An *ex ante* Impact Assessment of the Farm Level Impacts of Genetically Modified (GM) Sugarcane to Contain Insect Resistant (IR) and Herbicide Tolerant (HT) Genes in the Eston sugarcane supply region of KwaZulu-Natal, South Africa

By

Celumusa B. Mthimkhulu

Submitted in fulfilment of the requirements for the degree of
Master of Agricultural Management

in the Discipline of Agricultural Economics
School of Agricultural, Earth and Environmental Sciences
College of Agriculture, Engineering and Science
University of KwaZulu-Natal
Pietermaritzburg

UNIVERSITY OF KWAZULU-NATAL

November 2019

ABSTRACT

Notwithstanding public contention about GM crops, commonly defined as crops for which the genes have been engineered by inserting genes from other organisms such as bacteria or animals into their DNAs, there is a general consensus in the agricultural economics literature that adoption of GM crops has generally benefitted the farm sector through increased yields, reduced use of agrochemicals and profit gains for farmers. The South African sugar industry is a high-quality competitive producer of sugar. Nonetheless, it is under financial stress, which has been partly attributed to increased prevalence of various pests, notably eldana and cynodon grass. Genetic modification of sugarcane has been advocated as a strategy to partially counter these threats.

The South African Sugar Research Institute (SASRI) is currently developing an insect resistant (IR) and herbicide tolerant (HT) genetically modified (GM) sugarcane cultivar that is suited to coastal production regions. Some sugarcane cultivars suitable for production in coastal areas are also suited to commercial production in the inland regions where eldana and cynodon are also prevalent (e.g. the Eston cane supply region). This study investigates the socio-economic impacts of GM sugarcane in the Eston cane supply area in KwaZulu-Natal, assuming that the GM sugarcane cultivar is suitable for commercialization in the Eston area. In the Eston area, large-scale and smallholder growers produce 95% and 5% of sugarcane, respectively. Large scale farmers in the region were aggregated into three representative farms to account for climatic variation within the area. A fourth represents smallholder growers in the region.

Data for representative farm models were collected through focus group discussions with SASRI experts and commercial farmers. In this study, GM sugarcane is modified on the N52 cultivar because it fits the desired traits (high yields, and resistance to diseases and drought tolerance) of GM cane. Microsoft Excel was used to compile enterprise budgets of GM cane and conventional cane to compute their gross margins. Furthermore, Linear Programming (LP) farm planning models were compiled for each representative farm to determine the likelihood of GM cane adoption and the risks associated with the technology. The baseline scenario, "without" GM cane was compared with the GM cane scenario to analyze impact on farm decisions, *ceteris paribus.* In addition, focus group discussions with smallholders were held to gauge their demand for GM cultivars of sugarcane.

Results show that GM cane will be adopted on all four representative farms. Large scale farmers will save up to 29%, 75% and 49,3% on weed control at planting, ratoon management and on eldana control per hectare per annum, respectively. Farmers will also achieve up to a 34.5% share change in gross margin per ha per annum. The LP output shows that GM cane will perform well even in poorer soils: steep and marginal poor soils. Farmers and farm workers will also benefit from GM through sustainable farming and environmental conservation because less agrochemicals such as imazapyr will be used to control pests. Furthermore, higher yields on GM cultivars are expected to increase employment because ratoon management and harvesting will require more labours owing to higher yields.

Keywords: ex ante, eldana, cynodon, genetically modified, insect resistant, herbicide tolerant, linear programming

DEDICATION

This is dedicated to my late mother, Nomavila Mpungose-Mthimkhulu. Your support from the very beginning of this journey is amazing. Your spirit is still with me and forever will be, thank you MaMpungose.

PREFACE

I, Celumusa Bhekithemba Mthimkhulu, declare that:

(i) The research reported in this thesis, except where otherwise indicated, is my original work.

(ii) This thesis has not been submitted for any degree or examination at any other university.

(iii) This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

(iv) This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

(a) their words have been re-written, but the general information attributed to them has been referenced;

(b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced.

(v) Where I have reproduced a publication of which I am an author, co-author or editor, I have indicated, in detail, which part of the publication was actually written by myself alone and have fully referenced such publications.

(vi) This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References sections.

Signed: ______________________ Date: 20/03/2020______

Mr Celumusa Mthimkhulu

As the candidate's Supervisor, I have approved this dissertation for submission.

Signed: ______________________ Date: 20/03/2020________

Dr S.R.D. Ferrer

ACKNOWLEDGEMENTS

I would like to thank my God for granting me His favour and demonstrating His faithfulness through a number of people and organisations who have played a role in making this project possible.

I would also like to sincerely thank the following persons and organisations who have made the study possible:

- Dr SRD Ferrer (My supervisor) in the Discipline of Agricultural Economics, University of KwaZulu-Natal, for his guidance, encouragement, patience, objective criticism, continual support and direction throughout the study period.
- The University of KwaZulu-Natal, for providing other resources and office space that made this study possible, in particular the School of Agricultural Economics.
- Biosafety South Africa for providing funding throughout this research
- The South African Sugar Research Institute (SASRI), for providing information and support throughout this research.
- The Cane Testing Services (CTS) for their assistance in making sugarcane crushed and cane quality data accessible.
- Mr Paul Botha (Eston extension officer) for providing support and information throughout this research.
- The South African Cane Growers Association (SACGA) for making G6 forms (sugarcane cost schedules) accessible.
- My heart-felt thanks to my colleagues W. Mafunga, Z Ntuli and N. Buthelezi, family, friends, izinqandamathe zami and everyone who was involved in the successful completion of this thesis.

Table of Contents

List of Tables

List of Figures

List of Abbreviations or Symbols

ACB	African Centre for Biodiversity
Bt	*Bacillus thuringiensis*
BWSA	Bio-watch South Africa
CTS	Cane Testing Services
DAFF	Department of Agriculture, Forestry and Fisheries
DEAT	Department of Environmental Affairs and Tourism
ESM	Economic Surplus Model
FC	Flat clay soil
FGD(s)	Focus group discussion(s)
FS	Flat sandy soil
HT	Herbicide Tolerant
IR	Insect Resistant
GM	Genetically Modified
GMA	Gross Margin Analysis
GMO(s)	Genetically Modified Organism(s)
LP	Linear Programming
MGB	Mill Group Board
MP	Marginal poor soil
OECD	Organisation for Economic Co-operation and Development
Pers.comm	Personal communication
RV	Recoverable Value
SA	South Africa
SACGA	South African Cane Growers' Association
SACGL	South Africa Cane Growers Association Levy
SAGENE	South African Committee on Genetic Experimentation
SASA	South African Sugar Association
SASRI	South African Sugarcane Research Institute
SASTA	South African Sugar Technologist`s Association
SR	Steep Red soils
WTO	World Trade Organisation

Chapter 1: Introduction and Background

Notwithstanding public contention about genetically modified (GM) crops, commonly defined as crops for which the genes have been engineered by inserting DNA from other organisms such as bacteria or animals ((Azadi *et al*., 2016; Bio-watch South Africa (BWSA), 2016), there is a general consensus in the agricultural economics literature that adoption of GM crops has generally benefitted the farm sector through increased yields, reduced use of agrochemicals and profit gains for farmers (Klümper & Qaim, 2014; Ainembabazi *et al.*, 2015; Cheavegatti-Gianotto *et al.*, 2011). Azadi *et al.,* 2016Azadi *et al.,* 2016). Even though numerous prior studies and regulatory institutions have revealed evidence that GM crops are safe for the environment and for human consumption, some authors continue to argue that the evidence is mixed, contending that the results of studies that show large benefits may be due to inappropriate methods and data used (Klümper & Qaim, 2014). Widely adopted GM crops include cotton, maize, canola and soybean (Ainembabazi *et al.*, 2015). Brookes and Barfoot (2016) and Klümper and Qaim (2014) studies demonstrated the remarkable impact of GM crops at farm level, including yield increase, reduction in costs of pest management and significant profit gains for farmers.

