Information and communication along the supply chain is significant for the production and commercialization of GM cane.

Furthermore, future research should seek to conduct on-farm field trials in the future, to allow for variation among geographic and climatic conditions.

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APPENDICES

Appendix 1: Cane Planting Costs Modified for Gledhow Milling Farmers.

CANE PLANTING COSTS MECHANICAL LAND PREPARATION COASTAL REGION OF KWAZULU-NATAL									
Land Preparation: (Conventional Method) consisting of the following									
				HOURS		**COST/HR**		**COST/HA**	**COST/HA RANDS**
Ploughing				3.27		R315.71		R1 032.37	
Harrowing (twice)				2.56		R319.06		R816.79	
Ridging				2.06		R275.61		R567.76	
Contour Structures				2		R315.71		R631.42	
Total				**9.89**		**R1 226.09**		**3048.3419**	**R3 048.34**
Hand Planting									
	25 Labour days per Ha (Plant and Cover)								
	Cost of Labour per day					R146.28			**R3 657.00**
Agricultural Lime									
3	tons per hectare				@	R711.26	per ton		R2 133.78
	Tractor & Spreader	0.6	hours/ha		@	R397.09	hour		R238.25
	Labour @ 0,6 manday per hectare	0.6	mandays		@	R146.28	per day		R87.77
									R2 372.03
Fertiliser									
	1 Soil Sample test (SASRI)			R190.00	/sample	R190.00			
	200 kg DAP (38) + 0.5% Zn			R8 071.90	per ton	R1 614.38			
	400kg Mixture 1.0.1.(48) @			R5 313.25	per ton	R2 125.30			
	Labour: Split in furrow and top dress			R146.28	per day	R292.56			
	2- mandays @								**R4 222.24**
Seed Cane									
10	tons per Ha @			R626.87	/ton				**R6 268.70**
Weed control									
Materials :									
Pre-emergent :		2	litres Acetachlor		@	R153.70	per litre	R307.40	
		2.5	litres Diron		@	R77.52	per litre	R193.80	
		1	litre Paraquat		@	R50.50	per litre	R50.50	
Post-emergent :		4	litres Ametryn		@	R55.89	per litre	R223.56	
		3.5	litres MCPA		@	R47.11	per litre	R164.89	
		0.5	litres Wet/agent		@	R49.45	per litre	R24.73	
Spot spray:	5% of	4	litres Ametryn		@	R55.89	per litre	R11.18	
	5% of	3.5	litres MCPA		@	R47.11	per litre	R8.24	
	5% of	0.5	litres Wet/agent		@	R49.45	per litre	R1.24	
								R985.53	
Labour: pre-, post-emerg. & spot applic.		1.2	hours		@	R204.69		R245.63	
Hand-hoeing with		9	Labour Units		@	R146.28		R1 316.52	
Spot sprayer - Labour		1	Labour Unit		@	R146.28		R146.28	
								1562.15	
									R2 547.68
Sundries & Contingencies @		15%	of operational costs						**3 317**
TOTAL									**R25 432.99**

Appendix 2: Ratoon Management Costs:Dryland Cane, Burnt:Early Harvest 2017/18 season

Ratoon Management Costs:Dryland Cane, Burnt:Early Harvest 2017/18 season							
Operation	**Cost Components**					**Cost /Ha**	**Cost /Ha**
Field management							
Trash							
	Spread tops and clean up	2	Mandays/ha	R138.52	/Manday	R277.04	
Verge							
	Tractor & Slasher1 & 2	0.25	hours/ha	R251.24	/hr 4times	R251.24	
							R528.28
Fertilizer							
	1-0-1 (48)	565	Kg/ha	R5 167.50	/ton	R2 919.64	
	Topdress1	0.56	Hrs/ha	R312.17	/hour	R174.82	
	Labour - conductor	1	Manday/ha	R138.52	/manday	R138.52	313.3352
							R3 233
Weed Control							
Pre-Emergent							
	Acetochlor 960g/litre	2	litres/ha	R135.81	/litre	R271.62	
	Ametryn 500g/litre	3	litres/ha	R49.25	/litre	R147.75	
	Tractor & Boom Sprayer1	0.62	hours/ha	R199.83	/hour	R123.89	
	Labour - conductor	1	Manday/ha	R138.52	/manday	R138.52	
Post-Emergent							
	Ametryn 500g/litre	4.5	litres/ha	R49.25	/litre	R221.63	
	MCPA	3.5	litres/ha	R44.11	/litre	R154.39	
	Volcano Blend (Adjuvant)	0.5	litres/ha	R69.85	/litre	R34.93	830.305
	Tractor & Boom Sprayer1	0.62	hours/ha	R199.83	/hour	R123.89	
	Labour - conductor	1	Manday/ha	R138.52	/manday	R138.52	
	Hand-hoeing	8	Manday/ha	R138.52	/manday	R1 108.16	1 385.2
							R2 463
Sundries & Contingencies							**R622.46**
Total Ratoon Cost							**R6 847**

Appendix 3: Estimated harvesting cost for North Coast farmers

Figures are based on the cane salvage rates estimates of the 2017/18 season and average yield of 67 tons/ha					
Harvesting activity	**Cost/ton**	**Cost/ha**			
Cutting and loading of burnt cane	58.77	3937.59	**@**	67	tons/ha
Infield cane haulage by tractor and trailer inclusive of drivers and assistants, assuming average lead distance of 1,5km	25.28	1693.76	**@**	67	tons/ha
Loading and transhipment of burnt cane, inclusive of operators, by crane	11.48	769.16	**@**	67	tons/ha
Total	**95.53**	**6400.51**			

Appendix 4: Plant Cane Cost and Ratoon Management Cost Scenarios.

Scenario 1	: Normal Cane -Normal Spraying Programme								
	Chemical					Labour Cost			Total Cost
	Operation	Weed Control Agent	Application Rate (L/ha)	Herbicide Cost (R/L)	Herbicide Cost (R/ha)	Labour Cost (R/day)	Mandays (Days/ha)	Labour Cost (R/ha)	(R/ha)
	Cover Spray	Glyphosate 360 SL	8	57.26	458.08	146.28	1	146.28	604.36
	Pre-emergent					146.28	1	146.28	687.76
		Acetachlor Gold 960	2	153.7	307.40				
		Diuron 800 SC	2	76.06	152.12				
		Paraquat 200 SL	1.5	54.64	81.96				
	Post emergent					146.28	1	146.28	568.93
		Wet agent	0.5	51.25	25.63				
		Ametryn 500 SC	4	55.06	220.24				
		MCPA 400 SL	3.5	50.51	176.79				
	Spotspray Cynodon	Glyphosate	2	57.26	114.52	146.28	0.5	73.14	187.66
	Hand weeding					146.28	8	1170.24	1170.24
	Total Costs								**2614.59**

Scenario 2	GM Cane- Format 250 SL								
	Chemical					Labour Cost			Total Cost
	Operation	Weed Control Agent	Application Rate (L/ha)	Herbicide Cost (R/L)	Herbicide Cost (R/ha)	Labour Cost (R/day)	Mandays (Days/ha)	Labour Cost (R/ha)	(R/ha)
	Cover Spray	FORMAT 250 SL	5.01	303 93	1522.69	146.28	1	146.28	1668.97
	Spotspray Cynodon	FORMAT 250 SL	0 501	303 93	152.27	146.28	0.2	29.26	181.52
	Total Costs								**1850.49**

Appendix 5: Example of enterprise budgets comparing sugarcane cultivars

All figures are based on the 2017/18 Canegrowers season estimates										
		Weighted costs								
Enterprise budget in a typical year per hectare	**Cost/ha/yr**	**PPI**	**PPI**		**PPI**		**PPI**		**PPI**	
			N41		**N51**		**N52**		**N59**	
RV price per ton	4187	3685.14	3685 14		3685.14		3685.14		3685.14	
Average yield RV (Tons per hectare)	66.00	66.00	84.67		87.50		97.67		94.83	
RV%	0.122	0.122	0 129		0.138		0.128		0.140	
Gross receipts										
Income	**33736.33**	**19795.11**	26820.94		**29574.30**		**30786.48**		**32507.88**	
Allocated Costs										
Cane planting costs-Mechanical land prep										
Land preparation	3253		3253		3253		3253		3253	
Hand planting	3463		3463		3463		3463		3463	
Seedcane	8520		8520		8520		8520		8520	
Fertiliser and lime	4042		4446.2		**4446 2**		**4446.2**		**4446.2**	
Weed control	3008		3158.4		**3068.16**		3008		3098.24	
Sundries and contingencies	3354		3354		3253.38		3454.62		3253.38	
Total	**25640**	2848.89	26194.6	2910.511	26003.74	**2889.304**	26144.82	**2904.98**	26033.82	**2892.647**
Harvesting costs										
Cutting of burnt cane	4584.06		4584.06		4584.06		4584.06		4584.06	
Infield-cane haulage	1971.84		1971.84		1971.84		1971.84		1971.84	
Loading and transhipment of burnt cane	1093.56		1093 56		1093.56		1093.56		1093.56	
Total	**7649.46**	**5099.64**	7649.46	5099.64	**7649.46**	**5099.64**	**7649.46**	**5099.64**	**7649.46**	**5099.64**
Ratoon management costs: Dryland cane early harvest										
Field management	528.28		528.28		528 28		528.28		528.28	
Fertilizer	3233		3233		3233		3233		3233	
Weed control	2463		2536.89		2463		2463		2463	
Total	**6224.28**	**3457.93**	6298 17	3498.983	**6224.28**	**3457.933**	**6224.28**	**3457.933**	**6224.28**	**3457.933**
Eldana Control	2955	2955.00	2955	2955	**2955**	**2955**	**2955**	**2955**	**2955**	**2955**
Green manuring	**4291.95**	**357.66**	4291 95	357.6625	**4291.95**	**357.6625**	**4291.95**	**357.6625**	**4291.95**	**357.6625**
Cost excl *eldana* & weed control		**6293.12**		6171.507		**6273.38**		**6349.216**		**6246.643**
Total Costs		14719.12		14821.80		14759.54		14775.22		14762.88
Gross margin	**-13024.3562**	**5075.98**		**11999.14**		**14814.76**		**16011.27**		**17744.99**