GM varieties were established to meet the high demand for agricultural commodities, especially the highly valued commodities (Ainembabazi *et al.,* 2015). There has been a significant shift from traditional production to GM technologies globally (Klümper & Qaim, 2014). GM crops have been adopted even in some countries that embrace regulations and laws on biosafety and biotechnology policies (Ainembabazi *et al.,* 2015). South Africa was the first African country to approve GMO biotechnology (Aerni, 2005. The first field trials of insect resistant cotton were approved in 1992 and commercially released in 1997 (Aerni, 2005). Nevertheless, the debate in South Africa about GM implications continues, and it mainly is perpetuated by cultural, ecological and historical disparities. Vocal opponents, such as non-government organisations and religious groups are concerned about consumers' health and the environment (Aerni, 2005).

Sugarcane is a crop that has gained economic interest in the market owing to the increased global demand for sugar and sustainable energy production (Cheavegatti-Gianotto *et al.*, 2011). In South Africa, sugarcane plays a significant role in economic growth and development with over R12 billion in revenue from local and exportation sales of sugar, and there are significant employment opportunities created by the sugarcane sector. Approximately, 2 % of the South African population depends on the sugarcane supply chain for a living (South African Sugar Association (SASA), 2015). The South African sugar industry is among the top, high quality and competitive producers of sugar, ranked in the top 15 out of approximately, 120 producing countries globally (SASA, 2015; Media Matters, 2017). Sugarcane was reported to be the second largest field crop contributor towards national gross value after maize in five consecutive seasons (2008/9-2012/13), with an average of approximately 2.2 million tons of sugar per season (Department of Agriculture, Forestry and Fisheries (DAFF), 2014). South Africa, like other top sugar producing countries, has shifted from solely sugar production to both sugar and energy production from cane (Smithers, 2014). On average, South Africa produces more than 20 million tons of sugarcane containing the biomass that is equivalent to 1.5 million tons of coal that can produce up to 1600 MW of electricity (Smithers, 2014).

However, the sugar industry is negatively impacted by risks and uncertainties of sugar prices, land reform interventions, labour legislation, minimum wages, a volatile exchange rate, high input costs and an influx of sugar imports, leading to low revenue (Ortmann, 2005; Ndoro *et al.,* 2015). The health protection levy on sugary products that was introduced in 2018 is expected to further affect sugarcane profitability. The tax is expected to decrease the sugar demand due to higher prices (Mboyisa, 2017). On average, the returns to sugar cane producers have declined significantly due to large volumes of imports from high sugarcane producing countries, and hence the sugar prices are low. On the other hand, sugarcane production costs have increased significantly owing to the minimum wage and other changes in production systems such as mechanical ploughing and pest control.

Besides economic challenges, there are on-farm challenges that hinder sugarcane profitability. The growing financial stress of sugarcane farms, in general, has been partly attributed to an increased prevalence of various pests, notably *Eldana* *saccharina Walker* (hereon referred to as eldana) and *Cynodon dactylon (*hereon referred to as cynodon grass*).* Pest refers to any organism (animal or plant) detrimental to human concerns (Cheavegatti-Gianotto *et al.*, 2011). In this study, eldana and cynodon grass are referred to as pests. Genetic modification of sugarcane has been advocated as a strategy to partially address these problems. The South African Sugar Research Institute (SASRI) is currently developing an insect resistant (IR) and herbicide tolerant (HT) genetically modified (GM) sugarcane cultivar to counter the threats posed by eldana and cynodon grass. However, GM cultivars are likely to be commercially available at least in the next 10 years (Snyman, 2018, pers.comm).

Improving the productivity and profitability of production is the crucial step towards enhancing livelihoods as sugarcane contributes to employment along the supply chain from farm level up to the milling level (DAFF, 2014). According to Cheavegatti-Gianotto *et al.* (2011), biotechnological advancement might assist in mitigating negative impacts currently affecting conventional sugarcane technologies in the near future. Abstraction of new sugarcane varieties, through biotechnology, such as high-yielding, drought tolerant, insect resistant (IR) and herbicide tolerant (HT) is expected to play a crucial role in providing growers with profitable production systems. Ortmann (2005) concurs with Cheavegatti-Gianotto *et al.* (2011) that adoption of new technologies by farmers will promote competitiveness in the agriculture sector, and that good governance will play a crucial role in enhancing farm developments and thus, the sugarcane profitability can improve.

This study is part of a larger research project conducted with South African sugarcane producers. The broader study includes research on consumer perceptions of GM cane and the *ex ante* impact of GM cane on farming in other cane producing regions of South Africa up to the market level. The current GM development is intended for commercial production in the coastal, rainfed region of KwaZulu-Natal. As per this study, the focus is on the farm level impact of GM cane adoption. This study investigates the *ex-ante* socio-economic impact of GM sugarcane in the Eston cane supply area at Mkhambathini District Municipality in KwaZulu-Natal, an area where cynodon grass and eldana insects are prevalent. Eston cane growers grow sugarcane under the rainfed production with a 22-24 month production cycle. An impact assessment was conducted on large-scale rainfed farmers using linear programming to construct farm representative models.

1.1 Problem statement

1.1.1 General problem statement

The South African sugar industry is one of the top, high quality and competitive producers of sugar in the world. South Africa is ranked in the top 15 out of approximately, 120 producing countries globally (SASA, 2015). Climate change and pests are amongst the main factors that are adversely affecting the productivity and profitability of sugarcane in South Africa (Singels *et al*., 2017). To remain competitive, South African cane producers must adopt new coping strategies that will help them to improve profit margins. To mitigate the adverse impact of climate change and adamant pests, GM crops were adopted by many countries. Even though South Africa was the first African country to adopt GM technology, the debate about the benefits and costs associated with this technology is still prevalent.

While the evidence of socio-economic benefits of annual GM crops has been demonstrated by many researchers (Mudombi, 2010; Klümper & Qaim, 2014; Cuhra, 2015), very little has been reported about perennial GM crops. In other enterprises with annual crops such as maize, soybean and cotton, GM technology was adopted successfully to mitigate the adverse impact of adamant pests and herbicides (Klümper & Qaim, 2014). However, sugarcane is perennial in nature and there is no GM cane that is commercially cultivated anywhere in the world (Aerni, 2005; Cheavegatti-Gianotto *et al.*, 2011). Cheavegatti-Gianotto *et al.* (2011) conducted a reference study to assess the potential socio-economic impact of GM cane with incorporated genes resistance to both biotic and abiotic factors. The conclusion was that, a significant contribution to cane yield is expected from GM new cultivars. However, commercialisation of GM cane would be accomplished by following proper regulatory processes, and country-specific (Cheavegatti-Gianotto *et al.*, 2011)

1.1.2 Specific problem statement

Insects and weeds have contributed to the increased sugarcane production costs; hence sugarcane has become less profitable relative to the previous years in South Africa as the RV price also continues to decline relative to past years. Eldana, *Eldana saccharina Walker*, and creeping grass weed, *Cynodon dactylon* are the major pests that adversely impact the sugarcane industry (Nicholson *et al*., 2017; Rutherford, 2015). Eldana is an insect that feeds extensively within sugarcane stalks which causes an inferior cane quality due to an increased fibre due to loss of sucrose in infected stalks. In 2014, South African sugar cane growers experienced approximately, R344 000 000 direct loss per annum in the harvested area of 271 000 hectares owing to eldana infestation (Rutherford, 2015).

Weed control contributes between 13% and 18% to the planting and ratoon management costs, respectively (Nicholson *et al*., 2017). Despite the fact that cane growers have adopted integrated pest management (IPM), chemical control remains the major weed control choice (Cheavegatti-Gianotto *et al.*, 2011). A glyphosate, roundup herbicide is an effective chemical commonly used to control weeds in agriculture. However, some weedicides such as glyphosate and imazapyr are non-selective chemicals which kill the sugarcane crops too when used to control the weed at the post-emergence stage (Nicholson et al., 2017).

GM crops have demonstrated a significant mitigation in yield losses by insects and weeds. However, GM sugarcane has not yet been developed and adopted anywhere else in the world. SASRI has recently embarked on a programme to assess the viability and desirability of developing IR and HT GM sugarcane over the next decade. The GM development is intended for commercial production of sugarcane in rainfed, coastal regions of KwaZulu-Natal where the eldana and cynodon are particularly pervasive. Some cultivars, but not all, which are suitable for production in coastal areas are also suitable for production in the inland regions where eldana and cynodon are also pervasive. Therefore, SASRI needs to decide if the GM cultivar will be developed from a cultivar that is suitable for production in both coastal and inland regions of KwaZulu-Natal.