Appendix 6: Coastal representative farm model Linear Programming matrix

	Cane variety grown/ha								GM Cane/ha						Opportunity cost of land/ha					Weed Control		Eldana control										D1 (R)	D2 (R)	D3 (R)	D4 (R)	D5 (R)	D6 (R)	0.5TAD (R)	SD (R)		RHS
	SS N41	SS N51	SS N52	LS N51	LS N52	LS N59	Clay N52	Clay N59	S GM N51	SS GM N52	LS GM N51	LS GM 52	Clay GM N51	Clay GM N52	SS Macs	LS Macs	LS Banana	Clay Macs	Clay Banana	Weed ng conventional (R/ha/Yr)	Weed ng in GM cane (R/ha/Yr)	scout ng (hours/ha)	scouting GM (hours/ha)	Chemical control (R/ha/Yr)	Chemical control GM (R/ha/Yr)	Conventional cane (t)	GM Cane (t)	RV Sales (t)	Macs (t)	Banan	Labour hire (days)										
Sandy Soils (ha)	1	1	1						1	1					1																									≤	100
Loamy so ls (ha)				1	1	1					1	1				1	1																							≤	120
Clay (ha)							1	1					1	1				1	1																					≤	180
Labour (days)	300	300	300	300	300	300	300	300	240	240	240	240	240	240																	-1									=	0
Eldana Chemical Control (R)	2955	2955	2955	2955	2955	2955	2955	2955																-1																=	0
Eldana Chemical Control GM (R)									985	985	985	985	985	985											-1															=	0
Eldana control: scouting (Hours)	15	15	15	15	15	15	15	15														-1																		≤	600
Eldana control: scouting GM(Hours)									10	10	10	10	10	10									-1																	≤	400
Conventional transfer (t)	-56.73	-58.04	-66.75	-58 63	-65.44	-63.54	-63.47	-64 81																		1														=	0
GM cane Transfer (t)									-62.10	-71.42	-62.73	-70.02	-63 67	-69.32													1													=	0
Cane: RV Conversion (t)	-7.31	-7.98	-8.56	-8 07	-8.40	-8.87	-8.14	-9 04	-8.63	-9.26	-8.72	-9.07	-8 85	-8.98														1												=	0
Macadamia nuts transfer (t)															-2	-6		-8											1											=	0
Banana transfer (t)																	-20		-25											1										=	0
N41 Constraint	-2	1	1	1	1	1	1	1	1	1	1	1	1	1																										≥	0
N51 Constraint	1	-2	1	-2	1	1	1	1	1	1	1	1	1	1																										≥	0
N52 Constraint	1	1	-2	1	-2	1	-2	1	1	1	1	1	1	1																										≥	0
N59 Constraint	1	1	1	1	1	-2	1	-2	1	1	1	1	1	1																										≥	0
GM N51 Constraint	1	1	1	1	1	1	1	1	-2	1	-2	1	-2	1																										≥	0
GM N52 Constraint	1	1	1	1	1	1	1	1	1	-2	1	-2	1	-2																										≥	0
GM Constraint	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1																										≥	0
Macs /Banana Constraint	-0.2	-0.2	-0 2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0 2	0.8	0.8	0.8	0.8	0.8																					≤	0
Weeding Conventional (R)	5695.29	5531.16	5471	5531	5471	5561	5471	5561 24												-1																				=	0
Weeding GM (R)									2458.63	2458.63	2458.63	2458.63	2458 63	2458.63							-1																			=	0
Gross Margin ®																																									
GM deviations																																									
T1 (R)	2923.19	1053.23	1796.61	1054 92	2544.63	2692.77	2493.76	2733 34	952.54	2583.65	954.36	2547.36	957 07	2529.22	-4901.85	-4388.82	-18664.50	-3328 72	-18948.73													1								≥	0
T2 (R)	196.57	-438.24	1431.05	-438 99	955.17	2046.41	901.24	2107 88	-534.33	987.57	-535.13	949.10	-536 32	929.87	-451.14	-115.48	-13876.49	767 23	-14036.22														1							≥	0
T3 (R)	280.81	-1470.96	-559.34	-1475 51	-1183.71	88.23	-1184.38	113 50	-1386.15	-1081.30	-1391.02	-1081.78	-1398 31	-1082.02	215.87	182.25	-11757.38	695 69	-11746.98															1						≥	0
T4 (R)	-4621.12	-1218.48	-344.87	-1230 81	-1466.43	-3885.42	-1409.91	-3967 78	-1194.91	-1498.46	-1208.09	-1458.15	-1227 88	-1437.99	974.31	696.81	28193.64	966 37	26188.72																1					≥	0
T5 (R)	1420.64	628.11	-485.00	625 02	249.24	2226.32	269.75	2248.48	607.74	192.30	604.44	206.92	599.49	214.24	348.02	-553.07	24826.35	-907 10	22929.42																	1				≥	0
T6 (R)	-200.08	1446.35	-1838.46	1465 36	-1098.91	-3168.31	-1070.46	-3235.43	1555.11	-1183.76	1575.45	-1163.46	1605 95	-1153.31	2169.64	1470.59	16463.54	1318 60	15261.84																		1			≥	0
Sum (R)																																-1	-1	-1	-1	-1	-1	1		=	0
Conv (R)																																						-0.26	1	=	0
Without GM									1	1	1	1	1	1																										=	0
OBJ: L= E[GM]-θσ (R)	-14719.12	-14759.54	-14821.80	-14759 54	-14821.80	-14762.88	-14821.80	-14775 22	-13297.38	-13739.57	-13297.38	-13739.57	-13297 38	-13739.57	14577.18	20747.19	2266.55	23087 80	2266.55	-1	-1			-1	-1			4583.48											-1.036		MAX!

Appendix 7: Hinterland representative farm model Linear Programming matrix

	Cane variety grown/ha							GM Cane/ha				Opportunity cost of land/ha		Weed control		Eldana control										D1 (R)	D2 (R)	D3 (R)	D4 (R)	D5 (R)	D6 (R)	0.5TAD (R)	SD (R)		RHS
	SS N41	SS N51	SS N52	LS N41	LS N51	LS N52	LS N59	SS GM N51	SS GM N52	LS GM N51	LS GM N52	SS Macs	LS Bananas	Weeding conventional (R/ha/Yr)	Weeding in GM cane (R/ha/Yr)	scouting (hours/ha)	scouting GM (hours/ha)	Chemical control (R/ha/Yr)	Chemical control GM (R/ha/Yr)	Conventional c	GM Cane (t)	RV Sales (t)	Macs (t)	Banana (t	our hire (days)										
Sandy soil (ha)	1	1	1					1	1			1																						≤	40
Loamy soils (ha)				1	1	1	1			1	1		1																					≤	360
Labour (days)	300	300	300	300	300	300	300	240	240	240	240														-1									=	0
Eldana Chemical Control (R)	2955	2955	2955	2955	2955	2955	2955											-1																=	0
Eldana Chemical Control GM (R)								985	985	985	985								-1															=	
Eldana control: scouting (R)	15	15	15	15	15	15	15									-1																		≤	600
Eldana control: scouting GM (R)								10	10	10	10						-1																	≤	400
Conventional transfer (t)	-56.7266667	-58.625	-66.7454	-56.726667	-58.63	-65	-63.53833333													1														=	0
GM cane Transfer (t)								-62.1014625	-71.417578	-62.72875	-70.01723333										1													=	0
Cane: RV Conversion (t)	-7.31451987	-8.06540786	-8.56391084	-7.3145199	-8.06540786	-8.395991023	-8.865443828	-8.629123412	-9.255018449	-8.716286275	-9.073547499											1												=	0
Macadamia nuts transfer (t)												-2											1											=	0
Banana Transfer (t)													-20											1										=	0
N41 Constraint	-2	1	1	-2	1	1	1	1	1	1	1																							≥	0
N52 Constraint	1	1	-2	1	1	-2	1	1	1	1	1																							≥	0
N51 Constraint	1	-2	1	1	-2	1	1	1	1	1	1																							≥	0
N59 Constraint	1	1	1	1	1	1	-2	1	1	1	1																							≥	0
GM N51 Constraint	1	1	1	1	1	1	1	-2	1	-2	1																							≥	0
GM N52 Constraint	1	1	1	1	1	1	1	1	-2	1	-2																							≥	0
GM Constraint	1	1	1	1	1	1	1	-1	-1	-1	-1																							≥	0
Mac/banana Constraint	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	0.8	0.8																					≥	0
Weeding Conventional (R)	5695.29	5531.16	5471	5695.29	5531.16	5471	5561.24							-1																				=	0
Weeding GM (R)								2458.631775	2458.63	2458.631775	2458.631775				-1																			=	0
Gross Margin ®																																			
GM deviations																																			
T1 (R)	2923.19	1053.23	1796.61	2956.83	1054.92	2544.63	2692.77	952.54	2583.65	954.36	2547.36	-4901.85	-25185.17													1								≥	0
T2 (R)	196.57	-438.24	1431.05	213.29	-438.99	955.17	2046.41	-534.33	987.57	-535.13	949.10	-451.14	-18664.50														1							≥	0
T3 (R)	280.81	-1470.96	-559.34	300.98	-1475.51	-1183.71	88.23	-1386.15	-1081.30	-1391.02	-1081.78	215.87	-13876.49															1						≥	0
T4 (R)	-4621.12	-1218.48	-344.87	-4693.91	-1230.81	-1466.43	-3885.42	-1194.91	-1498.46	-1208.09	-1458.15	974.31	-11757.38																1					≥	0
T5 (R)	1420.64	628.11	-485.00	1423.65	625.02	249.24	2226.32	607.74	192.30	604.44	206.92	348.02	28193.64																	1				≥	0
T6 (R)	-200.08	1446.35	-1838.46	-200.83	1465.36	-1098.91	-3168.31	1555.11	-1183.76	1575.45	-1163.46	2169.64	24826.35																		1			≥	0
Sum (R)																										-1	-1	-1	-1	-1	-1	1		=	0
Conv (R)																																-0.26	1	=	0
Without GM								1	1	1	1																							=	0
OBJ: L= E[GM]-θσ (R)	-14719.12	-14759.54	-14759.54	-14821.80	-14759.54	-14759.54	-14762.88	-13297.38	-13739.57	-13297.38	-13739.57	14577.18	2266.55	-1	-1			-1	-1			4583.48											-1.036	MAX!	

Appendix 8: Coastal baseline scenario results

Microsoft Excel 15.0 Answer Report
Worksheet: [NC Farm representative in progress.xlsx]Coastal Area
Report Created: 2019/05/23 10:01:59 PM
Result: Solver found a solution. All Constraints and optimality conditions are satisfied.
Solver Engine
Engine: Simplex LP
Solution Time: 0.063 Seconds.
Iterations: 70 Subproblems: 0
Solver Options
Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegative

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$B$7	OBJ: L= E[GM]-θσ (R)	0	R 6 688 513.37

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$11	SS N41	0	0	Contin
$B$12	SS N51	0	0	Contin
$B$13	SS N52	0	100	Contin
$B$14	LS N51	0	106.6666667	Contin
$B$15	LS N52	0	6.666666667	Contin
$B$16	LS N59	0	6.666666667	Contin
$B$17	Clay N52	0	0	Contin
$B$18	Clay N59	0	100	Contin
$B$19	SS GM N51	0	0	Contin
$B$20	SS GM N52	0	0	Contin
$B$21	LS GM N51	0	0	Contin
$B$22	LS GM 52	0	0	Contin
$B$23	Clay GM N51	0	0	Contin
$B$24	Clay GM N52	0	0	Contin
$B$25	SS Macs	0	0	Contin
$B$26	LS Macs	0	0	Contin
$B$27	LS Banana	0	0	Contin
$B$28	Clay Macs	0	80	Contin
$B$29	Clay Banana	0	-7.47286E-14	Contin
$B$30	Weeding conventional (R/ha/Yr)	0	1766762.667	Contin
$B$31	Weeding in GM cane (R/ha/Yr)	0	0	Contin
$B$32	scouting (hours/ha)	0	4200	Contin

$B$33	scouting GM (hours/ha)	0	0	Contin
$B$34	Chemical control (R/ha/Yr)	0	945600	Contin
$B$35	Chemical control GM (R/ha/Yr)	0	0	Contin
$B$36	Conventional cane (t)	0	20268.61667	Contin
$B$37	GM Cane (t)	0	0	Contin
$B$38	RV Sales (t)	0	2736.052759	Contin
$B$39	Macs (t)	0	640	Contin
$B$40	Banana (t)	0	0	Contin
$B$41	Labour hire (days)	0	96000	Contin
$B$42	D1 (R)	0	0	Contin
$B$43	D2 (R)	0	0	Contin
$B$44	D3 (R)	0	153619.1169	Contin
$B$45	D4 (R)	0	520919.8401	Contin
$B$46	D5 (R)	0	0	Contin
$B$47	D6 (R)	0	274043.2814	Contin
$B$48	0.5TAD (R)	0	948582.2385	Contin
$B$49	SD (R)	0	246631.382	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$55	Sandy Soils (ha)	100	$B$55<=$D$55	Binding	0
$B$56	Loamy soils (ha)	120	$B$56<=$D$56	Binding	0
$B$57	Clay (ha)	180	$B$57<=$D$57	Binding	0
$B$59	Labour (days)	-2.47383E-09	$B$59=$D$59	Binding	0
$B$60	*Eldana* Chemical Control (R)	-2.6077E-08	$B$60=$D$60	Binding	0
$B$61	*Eldana* Chemical Control GM (R)	0	$B$61=$D$61	Binding	0
$B$62	*Eldana* control: scouting (Hours)	600	$B$62<=$D$62	Binding	0
$B$63	*Eldana* control: scouting GM(Hours)	0	$B$63<=$D$63	Not Binding	400
$B$65	Conventional transfer (t)	5.34783E-10	$B$65=$D$65	Binding	0
$B$66	GM cane Transfer (t)	0	$B$66=$D$66	Binding	0
$B$67	Cane: RV Conversion (t)	6.68479E-11	$B$67=$D$67	Binding	0
$B$68	Macadamia nuts transfer (t)	0	$B$68=$D$68	Binding	0
$B$69	Banana transfer (t)	1.86822E-12	$B$69=$D$69	Binding	0
$B$70	N41 Constraint	320	$B$70>=$D$70	Not Binding	320
$B$71	N51 Constraint	-1.68967E-11	$B$71>=$D$71	Binding	0
$B$72	N52 Constraint	2.00231E-11	$B$72>=$D$72	Binding	0
$B$73	N59 Constraint	-3.12639E-12	$B$73>=$D$73	Binding	0
$B$74	GM N51 Constraint	320	$B$74>=$D$74	Not Binding	320
$B$75	GM N52 Constraint	320	$B$75>=$D$75	Not Binding	320

$B$76	Macs /Banana Constraint	1.26183E-12	$B$76<=$D$76	Binding	0
$B$77	Weeding Conventional (R)	-4.58676E-08	$B$77=$D$77	Binding	0
$B$78	Weeding GM (R)	0	$B$78=$D$78	Binding	0
$B$82	T1 (R)	334138.4629	$B$82>=$D$82	Not Binding	334138.4629
$B$83	T2 (R)	388457.4679	$B$83>=$D$83	Not Binding	388457.4679
$B$84	T3 (R)	9.98261E-09	$B$84>=$D$84	Binding	0
$B$85	T4 (R)	8.44011E-09	$B$85>=$D$85	Binding	0
$B$86	T5 (R)	186952.9049	$B$86>=$D$86	Not Binding	186952.9049
$B$87	T6 (R)	1.72295E-08	$B$87>=$D$87	Binding	0
$B$88	Sum (R)	2.33995E-08	$B$88=$D$88	Binding	0
$B$89	Conv (R)	-7.567E-10	$B$89=$D$89	Binding	0
$B$90	Without GM	0	$B$90=$D$90	Binding	0

Microsoft Excel 15.0 Sensitivity Report
Worksheet: [NC Farm representative in progress.xlsx]Coastal Area
Report Created: 2019/05/23 10:01:59 PM

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$B$11	SS N41	0	-5494.87097	-14719.12472	5494.87097	1E+30
$B$12	SS N51	0	-1410.989291	-14759.54028	1410.989291	1E+30
$B$13	SS N52	100	0	-14821.79694	7.09627E+15	225.1649624
$B$14	LS N51	106.6666667	0	-14759.54028	837.5460149	1410.989291
$B$15	LS N52	6.666666667	0	-14821.79694	225.1649624	837.5460149
$B$16	LS N59	6.666666667	0	-14762.8825	640.2075454	1096.797415
$B$17	Clay N52	0	-1898.681603	-14821.79694	1898.681603	1E+30

$B$18	Clay N59	100	0	-14775.21583	1096.797415	640.2075454
$B$19	SS GM N51	0	-1914.357004	-13297.37716	1914.357004	1E+30
$B$20	SS GM N52	0	-225.1649624	-13739.57231	225.1649624	1E+30
$B$21	LS GM N51	0	-473.4945376	-13297.37716	473.4945376	1E+30
$B$22	LS GM 52	0	0	-13739.57231	1E+30	225.1649624
$B$23	Clay GM N51	0	-640.2075454	-13297.37716	640.2075454	1E+30
$B$24	Clay GM N52	0	-1174.686902	-13739.57231	1174.686902	1E+30
$B$25	SS Macs	0	-8682.323584	14577.18352	8682.323584	1E+30
$B$26	LS Macs	0	-1743.677301	20747.18831	1743.677301	1E+30
$B$27	LS Banana	0	-1096.797415	2266.55	1096.797415	1E+30
$B$28	Clay Macs	80	0	23087.79664	2.4733E+16	1743.677301
$B$29	Clay Banana	-7.47286E-14	0	2266.55	13623.16114	1370.996768
$B$30	Weeding conventional (R/ha/Yr)	1766762.667	0	-1	1.586579851	3.648705982
$B$31	Weeding in GM cane (R/ha/Yr)	0	0	-1	1E+30	1E+30
$B$32	scouting (hours/ha)	4200	0	0	0	1342.999481
$B$33	scouting GM (hours/ha)	0	0	0	0	1E+30
$B$34	Chemical control (R/ha/Yr)	945600	0	-1	2.964371878	6.81725625
$B$35	Chemical control GM (R/ha/Yr)	0	0	-1	1E+30	1E+30
$B$36	Conventional cane (t)	20268.61667	0	0	137.2908465	122.957575

$B$37	GM Cane (t)	0	0	0	160.7925304	64.96475548
$B$38	RV Sales (t)	2736.052759	0	4583.481008	1016.257052	1325.345449
$B$39	Macs (t)	640	0	0	3.05438E+15	685.4983842
$B$40	Banana (t)	0	-544.9264455	0	544.9264455	1E+30
$B$41	Labour hire (days)	96000	0	0	29.199063	67.14997407
$B$42	D1 (R)	0	-0.26936	0	0.26936	1E+30
$B$43	D2 (R)	0	-0.26936	0	0.26936	1E+30
$B$44	D3 (R)	153619.1169	0	0	0.26936	4.854356082
$B$45	D4 (R)	520919.8401	0	0	0.193794829	0.157426807
$B$46	D5 (R)	0	-0.26936	0	0.26936	1E+30
$B$47	D6 (R)	274043.2814	0	0	0.26936	0.172877136
$B$48	0.5TAD (R)	948582.2385	0	0	0.211122299	0.130313711
$B$49	SD (R)	246631.382	0	-1.036	0.81200884	0.501206581

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$B$55	Sandy Soils (ha)	100	17156.7311	100	0	14.28571429
$B$56	Loamy soils (ha)	120	16115.99378	120	500	14.28571429
$B$57	Clay (ha)	180	16882.8945	180	0	25
$B$59	Labour (days)	-2.47383E-09	0	0	96000	1E+30
$B$60	*Eldana* Chemical Control (R)	-2.6077E-08	1	0	945600	1E+30
$B$61	*Eldana* Chemical Control GM (R)	0	1	0	0	1E+30
$B$62	*Eldana* control: scouting (Hours)	600	0	600	4200	1E+30
$B$63	*Eldana* control: scouting GM(Hours)	0	0	400	1E+30	400
$B$65	Conventional transfer (t)	5.34783E-10	0	0	1E+30	20268.61667