1.2 Objectives of the study

The main objective of this study is to determine the likelihood of genetically modified sugarcane adoption and its socio-economic impact on South African sugarcane production. Specifically, the objectives are:

- To develop a representative farm model using a linear programming (LP) method that accounts for risk of GM cane adoption at the farm level in South Africa that is suitable for managerial analyses by comparing a baseline scenario vs a GM cane scenario
- To get a detailed understanding of current sugarcane production systems, including opportunity costs of land.
- To assess how the current sugarcane production systems might change in the future owing to an introduction of GM technology at the farm level, and its impact through *ex ante* impact assessment
  - Impact on farm gross margins, environmental (reduction on chemical usage, and employment on sugarcane production)

1.3 Limitations to the study

To date is no commercialized GM cane in the world. Consequently, this study assumes that the SASRI`s objective of developing a GM sugarcane cultivar is possible. Moreover, 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. Also, there are new cane cultivars that have relatively little historic information about their performance in commercial production.

Another important limitation to the study is that the development and roll-out of a GM sugarcane cultivar will take approximately ten0 years. It is likely that within this period there will be various advancements in pest management control, the roll out of new non-GM sugarcane varieties, and new pests in sugarcane production, amongst other possible changes. These are currently unknown, so the scenario for which the profitability of GM cane is compared to that of other cane varieties in this study is largely based on the ‘current scenario’.

1.4 Structure of Dissertation

In Chapter 1, the general background of GM crops in a broader view is presented, the status of GM crops in South Africa as well as the sugarcane industry are briefly reviewed. The problem statement that is derived from the South African sugarcane industry and the objectives of this study are described. In Chapter 2, adoption of GM crops and their impact are reviewed in both developing and developed countries. The main focus is on the methodologies used in different GM technology studies. In Chapter 3, the theoretical framework of impact assessment studies is discussed, including various methods of executing *ex ante* impact assessments. An overview of the South African sugarcane industry, challenges, policies and regulations are presented in Chapter 4. Methodologies used in this study, from data collection to data analysis, are detailed in Chapter 5. In Chapter 6, findings are presented and discussed. Findings include the likelihood of the GM cane adoption by both large scale and smallholder farmers in the Eston region. This is followed by conclusions and recommendations of the study in Chapter 7.

Chapter 2: A review of the literature on the adoption of genetically modified (GM) crops and their impacts

The status of GMOs in the world from the existing studies that were conducted in different countries is briefly elaborated in the first part of this chapter. This is followed by the discussion of the adoption of GMOs in the world and African countries. Moreover, institutions and research stations in South Africa are reviewed, and the contribution of biotechnology in the agricultural sector is demonstrated. Even though GM sugar cane is not yet commercialised, studies on various GMOs are reviewed, and the methodologies used are scrutinized as alternative methods of doing this study. More attention is given to herbicide-tolerant (HT) and insect-resistant (IR) crops. Even though there is little information about perennial GM crops, the information and evidence gathered from annual crops and few perennial organisms` studies will be reviewed and contextualized in this study.

Genetically modified (GM) crops are, as explained in the introduction, commonly defined as crops whose DNAs have been engineered by inserting genes from other organisms such as bacteria or animals into their DNAs (Azadi *et al.,* 2016; BWSA, 2016). GMOs are considered to be “unnatural” as the foreign genes are forced into the existing organisms by scientists through the complex processes (genetic engineering and modern biotechnology) at the laboratories that are conducted under trial and error methods (BWSA, 2016). There are two main types of biotechnology, 'green biotechnology' is applied for agricultural processes, while 'blue biotechnology' is for pharmaceutical and medicinal use (Abidoye & Mabaya, 2014). This study focuses on the ‘green biotechnology’ with common GM crops that are herbicide tolerant (HT) and insect resistant (IR). HT crops can be defined as crops that are developed to withstand the broad-spectrum of herbicides used to mitigate the surrounding weeds. IR crops on the other hand, are crops that resist insect damage by producing toxic compounds as a defence mechanism (Azadi *et al*., 2016)

2.1 GMOs in the developing countries

There is inadequate empirical evidence on the social implications of genetically modified crops that are vegetatively propagated. Very little is known about the potential success of the vegetative and perennial GM crops in the future because only a few developing countries have adopted GM crops that are seed-planted and annual crops successfully, and hence only their social impact has been scrutinized and accepted (Ainembabazi *et al.,* 2015).

Almost all GM technologies were developed by commercial firms to meet the needs of commercial farms in developed countries because commercial farmers can pay for those technologies. Studies (Qaim & Zilberman, 2003; Finger e*t al.,* 2011; Ainembabazi *et al.,* 2015) show that there are pronounced effects of GM technologies on yield gains and cost savings of GM technologies in developing countries. Smallholder farmers are often constrained by technical and financial parameters which makes it difficult for them to adopt and receive the benefits of GM crops. Lack of human capital in smallholder farming has been identified as the main limiting factor for advanced technology adoption (Finger *et al*., 2011). However, if functional institutions and financial support are available and accessible to them, the benefits are more pronounced than for commercial farmers.

Qaim and Traxler (2005) concur that the benefits of GM crops are not only limited to commercial farms. They demonstrated that cost-saving benefits were more pronounced for smallholders compared to large scale in the Roundup Ready (RR) soybean study in Argentina because the margin by the technology is relatively smaller on large scale farmers since other cost-saving methods such as water use efficiency and minimum tillage, and high yielding technologies are already in place in large-scale farming when the technology is being adopted. A similar study was undertaken by the African Centre for Biosafety (ACB) (2013) on the GM status in Africa. The GM crops benefit both large scale and small-scale farmers in terms of high yields and cost saving. In a case study of GM maize, their findings showed that GMO contribute significantly to reducing costs as the weed control in a hectare of GM maize requires three man-days while 28 man-days are needed in conventional weed control; saving 25 man-days for both large and small-scale farmers. However, the adoption rate on smallholders and subsistence farmers is being retarded by bureaucracy and regulation costs (ACB, 2013).

The overall benefits of GM crops vary from country to country. Qaim and Traxler (2005), in the study about GM herbicide-tolerant (HT) soybean, identified a 90% aggregate benefit welfare associated with this technology by farmers in Argentina. Contrary to the US, farmers received 43% overall benefits while supply chain captured 57% from GM HT soybean. Given the findings, they concluded that developing countries can benefit significantly from these foreign innovations through spill-overs due to weak intellectual properties in developing countries.

2.2 Adoption rate of Genetically Modified (GM) crops in both developing and developed countries

GM crops were first adopted and cultivated by some developed countries, especially the USA, adopted cotton in 1996. Marra *et al.* (2002) confirmed that transgenic crops were developed and approved for adoption in the United States for the first time in history. However, the adoption rate thrived in developing countries and in 2012, GM crops were cultivated in 20 developing countries (including South Africa), and eight developed countries (James, 2012). "Ironically, in the same year when developing countries took a lead in GM crop adoption, three European countries discontinued planting GM crops" (Abidoye & Mbaya, 2014 p.104), meaning more developing countries have adopted the technology while some of the early adopters stopped using the technology. Contrary to the past expectation about GM commercialization that GM technology adoption would remain higher in the developed countries due to accessibility and permissible policies, 52% and 48% of global GM crops were cultivated in developing and industrialized countries, respectively. The developing countries received higher economic benefits with US$49.9 billion compared to US$48.6 billion in industrialized countries from 1996 to 2011 (James, 2012).

James, (2012) and Abidoye and Mbaya, (2014) concluded that increasing adoption in developing countries was due to ever-growing populations while low productivity is inherent in their agriculture sector. Azadi *et al.* (2015) also concur with the fast adoption rate in developing countries. The author demonstrated that the number of GM adopters reached 16.7 million in 2011, and from the total number, 90% (15 million) were resource-poor farmers in developing countries. For the first time in history, developing countries grew up to 50% of global GM crops in the same year 2012 with China, South Africa, India, Argentina and Brazil leading the way, having grown a total of 71.4 million hectares which was 44% of the global GM crop-cultivation (Azadi *et al.,* 2016).