$B$66	GM cane Transfer (t)	0	0	0	1E+30	0
$B$67	Cane: RV Conversion (t)	6.68479E-11	4583.481008	0	1E+30	2736.052759
$B$68	Macadamia nuts transfer (t)	0	0	0	1E+30	640
$B$69	Banana transfer (t)	1.86822E-12	544.9264455	0	0	491.3550923
$B$70	N41 Constraint	320	0	0	320	1E+30
$B$71	N51 Constraint	-1.68967E-11	0	0	4.12115E-12	1E+30
$B$72	N52 Constraint	2.00231E-11	-279.182005	0	0	320
$B$73	N59 Constraint	-3.12639E-12	-697.1882303	0	4.12115E-12	0
$B$74	GM N51 Constraint	320	0	0	320	1E+30
$B$75	GM N52 Constraint	320	0	0	320	1E+30
$B$76	Macs /Banana Constraint	1.26183E-12	8759.718899	0	0	10
$B$77	Weeding Conventional (R)	-4.58676E-08	1	0	1766762.667	1E+30
$B$78	Weeding GM (R)	0	1	0	0	1E+30
$B$82	T1 (R)	334138.4629	0	0	334138.4629	1E+30
$B$83	T2 (R)	388457.4679	0	0	388457.4679	1E+30
$B$84	T3 (R)	9.98261E-09	-0.26936	0	1E+30	153619.1169
$B$85	T4 (R)	8.44011E-09	-0.26936	0	1E+30	520919.8401
$B$86	T5 (R)	186952.9049	0	0	186952.9049	1E+30
$B$87	T6 (R)	1.72295E-08	-0.26936	0	1.17301E+21	274043.2814
$B$88	Sum (R)	2.33995E-08	-0.26936	0	1E+30	948582.2385
$B$89	Conv (R)	-7.567E-10	-1.036	0	1E+30	246631.382
$B$90	Without GM	0	10020.00374	0	0	0

Microsoft Excel 15.0 Limits Report

Worksheet: [NC Farm representative in progress.xlsx]Coastal Area
Report Created: 2019/05/23 10:02:00 PM

Cell	Objective Name	Value
$B$7	OBJ: L= E[GM]-θσ (R)	6688513.37

Cell	Variable Name	Value	Lower Limit	Objective Result	Upper Limit	Objective Result
$B$11	SS N41	0	8.24609E-12	6688513.372	8.24609E-12	6688513.372
$B$12	SS N51	0	8.24609E-12	6688513.372	8.24609E-12	6688513.372
$B$13	SS N52	100	100	6688513.372	100	6688513.372
$B$14	LS N51	106.6666667	106.6666667	6688513.372	106.6666667	6688513.372
$B$15	LS N52	6.666666667	6.666666667	6688513.372	6.666666667	6688513.372
$B$16	LS N59	6.666666667	6.666666667	6688513.372	6.666666667	6688513.372
$B$17	Clay N52	0	8.24609E-12	6688513.372	8.24609E-12	6688513.372
$B$18	Clay N59	100	100	6688513.372	100	6688513.372
$B$19	SS GM N51	0	0	6688513.372	0	6688513.372
$B$20	SS GM N52	0	0	6688513.372	0	6688513.372
$B$21	LS GM N51	0	0	6688513.372	0	6688513.372
$B$22	LS GM 52	0	0	6688513.372	0	6688513.372
$B$23	Clay GM N51	0	0	6688513.372	0	6688513.372
$B$24	Clay GM N52	0	0	6688513.372	0	6688513.372
$B$25	SS Macs	0	0	6688513.372	0	6688513.372
$B$26	LS Macs	0	0	6688513.372	0	6688513.372
$B$27	LS Banana	0	9.34108E-14	6688513.372	9.34108E-14	6688513.372

$B$28	Clay Macs	80	80	6688513.372	80	6688513.372
$B$29	Clay Banana	-7.47286E-14	0	6688513.372	0	6688513.372
$B$30	Weeding conventional (R/ha/Yr)	1766762.667	1766762.667	6688513.372	1766762.667	6688513.372
$B$31	Weeding in GM cane (R/ha/Yr)	0	0	6688513.372	0	6688513.372
$B$32	scouting (hours/ha)	4200	4200	6688513.372	#N/A	#N/A
$B$33	scouting GM (hours/ha)	0	0	6688513.372	#N/A	#N/A
$B$34	Chemical control (R/ha/Yr)	945600	945600	6688513.372	945600	6688513.372
$B$35	Chemical control GM (R/ha/Yr)	0	0	6688513.372	0	6688513.372
$B$36	Conventional cane (t)	20268.61667	20268.61667	6688513.372	20268.61667	6688513.372
$B$37	GM Cane (t)	0	0	6688513.372	0	6688513.372
$B$38	RV Sales (t)	2736.052759	2736.052759	6688513.372	2736.052759	6688513.372
$B$39	Macs (t)	640	640	6688513.372	640	6688513.372
$B$40	Banana (t)	0	-1.86822E-12	6688513.372	-1.86822E-12	6688513.372
$B$41	Labour hire (days)	96000	96000	6688513.372	96000	6688513.372
$B$42	D1 (R)	0	2.33995E-08	6688513.372	2.33995E-08	6688513.372
$B$43	D2 (R)	0	2.33995E-08	6688513.372	2.33995E-08	6688513.372
$B$44	D3 (R)	153619.1169	153619.1169	6688513.372	153619.1169	6688513.372
$B$45	D4 (R)	520919.8401	520919.8401	6688513.372	520919.8401	6688513.372
$B$46	D5 (R)	0	2.33995E-08	6688513.372	2.33995E-08	6688513.372
$B$47	D6 (R)	274043.2814	274043.2814	6688513.372	274043.2814	6688513.372
$B$48	0.5TAD (R)	948582.2385	#N/A	#N/A	#N/A	#N/A
$B$49	SD (R)	246631.382	246631.382	6688513.372	246631.382	6688513.372

Appendix 9: Coastal results including GM cultivars

Microsoft Excel 15.0 Answer Report

Worksheet: [NC Farm representative in progress.xlsx]Coastal Area
Report Created: 2019/05/23 09:56:12 PM
Result: Solver found a solution. All Constraints and optimality conditions are satisfied.
Solver Engine
Engine: Simplex LP
Solution Time: 0.063 Seconds.
Iterations: 76 Subproblems: 0
Solver Options
Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegative

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$B$7	OBJ: L= E[GM]-θσ (R)	0	R 8 663 753.35

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$11	SS N41	0	0	Contin
$B$12	SS N51	0	0	Contin
$B$13	SS N52	0	4.34E-13	Contin
$B$14	LS N51	0	0	Contin
$B$15	LS N52	0	0	Contin
$B$16	LS N59	0	6.67	Contin
$B$17	Clay N52	0	0	Contin
$B$18	Clay N59	0	100	Contin
$B$19	SS GM N51	0	0	Contin
$B$20	SS GM N52	0	100	Contin
$B$21	LS GM N51	0	106.67	Contin
$B$22	LS GM 52	0	6.67	Contin

$B$2 3	Clay GM N51	0	0	Contin
$B$2 4	Clay GM N52	0	0	Contin
$B$2 5	SS Macs	0	0	Contin
$B$2 6	LS Macs	0	0	Contin
$B$2 7	LS Banana	0	0	Contin
$B$2 8	Clay Macs	0	80	Contin
$B$2 9	Clay Banana	0	-3.49E-14	Contin
$B$3 0	Weeding conventional (R/ha/Yr)	0	593198.93	Contin
$B$3 1	Weeding in GM cane (R/ha/Yr)	0	524508.11	Contin
$B$3 2	scouting (hours/ha)	0	1000	Contin
$B$3 3	scouting GM (hours/ha)	0	1733.33	Contin
$B$3 4	Chemical control (R/ha/Yr)	0	315200	Contin
$B$3 5	Chemical control GM (R/ha/Yr)	0	210133.33	Contin
$B$3 6	Conventional cane (t)	0	6904.50	Contin
$B$3 7	GM Cane (t)	0	14299.61	Contin
$B$3 8	RV Sales (t)	0	2879.11	Contin
$B$3 9	Macs (t)	0	640	Contin
$B$4 0	Banana (t)	0	0	Contin
$B$4 1	Labour hire (days)	0	83200	Contin
$B$4 2	D1 (R)	0	0	Contin
$B$4 3	D2 (R)	0	0	Contin
$B$4 4	D3 (R)	0	196122.82	Contin
$B$4 5	D4 (R)	0	633801.94	Contin
$B$4 6	D5 (R)	0	0	Contin

$B$47	D6 (R)	0	197261.54	Contin
$B$48	0.5TAD (R)	0	1027186.30	Contin
$B$49	SD (R)	0	267068.44	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$55	Sandy Soils (ha)	100	$B$55<=$D$55	Binding	0
$B$56	Loamy soils (ha)	120	$B$56<=$D$56	Binding	0
$B$57	Clay (ha)	180	$B$57<=$D$57	Binding	0
$B$59	Labour (days)	-2.91038E-10	$B$59=$D$59	Binding	0
$B$60	*Eldana* Chemical Control (R)	5.12227E-09	$B$60=$D$60	Binding	0
$B$61	*Eldana* Chemical Control GM (R)	-2.67755E-09	$B$61=$D$61	Binding	0
$B$62	*Eldana* control: scouting (Hours)	600	$B$62<=$D$62	Binding	0
$B$63	*Eldana* control: scouting GM(Hours)	400	$B$63<=$D$63	Binding	0
$B$65	Conventional transfer (t)	-1.60981E-10	$B$65=$D$65	Binding	0
$B$66	GM cane Transfer (t)	1.18234E-10	$B$66=$D$66	Binding	0
$B$67	Cane: RV Conversion (t)	1.50067E-11	$B$67=$D$67	Binding	0
$B$68	Macadamia nuts transfer (t)	8.07177E-12	$B$68=$D$68	Binding	0
$B$69	Banana transfer (t)	8.73278E-13	$B$69=$D$69	Binding	0
$B$70	N41 Constraint	320	$B$70>=$D$70	Not Binding	320
$B$71	N51 Constraint	320	$B$71>=$D$71	Not Binding	320
$B$72	N52 Constraint	320	$B$72>=$D$72	Not Binding	320
$B$73	N59 Constraint	1.09512E-12	$B$73>=$D$73	Binding	0
$B$74	GM N51 Constraint	4.2073E-12	$B$74>=$D$74	Binding	0
$B$75	GM N52 Constraint	-4.00924E-12	$B$75>=$D$75	Binding	0