Fifteen years later (from 1997-2012), South Africa was ranked the eighth highest producer based on biotech hectarage in the world, the USA being the largest biotech hectarage GM country (James, 2012), as shown in Table 2.1. Biotech hectarage refers to the number of hectares by which the biotechnological crops are produced per country (James, 2015). However, in 2015 the worst drought in 35 years of South African history impacted the hectarage of GM crops. There was a 700 000 ha (25%) decrease in GM crops (James, 2015). Table 2.1 shows that South Africa dropped to the 9th position below Pakistan in global hectarage rankings.

Table 2.1: Global hectarage rankings of biotech crops in from 2012 to 2015

Rank	Country	Area 2012 (Million Ha)	Area 2015 (Million Ha)	Change in Ha	Biotech Crops
1	USA	69,5	70,9	1,4	Maize, soybean, cotton, canola, sugar-beet, alfalfa, papaya, squash, potato
2	Brazil	36,6	44,2	7,6	Soybean, maize, cotton
3	Argentina	23,9	24,5	0,6	Soybean, maize, cotton
4	India	11,6	11,6	0	Cotton
5	Canada	10,8	11	0,2	canola, maize, soybean, sugar beet
6	China	4	3,7	-0,3	Cotton, papaya, poplar
7	Paraguay	3,4	3,6	0,2	Soybean, maize, cotton
8	Pakistan	2,8	2,9	0,1	Cotton
9	South Africa	2,9	2,3	-0,6	Maize, soybean, cotton
10	Uruguay	1,4	1,4	0	Soybean, maize
11	Bolivia	1	1,1	0,1	Soybean
12	Philippines	0,8	0,7	-0,1	Maize

13	Australia	0,7	0,7	0	Cotton, canola
14	Burkina Faso	0,3	0,4	0,1	Cotton
15	Myanmar	0,3	0,3	0	Cotton
16	Mexico	0,2	0,1	-0,1	Cotton, soybean
17	Spain	0,1	0,1	0	Maize
18	Colombia	<0,05	0,1	-	Cotton, maize
19	Sudan	<0,05	0,1	-	Cotton
20	Honduras	<0,05	<0,1	-	Maize
21	Chile	0,1	<0,1	-	Maize, soybean, canola
22	Portugal	<0,05	<0,1	-	Maize
23	Vietnam	<0,05	<0,1	-	Maize
24	Czech Republic	<0,05	<0,1	-	Maize
25	Slovakia	<0,05	<0,1	-	Maize
26	Costa Rica	<0,05	<0,1	-	Cotton, soybean
27	Bangladesh	<0,05	<0,1	-	Brinjal
28	Romania	<0,05	<0,1	-	Maize

Adapted from: James (2015)

Prior to democratic governance, South Africa was politically isolated from international society and therefore it relied solely on its own scientific and technological development for many years (Gouse, 2005). Genetic biotechnology was not recognized as necessary for survival and self-sufficiency of the country (Gouse, 2005; Andanda, 2009). After 1994, biotechnology was then seen as essential for economic development as South African politics was transformed into international standards (Cloete *et al.,* 2006). Since South Africa was negatively impacted by apartheid and hence, the socio-economic imbalances of the past, biotechnology is now believed to be the solution to social disparities in South Africa (Gouse, 2005; Cloete *et al*., 2006). This technology creates employment opportunities for small scale and resource-poor countries, attracts young academics through innovative research and skills transferred via international partnering (Cloete *et al.,* 2006). Approximately, R717,66/ha direct benefits were estimated in Makhathini regions of South Africa for smallholders growing Bacillus thuringiensis (*Bt*) cotton in 2015 (Azadi *et al.,* 2016).

Gouse *et al.* (2005) also conducted the study in South Africa and demonstrated that smallholder farmers could benefit from GM crops as much as commercial farmers do despite the production system differentials if they can adopt GM technologies. Smallholders managed to save on pesticide costs as they used less than 5% of pesticides on GM maize and higher yields were achieved. However, the adoption rate remains with large scale farmers as smallholders are very reluctant to change from their traditional practices to modern technologies (Gouse *et al.,* 2005). The adoption rate in South Africa is very high. This can be explained by the maize adoption rate where 72% of all maize seeds traded by large scale producers in South Africa which was GM during 2011/2012 season after it was introduced in 2000 (Department of Trade and Industry, 2013). There are two other GM crops in South Africa besides GM maize, cotton, and soybean which will be elaborated on in the next section.

2.3 Biotechnology in the South African agriculture

There is currently no commercialised GM sugarcane in the world. The only GM crops adopted and commercialized in South African agriculture are maize, cotton and soya bean. These enterprises are now dominated by those GM cultivars rather than conventional seeds (DAFF, 2017).

Insect-resistant cotton was the first GM crop that was adopted in South Africa in 1997. It was subsequently upgraded to the double-stacked genome of both HT and IR genes. The South African cotton industry is now 100% transgenic cotton. Herbicide-tolerant soybean was adopted in 2001 and the adoption rate was relatively fast. In the 2012/13 season, adoption reached 95% of the total area cultivated under soybean (SACGA, 2013). Insect-resistant maize was adopted early in 1998, and now there is also a HT maize double-stacked with insect-resistant and herbicide-tolerant cultivars. By 2014, more than 80% of GM maize was produced and consumed in South Africa (SACGA 2013). GM adoption has been very slow in other African countries even though South Africa pioneered the technology long ago. The slow rate was due to uncertainties about the benefits-costs, access and technicality associated with this foreign technology (Swanby, 2008). However, only a few African countries (Burkina Faso, Sudan, and Egypt) have joined South Africa, while other countries are showing interest in GM crops despite an ongoing controversy among proponents and opponents of GMOs.

Biotechnology is broad, it can be defined as the process of modification and development of desired products derived from living systems and organisms. Agrobiotechnology is the biotechnology performed in agricultural sciences which involves genetic engineering, modification and tissue culture (Abidoye and Mabaya 2014; BWSA, 2016). Agrobiotechnology such as GM crops shed light on addressing productivity constraints such as diseases, insect, pests, weeds and other environmental stressors in the African agricultural sector (Virgin *et al.,* 2007). Swanby (2008) believes that the sudden interest in GM crops by African countries is perpetuated by climate change which is now a political driver of GM crop adoption. There are GM crops that are resistant to drought which is expected to help Africa as most countries are relatively arid (Swanby, 2008). Abidoye and Mabaya (2014) also reported that African countries benefit the most from GM crops. They demonstrated that based on food security issues and the pivotal role of agriculture to economic development as shown in Figure 2.1, GMO proponents in South Africa and other African countries have managed to propitiate GMO critics.

Green biotechnology, the genetic modification done to produce environmentally friendly farming solutions (Virgin *et al.,* 2007; Abidoye and Mabaya, 2014) stands to benefit developing countries as they generally yield low agricultural productivity, especially the smallholders (Virgin *et al.,* 2007). However, GM crop adoption is complicated. Unlike most other agricultural technologies, GM technology falls beyond the jurisdiction of the department of agriculture. This technology attracts public and private stakeholders which causes an inherent ambivalence (Mabaya *et al.,* 2015). According to Mabaya *et al.* (2015), various departments, including agriculture, trade and commerce, environment, food safety and consumer protection, rural development, science, and technology participate in decision-making regarding GM crop adoption in Africa, as shown in Figure 2.1.