$B$76	Macs /Banana Constraint	1.56796E-13	$B$76<=$D$76	Binding	0
$B$77	Weeding Conventional (R)	1.75787E-08	$B$77=$D$77	Binding	0
$B$78	Weeding GM (R)	-7.79983E-09	$B$78=$D$78	Binding	0
$B$82	T1 (R)	402133.942	$B$82>=$D$82	Not Binding	402133.942
$B$83	T2 (R)	333813.5195	$B$83>=$D$83	Not Binding	333813.5195
$B$84	T3 (R)	5.41331E-09	$B$84>=$D$84	Binding	0
$B$85	T4 (R)	-7.567E-09	$B$85>=$D$85	Binding	0
$B$86	T5 (R)	252205.4361	$B$86>=$D$86	Not Binding	252205.4361
$B$87	T6 (R)	-8.44011E-09	$B$87>=$D$87	Binding	0
$B$88	Sum (R)	4.17931E-08	$B$88=$D$88	Binding	0
$B$89	Conv (R)	-5.52973E-09	$B$89=$D$89	Binding	0

Microsoft Excel 15.0 Sensitivity Report
Worksheet: [NC Farm representative in progress.xlsx]Coastal Area
Report Created: 2019/05/23 09:56:12 PM

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowab Decrea
$B$11	SS N41	0	-6332.416985	-14719.12472	6332.416985	1E
$B$12	SS N51	0	-2248.535306	-14759.54028	2248.535306	1E
$B$13	SS N52	4.34319E-13	0	-14821.79694	1028.853714	225.1649
$B$14	LS N51	0	-1062.710977	-14759.54028	1062.710977	1E
$B$15	LS N52	0	-225.1649624	-14821.79694	225.1649624	1E
$B$16	LS N59	6.666666667	0	-14762.8825	166.7130079	1028.853
$B$17	Clay N52	0	-2123.846565	-14821.79694	2123.846565	1E
$B$18	Clay N59	100	0	-14775.21583	1096.797415	166.7130

$B$19	SS GM N51	0	-1215.697504	-13297.37716	1215.697504	1E
$B$20	SS GM N52	100	0	-13739.57231	225.1649624	1028.853
$B$21	LS GM N51	106.6666667	0	-13297.37716	7550.189778	166.7130
$B$22	LS GM 52	6.666666667	0	-13739.57231	1028.853714	225.1649
$B$23	Clay GM N51	0	-166.7130079	-13297.37716	166.7130079	1E
$B$24	Clay GM N52	0	-1174.686902	-13739.57231	1174.686902	1E
$B$25	SS Macs	0	-8457.158621	14577.18352	8457.158621	1E
$B$26	LS Macs	0	-1743.677301	20747.18831	1743.677301	1E
$B$27	LS Banana	0	-1096.797415	2266.55	1096.797415	1E
$B$28	Clay Macs	80	0	23087.79664	2.46728E+16	1743.677
$B$29	Clay Banana	-3.49311E-14	0	2266.55	13623.16114	1370.996
$B$30	Weeding conventional (R/ha/Yr)	593198.9333	0	-1	1.357645018	11.40130
$B$31	Weeding in GM cane (R/ha/Yr)	524508.112	0	-1	1.535445416	
$B$32	scouting (hours/ha)	1000	0	0	0	5277.596
$B$33	scouting GM (hours/ha)	1733.333333	0	0	0	848.3798
$B$34	Chemical control (R/ha/Yr)	315200	0	-1	2.555055763	26.78982
$B$35	Chemical control GM (R/ha/Yr)	210133.3333	0	-1	3.832583644	
$B$36	Conventional cane (t)	6904.498889	0	0	112.1027287	130.8692
$B$37	GM Cane (t)	14299.60602	0	0	56.87697351	125.421
$B$38	RV Sales (t)	2879.107593	0	4583.481008	277.711151	2130.114
$B$39	Macs (t)	640	0	0	2.45059E+15	314.5912
$B$40	Banana (t)	0	-544.9264455	0	544.9264455	1E
$B$41	Labour hire (days)	83200	0	0	9.679730485	101.4922
$B$42	D1 (R)	0	-0.26936	0	0.26936	1E
$B$43	D2 (R)	0	-0.26936	0	0.26936	1E
$B$44	D3 (R)	196122.8199	0	0	0.26936	7.537301
$B$45	D4 (R)	633801.9402	0	0	0.193794829	0.157426
$B$46	D5 (R)	0	-0.26936	0	0.26936	1E
$B$47	D6 (R)	197261.5401	0	0	0.26936	0.279565
$B$48	0.5TAD (R)	1027186.3	0	0	0.211122299	0.130313
$B$49	SD (R)	267068.438	0	-1.036	0.81200884	0.501206

Constraints

		Final	Shadow	Constraint	Allowable	Allowab

Cell	Name	Value	Price	R.H. Side	Increase	Decrea
$B$55	Sandy Soils (ha)	100	21925.95732	100	7.312149533	14.28571
$B$56	Loamy soils (ha)	120	21110.38495	120	0	14.28571
$B$57	Clay (ha)	180	21877.28567	180	0	21.26086
$B$59	Labour (days)	-2.91038E-10	0	0	83200	1E
$B$60	*Eldana* Chemical Control (R)	5.12227E-09	1	0	315200	1E
$B$61	*Eldana* Chemical Control GM (R)	-2.67755E-09	1	0	210133.3333	1E
$B$62	*Eldana* control: scouting (Hours)	600	0	600	1000	3.90713E
$B$63	*Eldana* control: scouting GM(Hours)	400	0	400	1733.333333	1E
$B$65	Conventional transfer (t)	-1.60981E-10	0	0	1E+30	6904.498
$B$66	GM cane Transfer (t)	1.18234E-10	0	0	1E+30	14299.60
$B$67	Cane: RV Conversion (t)	1.50067E-11	4583.481008	0	1E+30	2879.107
$B$68	Macadamia nuts transfer (t)	8.07177E-12	0	0	1E+30	
$B$69	Banana transfer (t)	8.73278E-13	544.9264455	0	0	353.6866
$B$70	N41 Constraint	320	0	0	320	1E
$B$71	N51 Constraint	320	0	0	320	1E
$B$72	N52 Constraint	320	0	0	320	1E
$B$73	N59 Constraint	1.09512E-12	-342.9512378	0	20	
$B$74	GM N51 Constraint	4.2073E-12	-2827.93274	0	300	
$B$75	GM N52 Constraint	-4.00924E-12	-2985.764253	0	300	1.30296E
$B$76	Macs /Banana Constraint	1.56796E-13	2516.729926	0	0	
$B$77	Weeding Conventional (R)	1.75787E-08	1	0	593198.9333	1E
$B$78	Weeding GM (R)	-7.79983E-09	1	0	524508.112	1E
$B$82	T1 (R)	402133.942	0	0	402133.942	1E
$B$83	T2 (R)	333813.5195	0	0	333813.5195	1E
$B$84	T3 (R)	5.41331E-09	-0.26936	0	5.76461E+18	196122.8
$B$85	T4 (R)	-7.567E-09	-0.26936	0	1E+30	633801.9
$B$86	T5 (R)	252205.4361	0	0	252205.4361	1E
$B$87	T6 (R)	-8.44011E-09	-0.26936	0	1E+30	197261.5
$B$88	Sum (R)	4.17931E-08	-0.26936	0	1E+30	10271
$B$89	Conv (R)	-5.52973E-09	-1.036	0	1E+30	267068.

Microsoft Excel 15.0 Limits Report

Worksheet: [NC Farm representative in progress.xlsx]Coastal Area
Report Created: 2019/05/23 09:56:13 PM

Cell	Objective Name	Value
$B$7	OBJ: L= E[GM]-θσ (R)	8663753.34

Cell	Variable Name	Value	Lower Limit	Objective Result	Upper Limit	Obj Re
$B$11	SS N41	0	9.70128E-13	8663753.348	9.70128E-13	8663
$B$12	SS N51	0	9.70128E-13	8663753.348	9.70128E-13	8663
$B$13	SS N52	4.34319E-13	1.40669E-12	8663753.348	1.40669E-12	8663
$B$14	LS N51	0	9.70128E-13	8663753.348	9.70128E-13	8663
$B$15	LS N52	0	9.70128E-13	8663753.348	9.70128E-13	8663
$B$16	LS N59	6.666666667	6.666666667	8663753.348	6.666666667	8663
$B$17	Clay N52	0	9.70128E-13	8663753.348	9.70128E-13	8663
$B$18	Clay N59	100	100	8663753.348	100	8663
$B$19	SS GM N51	0	1.21266E-12	8663753.348	1.21266E-12	8663
$B$20	SS GM N52	100	100	8663753.348	100	8663
$B$21	LS GM N51	106.6666667	106.6666667	8663753.348	106.6666667	8663
$B$22	LS GM 52	6.666666667	6.666666667	8663753.348	6.666666667	8663
$B$23	Clay GM N51	0	1.21266E-12	8663753.348	1.21266E-12	8663
$B$24	Clay GM N52	0	1.21266E-12	8663753.348	1.21266E-12	8663
$B$25	SS Macs	0	4.03588E-12	8663753.348	4.03588E-12	8663
$B$26	LS Macs	0	1.34529E-12	8663753.348	1.34529E-12	8663
$B$27	LS Banana	0	4.36639E-14	8663753.348	4.36639E-14	8663
$B$28	Clay Macs	80	80	8663753.348	80	8663
$B$29	Clay Banana	-3.49311E-14	0	8663753.348	0	8663
$B$30	Weeding conventional (R/ha/Yr)	593198.9333	593198.9333	8663753.348	593198.9333	8663
$B$31	Weeding in GM cane (R/ha/Yr)	524508.112	524508.112	8663753.348	524508.112	8663
$B$32	scouting (hours/ha)	1000	1000	8663753.348	#N/A	#
$B$33	scouting GM (hours/ha)	1733.333333	1733.333333	8663753.348	#N/A	#
$B$34	Chemical control (R/ha/Yr)	315200	315200	8663753.348	315200	8663
$B$35	Chemical control GM (R/ha/Yr)	210133.3333	210133.3333	8663753.348	210133.3333	8663
$B$36	Conventional cane (t)	6904.498889	6904.498889	8663753.348	6904.498889	8663
$B$37	GM Cane (t)	14299.60602	14299.60602	8663753.348	14299.60602	8663
$B$38	RV Sales (t)	2879.107593	2879.107593	8663753.348	2879.107593	8663