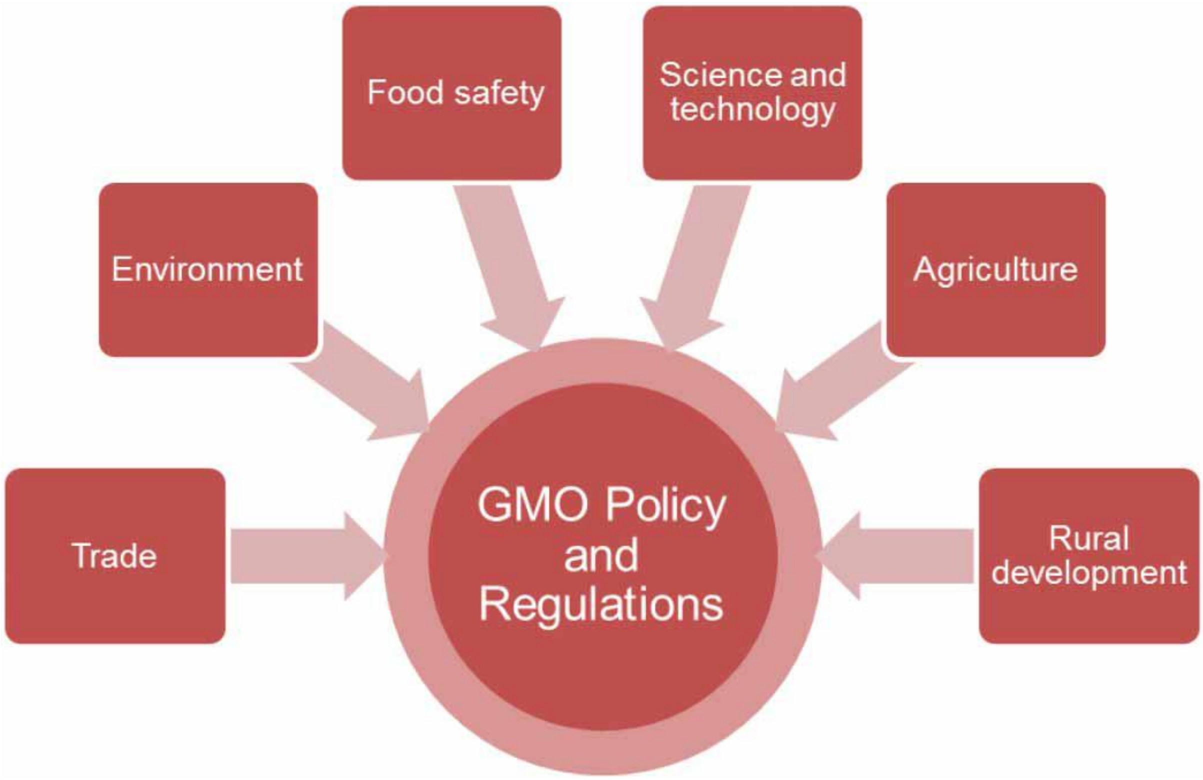

Figure 2.1: Key factors that influence the adoption of GM crops
Source: Mabaya et al. (2015)

A political power of government departments, therefore, has a direct effect on policies, rules, and regulations of GMOs. Hence, the adoption of GM technology is often determined by a political rather than scientific basis, political groups with special interests (Mabaya *et al.,* 2015). Aerni and Bernauer (2006) assessed the factors influencing GMO adoption in three countries, namely South Africa, the Philippines and Mexico. Their findings showed that drought was the common problem that is believed to be a driving force behind the relatively fast adoption of GM crops by all three countries. Pests, diseases, and chemical usage are the significant problems to be addressed by GM crops as shown in Figure 2.2.

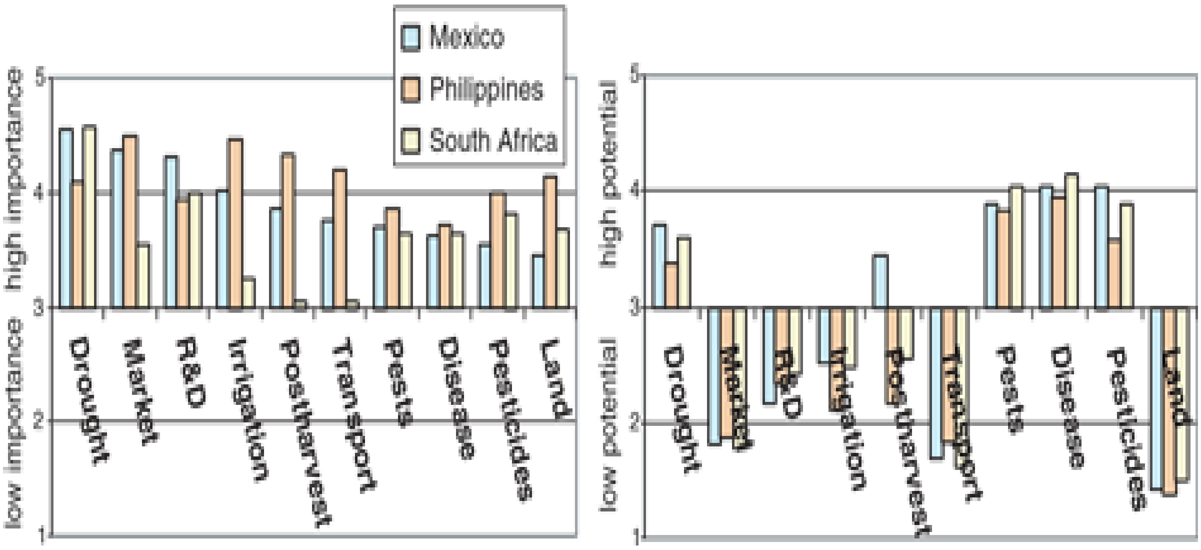

Figure 2.2: The significant problems in agriculture and the potential solution by biotechnology
Source: Aerni and Bernauer (2006)

In the South African context, Adenle *et al.* (2013) indicated that the success of GMO adoption can be justified by capacity building of modern biotechnology research and development as well as effective biosafety institutions put in place. Proper training of farmers and scientists participating in the program and effective information dissemination to the public play a significant role in South Africa.

Sugarcane is a crucial crop in South Africa which contributes significantly to the overall agricultural income; 13.9% contribution to field crops in 2009/10 season, second after maize (African Centre for Biosafety (ACB), 2012). Compared to other crops such as maize and cotton, genetic modification is not suitable for sugarcane owing to the complex nature of its genome (ACB, 2012). Therefore, there is currently no commercialised GM sugarcane in the world. Cheavegatti-Gianotto *et al.* (2011) concur with ACB (2012) about the complexity of the sugarcane genome which has hindered understanding sugarcane genetics and the aptitude for crop improvement using biotechnological methods. However, Cheavegatti-Gianotto *et al.* (2011) further argued that a series of in situ hybridization studies in the past few years have illuminated the understanding of the sugarcane genome. An advancement of biotechnology and genetic engineering tools have enabled gene transformation in sugarcane varieties despite the complex genome.

Among ongoing gene manipulation studies, research-based on herbicide-tolerant, drought-tolerant, enhanced nitrogen efficiency, altered sucrose production, and improved cellulosic ethanol production sugarcane varieties are still underway, being led by Australia and Brazil (world`s second largest sugar producer) (ACB, 2012). The review of herbicide-tolerant (HT) and insect-resistant (IR) crops in other enterprises assisted in understanding both costs and benefits involved in this technology (ACB, 2012).

2.4 Benefits of Herbicide-tolerant (HT) and Insect-resistant (IR) cultivars

Genetically modified glyphosate-tolerant cultivar varieties, known as roundup ready plants, have been widely accepted and adopted to satisfy the fast-growing agricultural products demand. Even though scientific evidence has been documented about the quality and safety of those new glyphosate-tolerant varieties, the debate continues. Cuhra (2015) said that there are methodological flaws in studies that show positive and beneficial evidence from roundup ready plants. The author found that glyphosate herbicides are often not applied in trial studies and that residual analysis is not done on those studies where glyphosate was applied. The author further concluded that the regulatory assessment is being systematically ignored as the levels of glyphosate residues were found to be unexpectedly high by an independent research unit. There is also a possibility that studies that are privately funded might inflate the benefits (Klümper & Qaim, 2014).

Farm-level impacts are hard to estimate and have been proved to be highly susceptible to biases. Since other measures beyond farm level rely on estimates made at this stage, it warrants an additional reason for extra care in estimating unbiased and fairly accurate measures. Unbiased farm level estimates will give rise to incorrect aggregate welfare which may result in detrimental environmental and pecuniary implications (Marra *et al.,* 2002).