$B$39	Macs (t)	640	640	8663753.348	640	8663
$B$40	Banana (t)	0	-8.73278E-13	8663753.348	-8.73278E-13	8663
$B$41	Labour hire (days)	83200	83200	8663753.348	83200	8663
$B$42	D1 (R)	0	4.17931E-08	8663753.348	4.17931E-08	8663
$B$43	D2 (R)	0	4.17931E-08	8663753.348	4.17931E-08	8663
$B$44	D3 (R)	196122.8199	196122.8199	8663753.348	196122.8199	8663
$B$45	D4 (R)	633801.9402	633801.9402	8663753.348	633801.9402	8663
$B$46	D5 (R)	0	4.17931E-08	8663753.348	4.17931E-08	8663
$B$47	D6 (R)	197261.5401	197261.5401	8663753.348	197261.5401	8663
$B$48	0.5TAD (R)	1027186.3	#N/A	#N/A	#N/A	#
$B$49	SD (R)	267068.438	267068.438	8663753.348	267068.438	8663

Appendix 10: Hinterland baseline scenario results

Microsoft Excel 15.0 Answer Report
Worksheet: [NC Farm representative in progress.xlsx]Inlands
Report Created: 2019/05/23 10:29:08 PM
Result: Solver found a solution. All Constraints and optimality conditions are satisfied.
Solver Engine
Engine: Simplex LP
Solution Time: 0.047 Seconds.
Iterations: 59 Subproblems: 0
Solver Options
Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegative

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$B$6	OBJ: L= E[GM]-θσ (R)	0	R 4 818 310.18

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$11	SS N41	0	0	Contin
$B$12	SS N51	0	0	Contin

$B$13	SS N52	0	0	Contin
$B$14	LS N41	0	-2.73689E-10	Contin
$B$15	LS N51	0	106.6666667	Contin
$B$16	LS N52	0	106.6666667	Contin
$B$17	LS N59	0	106.6666667	Contin
$B$18	SS GM N51	0	0	Contin
$B$19	SS GM N52	0	0	Contin
$B$20	LS GM N51	0	0	Contin
$B$21	LS GM N52	0	0	Contin
$B$22	SS Macs	0	40	Contin
$B$23	LS Bananas	0	40	Contin
$B$24	Weeding conventional (R/ha/Yr)	0	1766762.667	Contin
$B$25	Weeding in GM cane (R/ha/Yr)	0	0	Contin
$B$26	scouting (hours/ha)	0	4200	Contin
$B$27	scouting GM (hours/ha)	0	0	Contin
$B$28	Chemical control (R/ha/Yr)	0	945600	Contin
$B$29	Chemical control GM (R/ha/Yr)	0	0	Contin
$B$30	Conventional cane (t)	0	20010.66667	Contin
$B$31	GM Cane (t)	0	0	Contin
$B$32	RV Sales (t)	0	2701.529889	Contin
$B$33	Macs (t)	0	80	Contin
$B$34	Banana (t)	0	800	Contin
$B$35	Labour hire (days)	0	96000	Contin
$B$36		0	0	Contin
$B$37	D1 (R)	0	532299.6328	Contin
$B$38	D2 (R)	0	491282.0821	Contin
$B$39	D3 (R)	0	820663.7649	Contin
$B$40	D4 (R)	0	1133472.234	Contin
$B$41	D5 (R)	0	0	Contin
$B$42	D6 (R)	0	0	Contin
$B$43	0.5TAD (R)	0	2977717.713	Contin
$B$44	SD (R)	0	774206.6055	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$50	Sandy soil (ha)	40	$B$50<=$D$50	Binding	0
$B$51	Loamy soils (ha)	360	$B$51<=$D$51	Binding	0
$B$52	Labour (days)	-7.69069E-08	$B$52=$D$52	Binding	0
$B$53	*Eldana* Chemical Control (R)	-7.33417E-07	$B$53=$D$53	Binding	0
$B$54	*Eldana* Chemical Control GM (R)	0	$B$54=$D$54	Binding	0
$B$55	*Eldana* control: scouting (R)	600	$B$55<=$D$55	Binding	0
$B$56	*Eldana* control: scouting GM (R)	0	$B$56<=$D$56	Not Binding	400
$B$58	Conventional transfer (t)	1.45956E-08	$B$58=$D$58	Binding	0

$B$59	GM cane Transfer (t)	0	$B$59=$D$59	Binding	0
$B$60	Cane: RV Conversion (t)	2.045E-09	$B$60=$D$60	Binding	0
$B$61	Macadamia nuts transfer (t)	2.41585E-13	$B$61=$D$61	Binding	0
$B$62	Banana Transfer (t)	3.22871E-11	$B$62=$D$62	Binding	0
$B$63	N41 Constraint	320	$B$63>=$D$63	Not Binding	320
$B$64	N52 Constraint	-2.72507E-10	$B$64>=$D$64	Binding	0
$B$65	N51 Constraint	-3.15794E-10	$B$65>=$D$65	Binding	0
$B$66	N59 Constraint	-2.32774E-10	$B$66>=$D$66	Binding	0
$B$67	GM N51 Constraint	320	$B$67>=$D$67	Not Binding	320
$B$68	GM N52 Constraint	320	$B$68>=$D$68	Not Binding	320
$B$69	Mac/banana Constraint	5.45057E-11	$B$69>=$D$69	Binding	0
$B$70	Weeding Conventional (R)	-1.23307E-06	$B$70=$D$70	Binding	0
$B$71	Weeding GM (R)	0	$B$71=$D$71	Binding	0
$B$75	T1 (R)	-8.34116E-07	$B$75>=$D$75	Binding	0
$B$76	T2 (R)	-9.21427E-08	$B$76>=$D$76	Binding	0
$B$77	T3 (R)	-1.32015E-07	$B$77>=$D$77	Binding	0
$B$78	T4 (R)	1.26846E-06	$B$78>=$D$78	Not Binding	1.26846E-06
$B$79	T5 (R)	1472394.846	$B$79>=$D$79	Not Binding	1472394.846
$B$80	T6 (R)	780974.6685	$B$80>=$D$80	Not Binding	780974.6685
$B$81	Sum (R)	-1.11759E-08	$B$81=$D$81	Binding	0
$B$82	Conv (R)	1.24564E-08	$B$82=$D$82	Binding	0
$B$83	Without GM	0	$B$83=$D$83	Binding	0

Microsoft Excel 15.0 Sensitivity Report
Worksheet: [NC Farm representative in progress.xlsx]Inlands
Report Created: 2019/05/23 10:29:09 PM

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowa Decrea
$B$11	SS N41	0	-29802.13999	-14719.12472	29802.13999	1E

$B$12	SS N51	0	-29901.13188	-14759.54028	29901.13188	1E
$B$13	SS N52	0	-28738.78295	-14759.54028	28738.78295	1E
$B$14	LS N41	-2.73689E-10	0	-14821.79694	3434.379495	29802.13
$B$15	LS N51	106.6666667	0	-14759.54028	5.81883E+15	3434.379
$B$16	LS N52	106.6666667	0	-14759.54028	6.42738E+15	5801.69
$B$17	LS N59	106.6666667	0	-14762.8825	5.9949E+15	7884.70
$B$18	SS GM N51	0	-32340.47228	-13297.37716	32340.47228	1E
$B$19	SS GM N52	0	-29064.24498	-13739.57231	29064.24498	1E
$B$20	LS GM N51	0	-2040.131302	-13297.37716	2040.131302	1E
$B$21	LS GM N52	0	0	-13739.57231	1E+30	2040.13
$B$22	SS Macs	40	0	14577.18352	3.62873E+15	28738.78
$B$23	LS Bananas	40	0	2266.55	28738.78295	45276.16
$B$24	Weeding conventional (R/ha/Yr)	1766762.667	0	-1	20.92475169	2.050130
$B$25	Weeding in GM cane (R/ha/Yr)	0	0	-1	1E+30	1E
$B$26	scouting (hours/ha)	4200	0	0	2.27374E-13	754.602
$B$27	scouting GM (hours/ha)	0	0	0	0	1E
$B$28	Chemical control (R/ha/Yr)	945600	0	-1	7.00984E+11	3.83047
$B$29	Chemical control GM (R/ha/Yr)	0	0	-1	1E+30	7.64832E
$B$30	Conventional cane (t)	20010.66667	0	0	21959.23512	181.0081
$B$31	GM Cane (t)	0	0	0	20755.06529	279.9116
$B$32	RV Sales (t)	2701.529889	0	4583.481008	160159.2156	1340.756
$B$33	Macs (t)	80	0	0	1.8142E+15	14369.39
$B$34	Banana (t)	800	0	0	1436.939148	2263.808
$B$35	Labour hire (days)	96000	0	0	7.07234E+12	37.73013
$B$36		0	0	0	0	1E
$B$37	D1 (R)	532299.6328	0	0	0.26936	1.80575
$B$38	D2 (R)	491282.0821	0	0	0.26936	2.96937
$B$39	D3 (R)	820663.7649	0	0	0.26936	1.933235
$B$40	D4 (R)	1133472.234	0	0	0.26936	2.204910
$B$41	D5 (R)	0	-0.26936	0	0.26936	1E
$B$42	D6 (R)	0	-0.26936	0	0.26936	1E
$B$43	0.5TAD (R)	2977717.713	0	0	0.26936	0.647896
$B$44	SD (R)	774206.6055	0	-1.036	1.036	2.491908