Besides an ongoing controversy about GM crops, several *ex post* studies have shown significant benefits of adopting these biotechnologies. In a study that was conducted in Germany by Klümper and Qaim (2014), it was reported that both insecticide-resistant (IR) and herbicide-tolerant (HT) crops have increased crop yield by 21% on average. However, the yield increase was due to effective pest management rather than the high yielding potential of adopted technology where pesticide costs were reduced by 39% as illustrated in Figure 2.3. Even though adopters have to pay the premium for GM seeds, extra costs are compensated by savings on pest control (Klümper & Qaim, 2014).

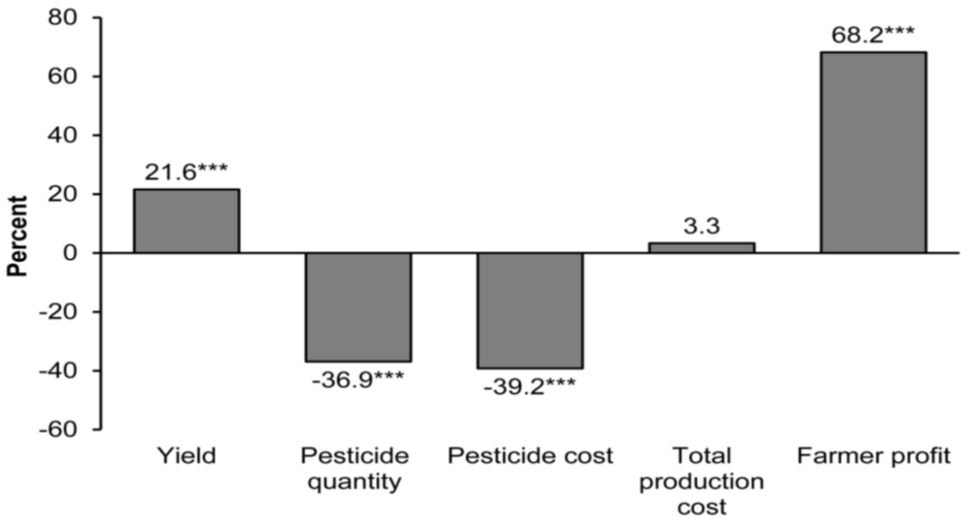

Figure 2.3: The overall benefits of HT and IR GM crops, globally. *Source: Klümper and Qaim, 2014*

Brookes and Barfoot (2014) reported that there has been a significant net economic benefit amounting to $18.8 billion at the farm level in 2012, which have been achieved globally since the introduction and adoption of GM technologies. However, the authors pointed out some crucial factors that should be noted for two main GM technologies, GM-HT and GM-IR.

For GM-HT:

- There was an average increase in cost associated with GM-HT in the period 2008-2009 due to the substantial price increase of glyphosate since this was the chemical suitable for GM-HT cultivar ;
- The willingness of farmers to pay for GM technology is inherently influenced by the benefits that farmers are likely to derive, which is mainly affected by intellectual property rights;
- The incidence of glyphosate weed resistance have been reported where glyphosate is used as a sole herbicide, and therefore farmers are alerted to be proactive and integrate glyphosate with other herbicides.

For GM-IR:

- Farm incomes have improved through higher yields as a result of lower levels of pest damage on crops;
- Developing countries benefit the most from yield improvements while cost savings resulting from reduced insecticide use are manifested in developed countries.

(Brookes & Barfoot, 2014)

A few studies have demonstrated a variety of benefits of GM crops in South Africa, and the reason for substantial success in the adoption of GMOs. However, all GMOs are subject to regulations and policies put in place to protect human health and biodiversity, as discussed in the next section.

2.5 The regulatory framework for the adoption of GMOs in South Africa

Even though South Africa has pioneered GMO adoption in Africa, there is an ongoing disagreement about the benefits of GMOs among stakeholders. The South African government has instituted some rules and regulations that are associated with GMO approval and adoption. The government prioritised the implementation of biosafety regimes that harness the safety and monitor the possible negative unintended consequences of GMOs (Andanda, 2009). The South African Committee on Genetic Experimentation (SAGENE) was established to draft biosafety guidelines in 1978 (Gouse, 2005) to conduct field tests of GMOs before adoption to avoid negative externalities (Abidoye & Naya, 2014). All GMO activities which include research and development, import or export, production, consumption and other uses of GMOs and their products are regulated by the Genetically Modified Organisms Act no. 15 of 1997 (GMO Act) in South Africa. This Act which is based on expert-ruled policy sets the minimum required standards in GMO to facilitate safety in food and the environment as well as socio-economic sustainability. The GMO Act is controlled by the Department of Agriculture, Forestry and Fisheries (DAFF) which is made up of two regulatory structures, an advisory committee, executive council and inspectors (Department of Trade and Industry, 2013). South Africa did not experience any change in political authority since 1994, with the African National Congress being the uncontested ruling party. This helped in hastening the adoption of GM technology by already existing structures in the committees with no major changes in regulatory stakeholders (Aerni & Bernauer, 2006).

In 2000, genetic engineering and other biotechnological practices received public attention as the South African government began to support research and development of genetic modification. As a result, the National Biotechnology Strategy (NBS) which is a policy framework to incentivise biotechnological practices (Andanda, 2009) was established. The strategy is driven by various government departments led by the Department of Science and Technology (DST). NBS was adopted to ensure the smooth link between research and commercialization of GMOs through funding, human resource development, regulations and legal issues (Cloete *et al.,* 2006). NBS attempts to guarantee a stringent biosafety regulatory system aiming to minimise disruption to the environment while addressing sustainable development goals in the country (Andanda, 2009).

For genetically modified products to be acceptable in the international markets, the country must meet international standards by the World Trade Organisation (WTO). So, adoption of GM technology in South Africa is governed by the Patents Act of 1978, which was amended in 1997 to Counterfeit Goods Act and Intellectual Property Laws Amendment Act bills. The main aim of this Act is to protect communities and individuals with indigenous knowledge from bio-prospectors` exploitation. The Department of Environmental Affairs and Tourism (DEAT) has to approve the patent if certain conditions are met. Otherwise, co-ownership, shared-benefits and compensation conditions are imposed before the approval. Unfortunately, the Act has negative unintended consequences because it dis-incentivises bio-prospecting given the low level of patenting in South Africa (Gouse, 2005; Aerni & Bernauer, 2006).

The South African government has advocated transgenic research on other various crops (strawberry, vineyards, and sugarcane) after commercialising *Bt* soybean, *Bt* maize and *Bt* cotton (Aerni & Bernauer, 2006). Currently, South Africa conducts a significant proportion of Africa`s research and development pertaining to biotechnology as the country is recognised as a suitable research area for addressing development problems like food security and advanced health care. Rapid commercialisation of GM crops in South Africa can be attributed to its rich natural resources (gold and diamonds) and well developed legal, financial, communications, transport, and energy sectors which provide well-suited infrastructures for biotechnology. Even though South African biotechnology is the best compared to other African countries, it has shortcomings and weaknesses. Institutional arrangements are not conducive to promote sufficient and effective connections among researchers in different disciplines and organisations, and there are only limited employment opportunities for local stakeholders and graduates in this sector (Andanda, 2009).

However, in 2000 non-governmental organisations (NGOs) challenged government regulatory policy. They argued that the policy is too receptive to the needs of foreign companies while it is too secretive regarding public scrutiny surrounding permits for GM crops. Bio-watch South Africa, a major opposition to genetic modification of food in South Africa, has also criticised government for not being transparent about GM approval in South Africa. In 2004, Bio-watch SA also protested against the World Food Programme (WFP) and US Agency for International Development (USAID) for refusing Africans the right to voice their concerns about GM aid (Aerni & Bernauer, 2006).

Despite being in full support of biotechnology, South Africa has ratified the Cartegena Protocol on biosafety and abides by its rules. The Cartegena Protocol on Biosafety is an international agreement concerning the movement of living modified organisms and outcomes of biotechnology across the countries. An agreement was adopted on 29 January 2000, supplementing the Convention on Biological Diversity and was enforced on 11th of September 2003 (Biosafety Clearing House (BCH)). The protocol is aimed at protecting biodiversity against potential risks brought by GMOs and hence, an advanced informed agreement procedure (AIP) was established. AIP thereby ensures that countries make informed decisions regarding GMOs by providing all the essential information pertaining to those organisms before they agree to adopt.

2.5 Empirical evidence of GMOs` impacts in different countries

Ainembabazi *et al.* (2015) demonstrated the social impact of a genetically modified banana plant that is resistant to destructive disease, Xanthomonas wilt. assessment was conducted in the Great Lakes Region of Africa (GLA) to understand the future adoption and consumption, and the potential economic impact of GM varieties that are resistant to *Xanthomonas wilt.* Local scientists, extension agents, officials from private tissue culture development laboratories and agricultural experts were identified to select the major banana producers. Then, local extension officers helped to identify respondents (producers and traders). Data was collected from both smallholders and large-scale farmers in the selected regions.

Ainembabazi *et al.* (2015) used the Economic Surplus Model (ESM) approach over other *ex ante* methods. The justification was that ESM controls both international prices and distributional effects as it does not assume the perfect elastic or inelastic supply and demand of goods.

Results showed that the release and adoption of GM banana will benefit both farmers and consumers. Yields are anticipated to grow significantly, leading to falling prices due to a large supply in the market. Therefore, consumers are expected to pay less while an increased yield is also expected to benefit farmers through larger supplies at a lower cost. Hence, an economic surplus is expected to improve. The data accumulation period is from 2013 to 2020 (expected release date). Costs associated with the adoption rate were enumerated from the year 2013 until the expected adoption date in 2037. Approximately, 65% of farmers showed a willingness to adopt GM banana plants immediately upon the release date. However, some farmers were reluctant to adopt as they indicated that they would rather wait and learn about social and economic implications brought about from the new variety.

Notwithstanding the reluctance of other farmers, Ainembabazi *et al. (*2015**)** found that the adoption rate is expected to reach 100% between 2 to 10 years from the release date. The price for GM planting material was projected to be fairly constant as almost all (90%) farmers are willing to pay the premium while others are willing to buy at a discounted price. Since banana plants, *Musa* is a perennial and vegetatively planted crop, the findings and methodology used in this study were found to be useful in the sugarcane context because it is both a vegetative and perennial crop as well. Different methodologies that are widely used on the *ex ante* assessments are discussed in the next chapter.

Finger *et al*. (2011) concurred with Ainembabazi *et al.s.* (2015) study. In their meta-analysis of GM crops, Finger et al. (2011) demonstrated the significant improvement at farm level owing to GM crop adoption. The results from the Mann-Whitney U-test (non-parametric test) showed higher gross margins derived from GM cotton, approximately 86% higher than conventional cotton in India while South Africa, Spain, China, and the USA achieved relatively lower yield increases. The lower yield advantages on other countries, other than India, may be due to appropriate pest control mechanisms already in place which suppresses pest-infestation. Klümper and Qaim (2014), cautioned that the higher yields are not concomitant to GM insect-resistant crops. Rather, the reduction in yield loss because of pests leads to higher yields at harvesting time. Besides, GM crops (both Bt maize and Bt cotton) seem to benefit farmers through cost-saving on pesticides in many regions but farmers must pay a premium for GM seeds.

Having reviewed the adoption of GM crops and their impact, it was discovered that there is little available information about perennial GM crops as most countries have adopted seed-planted and annual GM crops. Reviewing the annual GM technologies and a few perennials as a baseline scenario for this study, developing countries benefit significantly from these technologies. GM crops have assisted the resource-poor and smallholder farmers to increase the yields and therefore, meeting the food demands of ever-growing populations in developing countries. African countries appear to be benefiting the most from GMOs in terms of food security under volatile climate change. Even though biotechnology has improved productivity in South African agriculture, the adoption of GM technology involves various stakeholders that are outside the agriculture jurisdiction. Therefore, the assessment of GMOs should go beyond farm level impact to analyse externalities and spill overs. This can be achieved by choosing the best methodology that accurately covers all intended components. The economic theory and various methodologies widely used in conducting *ex ante* studies are presented in the next chapter.

Chapter 3: Theoretical and conceptual framework

This chapter aims at presenting the conceptual background of impact assessment studies. This followed by the presentation of features of *ex ante* assessment and how this assessment method differs from *ex post* impact assessment. Following on are the crucial steps in executing farm investment analysis of new technology. Lastly, the various methods used in *ex ante* studies, their weaknesses and strengths are presented in this chapter.

3.1 An overview of an impact assessment analysis

Impact assessment is defined as an evaluation of how the intervention being assessed affects outcomes, whether intended or unintended (Baker, 2000). According to Rogers *et al. (*2014) impacts are defined as "positive and negative, primary and secondary long-term effects produced by a development intervention, directly or indirectly, intended or unintended." Unlike evaluation analysis that focuses more on the outcome that has already been produced, impact assessment also focuses on narrow and tightly designed outcomes of the proposed intervention (Organisation for Economic Co-operation and Development (OECD), 2002). Impact assessment studies on GM technologies, for instance, raise arguments between their advocates: policy-makers and academic researchers, and the opposing parties such as NGOs because regardless of the benefits of those GM crops, there are still safety and health concerns raised by opposing parties. There is a strong belief that studies that are sponsored by money industries tend to inflate benefits. However, Klümper and Qaim (2014) argued that the sources of funding have no significant influence on impact estimations.

Impact assessment is usually conducted for two purposes: summative and formative purposes. Summative impact assessments are done at the beginning of the program to inform decisions whether to continue, stop, replicate or scale-up that intervention or policy (Rogers et *al*., 2014). Summative assessment goes beyond findings of what will work, it informs the decision makers about how to make an intervention work in different scenarios for different groups. Formative assessment, on the other hand, is undertaken to inform decisions on the already ongoing intervention to improve the processes (Rogers et *al*., 2014).

The counterfactual analysis is an important component of impact assessment that compares the 'with and without' intervention. Sometimes 'before and after' the intervention can be used for comparison, but not very common as it may lead to the wrong attribution. This analysis evaluates the "without intervention" outcomes. Impact assessment is conducted if there is a need for a strong baseline to inform decision-makers with strong evidence before the intervention is instituted (Baker, 2000).

There are two types of quantitative impact assessment, *ex ante*, and *ex post*. *Ex ante* is conducted before the potential intervention takes place to ascertain the impact on the economy and society, while an *ex post a*ssessment is undertaken after approval and adoption of an intervention. According to Partharsarathy and Bhattacherjee (1998), both e*x ante* and *ex post* impact assessment of agricultural technologies has been restricted to International Agricultural Research Centres (IARC). Very few studies were conducted in developing countries until 1960s and 1970s when other developing regions participated in a few socio-economic studies in the wake of the `green revolution`. Cost-benefits of modern biotechnology, genetic engineering impact studies have only been conducted by developed countries. However, developing countries have least benefited due to biased results which fail to account for integration of efficiency, sustainability and social issues (Partharsarathy & Bhattacherjee, 1998). Lack of substantial preparations, wasteful and inefficient expenditures and uneconomic use of available funds have shown detrimental outcomes in most projects in developing countries where capital tends to be a constraining factor (Gittinger, 1984).

3.1.1 *Ex ante* vs *ex post* impact assessments

An ex ante impact assessment refers to the socio-economic assessment that is undertaken prior to the potential release or adoption of technology (Mudombi, 2010). *Ex ante* is useful in computing the magnitude of future impacts of the programs and technologies on the targeted group. This type of assessment involves various processes (biosafety approval and actual trials or surveys) as it is intended to avoid adverse impacts to society, and it is aimed at informing decision-makers and investors about projections of risks and opportunities associated with a new technology (Khandker *et al.*, 2010; Mudombi, 2010).

In most cases, structural models based on the economic environment facing potential players are the backbone of *ex ante* assessments (Wander e*t al.*, 2004). Identification of the main economic agent in establishing the project and those agents linked with different markets are important components of structural models (Khandker *et al.*, 2010). Agricultural resources are scarce, not only for production processes but for research as well. Therefore, an *ex ante* assessment serves as an efficient resource and empirical justification for their use in a society based on the economic impact's valuation (Wander e*t al.*, 2004). *Ex ante* assessment involves prospective analysis and therefore, observer effect and Hawthorne effect are inevitably inherent. Observer and Hawthorne effects is when the respondents alter their behaviours or responses just because they are being observed (OECD, 1993).