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowa Decrea
$B$50	Sandy soil (ha)	40	38960.65409	40	31.45191383	
$B$51	Loamy soils (ha)	360	9055.233372	360	0	158.4658
$B$52	Labour (days)	-7.69069E-08	0	0	96000	1E
$B$53	*Eldana* Chemical Control (R)	-7.33417E-07	1	0	945600	1E
$B$54	*Eldana* Chemical Control GM (R)	0	1	0	0	1E
$B$55	*Eldana* control: scouting (R)	600	2.27374E-13	600	4200	3.10812E
$B$56	*Eldana* control: scouting GM (R)	0	0	400	1E+30	
$B$58	Conventional transfer (t)	1.45956E-08	0	0	1E+30	20010.66
$B$59	GM cane Transfer (t)	0	0	0	1E+30	
$B$60	Cane: RV Conversion (t)	2.045E-09	4583.481008	0	3.4937E+17	
$B$61	Macadamia nuts transfer (t)	2.41585E-13	0	0	1E+30	
$B$62	Banana Transfer (t)	3.22871E-11	0	0	1E+30	
$B$63	N41 Constraint	320	0	0	320	1E
$B$64	N52 Constraint	-2.72507E-10	-1933.897809	0	320	
$B$65	N51 Constraint	-3.15794E-10	-1144.793165	0	320	
$B$66	N59 Constraint	-2.32774E-10	-2628.235627	0	0	
$B$67	GM N51 Constraint	320	0	0	320	1E
$B$68	GM N52 Constraint	320	0	0	320	1E
$B$69	Mac/banana Constraint	5.45057E-11	-31880.95952	0	0	19.5105
$B$70	Weeding Conventional (R)	-1.23307E-06	1	0	1766762.667	1E
$B$71	Weeding GM (R)	0	1	0	0	1E
$B$75	T1 (R)	-8.34116E-07	-0.26936	0	8.52616E+18	532299.6
$B$76	T2 (R)	-9.21427E-08	-0.26936	0	1E+30	491282.0
$B$77	T3 (R)	-1.32015E-07	-0.26936	0	0	820663.7
$B$78	T4 (R)	1.26846E-06	-0.26936	0	6.38928E+18	
$B$79	T5 (R)	1472394.846	0	0	1472394.846	1E
$B$80	T6 (R)	780974.6685	0	0	780974.6685	1E
$B$81	Sum (R)	-1.11759E-08	-0.26936	0	1E+30	2977717
$B$82	Conv (R)	1.24564E-08	-1.036	0	1E+30	774206.6
$B$83	Without GM	0	14938.38292	0	0	

Microsoft Excel 15.0 Limits Report

Worksheet: [NC Farm representative in progress.xlsx]Inlands
Report Created: 2019/05/23 10:29:09 PM

Cell	Objective Name	Value
$B$6	OBJ: L= E[GM]-θσ (R)	4818310.18

Cell	Variable Name	Value	Lower Limit	Objective Result	Upper Limit	Obje Re
$B$11	SS N41	0	2.56356E-10	4818310.177	2.56356E-10	48183
$B$12	SS N51	0	2.56356E-10	4818310.177	2.56356E-10	48183
$B$13	SS N52	0	2.56356E-10	4818310.177	2.56356E-10	48183
$B$14	LS N41	-2.73689E-10	-1.73653E-11	4818310.177	-1.73653E-11	48183
$B$15	LS N51	106.6666667	106.6666667	4818310.177	106.6666667	48183
$B$16	LS N52	106.6666667	106.6666667	4818310.177	106.6666667	48183
$B$17	LS N59	106.6666667	106.6666667	4818310.177	106.6666667	48183
$B$18	SS GM N51	0	#N/A	#N/A	#N/A	#N
$B$19	SS GM N52	0	#N/A	#N/A	#N/A	#N
$B$20	LS GM N51	0	#N/A	#N/A	#N/A	#N
$B$21	LS GM N52	0	#N/A	#N/A	#N/A	#N
$B$22	SS Macs	40	#N/A	#N/A	#N/A	#N
$B$23	LS Bananas	40	#N/A	#N/A	#N/A	#N
$B$24	Weeding conventional (R/ha/Yr)	1766762.667	#N/A	#N/A	#N/A	#N
$B$25	Weeding in GM cane (R/ha/Yr)	0	#N/A	#N/A	#N/A	#N
$B$26	scouting (hours/ha)	4200	#N/A	#N/A	#N/A	#N
$B$27	scouting GM (hours/ha)	0	#N/A	#N/A	#N/A	#N
$B$28	Chemical control (R/ha/Yr)	945600	#N/A	#N/A	#N/A	#N
$B$29	Chemical control GM (R/ha/Yr)	0	#N/A	#N/A	#N/A	#N
$B$30	Conventional cane (t)	20010.66667	#N/A	#N/A	#N/A	#N
$B$31	GM Cane (t)	0	#N/A	#N/A	#N/A	#N
$B$32	RV Sales (t)	2701.529889	#N/A	#N/A	#N/A	#N
$B$33	Macs (t)	80	#N/A	#N/A	#N/A	#N
$B$34	Banana (t)	800	#N/A	#N/A	#N/A	#N
$B$35	Labour hire (days)	96000	#N/A	#N/A	#N/A	#N
$B$36		0	#N/A	#N/A	#N/A	#N
$B$37	D1 (R)	532299.6328	#N/A	#N/A	#N/A	#N
$B$38	D2 (R)	491282.0821	#N/A	#N/A	#N/A	#N
$B$39	D3 (R)	820663.7649	#N/A	#N/A	#N/A	#N
$B$40	D4 (R)	1133472.234	#N/A	#N/A	#N/A	#N

$B$41	D5 (R)	0	#N/A	#N/A	#N/A	#I
$B$42	D6 (R)	0	#N/A	#N/A	#N/A	#I
$B$43	0.5TAD (R)	2977717.713	#N/A	#N/A	#N/A	#I
$B$44	SD (R)	774206.6055	#N/A	#N/A	#N/A	#I

Appendix 11: Hinterland results including GM cultivars

Microsoft Excel 15.0 Answer Report
Worksheet: [NC Farm representative in progress.xlsx]Inlands
Report Created: 2019/05/23 10:29:35 PM
Result: Solver found a solution. All Constraints and optimality conditions are satisfied.
Solver Engine
Engine: Simplex LP
Solution Time: 0.063 Seconds.
Iterations: 58 Subproblems: 0
Solver Options
Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegative

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$B$6	OBJ: L= E[GM]-θσ (R)	0	6802370.083

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$11	SS N41	0	0	Contin
$B$12	SS N51	0	0	Contin
$B$13	SS N52	0	0	Contin
$B$14	LS N41	0	0	Contin
$B$15	LS N51	0	0	Contin
$B$16	LS N52	0	4.87902E-11	Contin
$B$17	LS N59	0	106.6666667	Contin
$B$18	SS GM N51	0	0	Contin
$B$19	SS GM N52	0	0	Contin
$B$20	LS GM N51	0	106.6666667	Contin
$B$21	LS GM N52	0	106.6666667	Contin
$B$22	SS Macs	0	40	Contin
$B$23	LS Bananas	0	40	Contin
$B$24	Weeding conventional (R/ha/Yr)	0	593198.9333	Contin
$B$25	Weeding in GM cane (R/ha/Yr)	0	524508.112	Contin
$B$26	scouting (hours/ha)	0	1000	Contin

$B$27	scouting GM (hours/ha)	0	1733.333333	Contin
$B$28	Chemical control (R/ha/Yr)	0	315200	Contin
$B$29	Chemical control GM (R/ha/Yr)	0	210133.3333	Contin
$B$30	Conventional cane (t)	0	6777.422222	Contin
$B$31	GM Cane (t)	0	14159.57156	Contin
$B$32	RV Sales (t)	0	2843.229611	Contin
$B$33	Macs (t)	0	80	Contin
$B$34	Banana (t)	0	800	Contin
$B$35	Labour hire (days)	0	83200	Contin
$B$36		0	0	Contin
$B$37	D1 (R)	0	542735.3864	Contin
$B$38	D2 (R)	0	502184.3074	Contin
$B$39	D3 (R)	0	800778.491	Contin
$B$40	D4 (R)	0	1130167.042	Contin
$B$41	D5 (R)	0	0	Contin
$B$42	D6 (R)	0	0	Contin
$B$43	0.5TAD (R)	0	2975865.227	Contin
$B$44	SD (R)	0	773724.9591	Contin

Constraints

Cell	**Name**	**Cell Value**	**Formula**	**Status**	**Slack**
$B$50	Sandy soil (ha)	40	$B$50<=$D$50	Binding	0
$B$51	Loamy soils (ha)	360	$B$51<=$D$51	Binding	0
$B$52	Labour (days)	6.33736E-09	$B$52=$D$52	Binding	0
$B$53	*Eldana* Chemical Control (R)	2.2084E-07	$B$53=$D$53	Binding	0
$B$54	*Eldana* Chemical Control GM (R)	4.13274E-08	$B$54=$D$54	Binding	0
$B$55	*Eldana* control: scouting (R)	600	$B$55<=$D$55	Binding	0
$B$56	*Eldana* control: scouting GM (R)	400	$B$56<=$D$56	Binding	0
$B$58	Conventional transfer (t)	-3.14139E-09	$B$58=$D$58	Binding	0
$B$59	GM cane Transfer (t)	-1.03319E-09	$B$59=$D$59	Binding	0
$B$60	Cane: RV Conversion (t)	-8.21274E-10	$B$60=$D$60	Binding	0
$B$61	Macadamia nuts transfer (t)	0	$B$61=$D$61	Binding	0
$B$62	Banana Transfer (t)	-1.7053E-12	$B$62=$D$62	Binding	0
$B$63	N41 Constraint	320	$B$63>=$D$63	Not Binding	320
$B$64	N52 Constraint	320	$B$64>=$D$64	Not Binding	320
$B$65	N51 Constraint	320	$B$65>=$D$65	Not Binding	320
$B$66	N59 Constraint	6.52989E-11	$B$66>=$D$66	Binding	0
$B$67	GM N51 Constraint	1.56177E-11	$B$67>=$D$67	Binding	0
$B$68	GM N52 Constraint	6.54552E-11	$B$68>=$D$68	Binding	0

$B$69	Mac/banana Constraint	-1.80336E-11	$B$69>=$D$69	Binding	0
$B$70	Weeding Conventional (R)	2.11643E-07	$B$70=$D$70	Binding	0
$B$71	Weeding GM (R)	1.14669E-07	$B$71=$D$71	Binding	0
$B$75	T1 (R)	1.99303E-07	$B$75>=$D$75	Binding	0
$B$76	T2 (R)	-3.19415E-08	$B$76>=$D$76	Binding	0
$B$77	T3 (R)	8.10833E-08	$B$77>=$D$77	Binding	0
$B$78	T4 (R)	-2.23081E-07	$B$78>=$D$78	Binding	0
$B$79	T5 (R)	1465685.451	$B$79>=$D$79	Not Binding	1465685.451
$B$80	T6 (R)	785831.5772	$B$80>=$D$80	Not Binding	785831.5772
$B$81	Sum (R)	1.85799E-07	$B$81=$D$81	Binding	0
$B$82	Conv (R)	-8.19564E-08	$B$82=$D$82	Binding	0

Microsoft Excel 15.0 Sensitivity Report
Worksheet: [NC Farm representative in progress.xlsx]Inlands
Report Created: 2019/05/23 10:29:35 PM

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$B$11	SS N41	0	-35603.83341	-14719.12472	35603.83341	1E+30
$B$12	SS N51	0	-32268.44581	-14759.54028	32268.44581	1E+30
$B$13	SS N52	0	-28738.78295	-14759.54028	28738.78295	1E+30
$B$14	LS N41	0	-5801.693426	-14821.79694	5801.693426	1E+30
$B$15	LS N51	0	-2367.313931	-14759.54028	2367.313931	1E+30
$B$16	LS N52	4.87902E-11	0	-14759.54028	2083.013455	2367.313931

$B$17	LS N59	106.6666667	0	-14762.8825	6.71576E+17	2083.013455
$B$18	SS GM N51	0	-30300.34098	-13297.37716	30300.34098	1E+30
$B$19	SS GM N52	0	-29064.24498	-13739.57231	29064.24498	1E+30
$B$20	LS GM N51	106.6666667	0	-13297.37716	1.93949E+17	7096.55819
$B$21	LS GM N52	106.6666667	0	-13739.57231	2.55138E+16	9136.689492
$B$22	SS Macs	40	0	14577.18352	1.56428E+17	28738.78295
$B$23	LS Bananas	40	0	2266.55	28738.78295	70076.91568
$B$24	Weeding conventional (R/ha/Yr)	593198.9333	0	-1	1.297122681	9.450713646
$B$25	Weeding in GM cane (R/ha/Yr)	524508.112	0	-1	4.75312E+12	2.886385128
$B$26	scouting (hours/ha)	1000	0	0	0	3503.845784
$B$27	scouting GM (hours/ha)	1733.333333	0	0	0	709.655819
$B$28	Chemical control (R/ha/Yr)	315200	0	-1	2.401542535	17.78601921
$B$29	Chemical control GM (R/ha/Yr)	210133.3333	0	-1	3.99099E+13	7.204627604
$B$30	Conventional cane (t)	6777.422222	0	0	108.4492617	347.5381352
$B$31	GM Cane (t)	14159.57156	0	0	20755.06529	113.130872
$B$32	RV Sales (t)	2843.229611	0	4583.481008	160159.2155	1971.75537
$B$33	Macs (t)	80	0	0	7.82139E+16	14369.39148
$B$34	Banana (t)	800	0	0	1436.939148	3503.845784
$B$35	Labour hire (days)	83200	0	0	118.2759698	67.38164969
$B$36		0	0	0	0	1E+30
$B$37	D1 (R)	542735.3864	0	0	0.26936	4.140229958
$B$38	D2 (R)	502184.3074	0	0	0.26936	4.555186705

$B$39	D3 (R)	800778.491	0	0	0.26936	3.907679128
$B$40	D4 (R)	1130167.042	0	0	0.26936	0.861107204
$B$41	D5 (R)	0	-0.26936	0	0.26936	1E+30
$B$42	D6 (R)	0	-0.26936	0	0.26936	1E+30
$B$43	0.5TAD (R)	2975865.227	0	0	0.26936	1.003124078
$B$44	SD (R)	773724.9591	0	-1.036	1.036	3.858169531

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$B$50	Sandy soil (ha)	40	43920.80385	40	32.11804097	40
$B$51	Loamy soils (ha)	360	14015.38314	360	1E+30	160.3273549
$B$52	Labour (days)	6.33736E-09	0	0	83200	1E+30
$B$53	Eldana Chemical Control (R)	2.2084E-07	1	0	315200	1E+30
$B$54	Eldana Chemical Control GM (R)	4.13274E-08	1	0	210133.3333	1E+30
$B$55	Eldana control: scouting (R)	600	0	600	1000	1E+30
$B$56	Eldana control: scouting GM (R)	400	0	400	1733.333333	1E+30
$B$58	Conventional transfer (t)	-3.14139E-09	0	0	1E+30	6777.422222
$B$59	GM cane Transfer (t)	-1.03319E-09	0	0	1E+30	14159.57156
$B$60	Cane: RV Conversion (t)	-8.21274E-10	4583.481008	0	1E+30	2843.229611
$B$61	Macadamia nuts transfer (t)	0	0	0	1E+30	80
$B$62	Banana Transfer (t)	-1.7053E-12	0	0	1E+30	800
$B$63	N41 Constraint	320	0	0	320	1E+30
$B$64	N52 Constraint	320	0	0	320	1E+30
$B$65	N51 Constraint	320	0	0	320	1E+30
$B$66	N59 Constraint	6.52989E-11	-694.3378184	0	320	1.46371E-10

$B$67	GM N51 Constraint	1.56177E-11	-2365.519397	0	320	1.46371E-10
$B$68	GM N52 Constraint	6.54552E-11	-3045.563164	0	320	1.46371E-10
$B$69	Mac/banana Constraint	-1.80336E-11	-38081.14672	0	200	19.9168933
$B$70	Weeding Conventional (R)	2.11643E-07	1	0	593198.9333	1E+30
$B$71	Weeding GM (R)	1.14669E-07	1	0	524508.112	1E+30
$B$75	T1 (R)	1.99303E-07	-0.26936	0	5.96738E+18	542735.3864
$B$76	T2 (R)	-3.19415E-08	-0.26936	0	1.89038E+18	502184.3074
$B$77	T3 (R)	8.10833E-08	-0.26936	0	1E+30	800778.491
$B$78	T4 (R)	-2.23081E-07	-0.26936	0	1E+30	1130167.042
$B$79	T5 (R)	1465685.451	0	0	1465685.451	1E+30
$B$80	T6 (R)	785831.5772	0	0	785831.5772	1E+30
$B$81	Sum (R)	1.85799E-07	-0.26936	0	1E+30	2975865.227
$B$82	Conv (R)	-8.19564E-08	-1.036	0	1E+30	773724.9591

Microsoft Excel 15.0 Limits Report
Worksheet: [NC Farm representative in progress.xlsx]Inlands
Report Created: 2019/05/23 10:29:36 PM

Cell	Objective Name	Value
$B$6	OBJ: L= E[GM]-θσ (R)	R 6 802 370.08

Cell	Variable Name	Value	Lower Limit	Objective Result	Upper Limit	Objective Result
$B$11	SS N41	0	-2.11245E-11	6802370.083	-2.11245E-11	6802370.083

$B$12	SS N51	0	-2.11245E-11	6802370.083	-2.11245E-11	6802370.083
$B$13	SS N52	0	-2.11245E-11	6802370.083	-2.11245E-11	6802370.083
$B$14	LS N41	0	-2.11245E-11	6802370.083	-2.11245E-11	6802370.083
$B$15	LS N51	0	-2.11245E-11	6802370.083	-2.11245E-11	6802370.083
$B$16	LS N52	4.87902E-11	2.76486E-11	6802370.083	2.76486E-11	6802370.083
$B$17	LS N59	106.6666667	106.6666667	6802370.083	106.6666667	6802370.083
$B$18	SS GM N51	0	-2.64057E-11	6802370.083	-2.64057E-11	6802370.083
$B$19	SS GM N52	0	-2.64057E-11	6802370.083	-2.64057E-11	6802370.083
$B$20	LS GM N51	106.6666667	106.6666667	6802370.083	106.6666667	6802370.083
$B$21	LS GM N52	106.6666667	106.6666667	6802370.083	106.6666667	6802370.083
$B$22	SS Macs	40	40	6802370.083	40	6802370.083
$B$23	LS Bananas	40	40	6802370.083	40	6802370.083
$B$24	Weeding conventional (R/ha/Yr)	593198.9333	593198.9333	6802370.083	593198.9333	6802370.083
$B$25	Weeding in GM cane (R/ha/Yr)	524508.112	#N/A	#N/A	#N/A	#N/A
$B$26	scouting (hours/ha)	1000	#N/A	#N/A	#N/A	#N/A
$B$27	scouting GM (hours/ha)	1733.333333	#N/A	#N/A	#N/A	#N/A
$B$28	Chemical control (R/ha/Yr)	315200	315200	6802370.083	315200	6802370.083
$B$29	Chemical control GM (R/ha/Yr)	210133.3333	#N/A	#N/A	#N/A	#N/A
$B$30	Conventional cane (t)	6777.422222	#N/A	#N/A	#N/A	#N/A
$B$31	GM Cane (t)	14159.57156	#N/A	#N/A	#N/A	#N/A
$B$32	RV Sales (t)	2843.229611	#N/A	#N/A	#N/A	#N/A
$B$33	Macs (t)	80	#N/A	#N/A	#N/A	#N/A
$B$34	Banana (t)	800	#N/A	#N/A	#N/A	#N/A
$B$35	Labour hire (days)	83200	#N/A	#N/A	#N/A	#N/A

$B$36		0	#N/A	#N/A	#N/A	#N/A
$B$37	D1 (R)	542735.3864	542735.3864	6802370.083	542735.3864	6802370.083
$B$38	D2 (R)	502184.3074	502184.3074	6802370.083	502184.3074	6802370.083
$B$39	D3 (R)	800778.491	800778.491	6802370.083	800778.491	6802370.083
$B$40	D4 (R)	1130167.042	1130167.042	6802370.083	1130167.042	6802370.083
$B$41	D5 (R)	0	1.85799E-07	6802370.083	1.85799E-07	6802370.083
$B$42	D6 (R)	0	1.85799E-07	6802370.083	1.85799E-07	6802370.083
$B$43	0.5TAD (R)	2975865.227	#N/A	#N/A	#N/A	#N/A
$B$44	SD (R)	773724.9591	#N/A	#N/A	#N/A	#N/A

Appendix 12: Turnitin Originality Report for this Dissertation

Dissertation 3 December 2020

by Zama Ntuli

Submission date: 03-Dec-2020 09:07AM (UTC+0200)

Submission ID: 1463327116

File name: cane_in_the_ILembe_District_of_KwaZulu-Natal._December_2020.docx (1.56M)

Word count: 34841

Character count: 190084

Dissertation 3 December 2020

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