Ex ante analyses of technologies that are not yet adopted are rigorously constrained by data availability and quality. Demont *et al.* (2008) reported that the impact of *ex ante* on technologies are typically underestimated because researchers tend to ignore farmers heterogeneity towards technology adoption and therefore, results from cross-sectional comparisons are affected by homogeneity bias. The literature manifests that cross-sectional comparisons only use first order statistics (central tendency values) which can be easily affected by outliers and variation (Klümper & Qaim, 2014). Therefore, the potential adopters and non-adopters of technology are not segmented. The remedial action to avoid homogeneity bias is to incorporate second order statistics (variability values) on farmer heterogeneity analyses (Demont *et al.*, 2008).

Contrarily, *ex post* assessment assesses the actual impact attributable to the intervention. Unlike *ex ante* analysis which uses structural models, *ex post* analyses mainly use treatment effect models in evaluating the impact. Shortcomings of this type of assessment are: (i) evaluation fails to capture mechanisms underlying the intervention`s impact on the targeted population, especially in future settings. (ii) *Ex post* evaluations are very costly and tedious owing to actual data collection of both participating and nonparticipating groups. (iii) The failure of an intervention is even more costly, which might have been forecasted by using an *ex ante* analysis (Khandker *et al.,* 2010). *Ex post* is further critiqued due to its failure to establish viable counterfactuals, deal with long lag times and attribute impact from the project (Gramlich, 1990).

Various approaches have been used in *ex ante* studies to estimate the economic impact of genetically modified crops in the past. Those approaches include cost benefits analysis (CBA), the economic surplus model (ESM) and simple gross margin analysis (GMA) (Mudombi, 2010). *Ex ante* assessment is very important, however, to attach a value to the project proposed it is necessary that a farm investment analysis is conducted before the project is approved to test the feasibility of that project.

3.1.2 Farm Financial analysis of the adoption of a new technology

A financial analysis of a proposed project is the fundamental assessment of performance of that project. The complexity of the project determines the level of details required in the execution of financial analysis (Gittinger, 1984; Bhogal, 2017). In agricultural projects, financial analysis is based on the farm plan model that projects resource allocation and income flows for other participating farms to a similar project (Bhogal, 2017). Other entities in both private and public sectors may be simple and be summarized for an organized project while those complex projects that involve various entities with special problems require a complex financial analysis (Gittinger, 1984). Bhogal (2017) concurs with Gittinger (1984) about the six key objectives of financial analysis as per below:

1) **Financial impact on the project entities should be assessed:** Assessment of the financial effects the project will bring to all stakeholders (farmers, public and private firms, government agencies and other players) is the primary objective of financial analysis. This step addresses each stakeholder`s current and future financial performance after project implementation
2) **Assessment of efficient resource allocation and use:** There are two indicators of efficient resource allocation, (i) overall project returns are important because management works within the framework of the market price and (ii) loan repayment received by each enterprise.
3) **Assessment of incentives associated with that project:** A project should be assessed as to whether it has the necessary incentives that will encourage entities (farmers, managers and other participants in the value chain) to participate in that project. Also, to assess whether the incremental income is

adequate to compensate for the additional effort and risk incurred, the returns on equity capital and whether the external funds are used.

4) **Provision of a sound financial plan:** Here, a financial plan is worked out based on the situation of stakeholders as well as the project itself to determine sources of funding and timing. Terms and conditions for repayments of outsourced funds are set here. Effect of inflation is considered as well on projected costs and revenues. Lastly, the rate at which the project itself will generate income is estimated.
5) **Financial contribution is coordinated:** Contributions by various participants are coordinated to conduct an overall financial projection of the whole project. Available resources and funds are matched with expenses as well as timing of expected expenditure and income for stakeholders.
6) **Competence of financial management:** A financial analyst should be able to judge the complexity of financial management required by that project and assess the capability of current management to handle implementation. And therefore, changes, improvements or training are made before the project is implemented (Gittinger, 1984; Bhogal, 2017).

These are the basic objectives of financial analysis prior to the technology adoption or project implementation. Attaching the value of the new farm investment and the required technology comes with many challenges. A farm entity consists of many components that are interacting economically, socially, biologically and financially (Rendel *et al.*, 2015). Most investments tend to impact distinctively depending on the area of application on the farm. There are two main challenges in attaching value to new farm technology, (i) adjusting the current practices to realise the full potential of a new technology, (ii) isolation, quantification and valuation of a specific contribution considering that new developments are not easy (Rendel *et al*., 2015).

Financial analysis of an intervention is very important before that intervention is adopted. However, before the costs associated with development project on the farm is established, the purpose and objectives should be comprehensive. Agricultural development projects aim to increase productivity, profitability, and creating employment with the optimum contribution to the food and agricultural business sector as a whole (Anandajaysekeram *et al.* 2004). Before the decision is made about a new project, the resources and funding are considered. In developing areas, projects are funded by government while private financing is prevalent in commercialised agriculture. Various methods are widely used in conducting ex ante impact assessments and are discussed in the next section.

3.1.3 Economic surplus model (ESM)

The economic surplus model (ESM) is an economic assessment aimed at measuring the aggregated public benefits of a particular research project. This method is widely used in *ex ante* studies as it enables researchers to estimate the investment returns by calculating both producer and consumer surplus via that technological change driven by research. Then, an economic surplus is used together with the initial cost of the project to calculate metric functions such as net present value or internal rate of return. The major advantage of ESM is that there is less information required than other methods (Wander *et al*., 2004). Assumptions of ESM are:

- The functional form of the supply curve is not known;
- The country operates under a closed economy or is the only exporter of that commodity while other countries are expected not to adopt the technology;
- The parallel shift of the supply curve is expected after adoption;
- Costs and benefits accrued to each member of a relevant group should be added and
- The competitive demand price and supply price for a given unit measures the value of that unit to the customer and the producer, respectively (Jaiprakash, 2016).

This approach is one of the best economic analysis tools that is commonly used for both *ex ante* and ex post-assessments (Wander *et al*., 2004). However, there are certain disadvantages of this approach that should be considered to avoid incorrect evaluation of the project. ESM tends to overestimate the benefits of the project as it ignores transaction costs. It only gives gross benefits of the intervention and ignores the net benefits. The relationship's effect with other products and factors in the market are ignored because the model is a partial budget in nature. The effect on the input market is not clear and the approach does not explicitly account for returns on the important factors of measuring the impact of new technology which is labour and land.

Reliable cross-sectional time-series data is required which is not yet readily available for genetically modified assessments (Mudombi, 2010; Jaiprakash, 2016).

Using a different approach from the above methodologies, Flannery *et al.* (2004) carried the projection study in Ireland to assess the potential costs and benefits associated with the adoption of GM crops. Assuming that producers would base their decisions on price relatives of conventional and GM planting materials, synthetic pesticides, capital, labour and other relevant resources, it was reported that the system which minimizes costs associated with these activities would be chosen by the individual producer. Five hypothetical crops (sugar beet (premium-tolerant), winter wheat, spring barley, and potatoes) were chosen and analysed using cost-benefit analysis (CBA), and the selection of crops was justified based on their economic importance in the country.

For this study, the results of HT sugar beet from Flannery *et al.* (2004) findings will be considered. With an estimated yield effect of 6% calculated from Ireland, there was a reduction in both volumes and the number of applications required in the GM cultivar. However, an extra cost of €30/ha was incurred for GM seeds. These extra costs were compensated by 9.69% and 6% increase in gross margin and yield, respectively (Flannery *et al.,* 2004). Other GM crops showed significant, potential benefits to the farmers, and the authors concluded that the overall productivity can be improved at the farm level by adopting GM crops. However, because GM crops are not yet cultivated in Ireland, the results are merely suggestive rather than conclusive evidence.

3.2 Background on the cost-benefit analysis

Cost-benefit analysis (CBA) is a process of quantifying economic costs and benefits, over a certain time horizon, and opportunity costs forgone attributable to a particular intervention or project to resolve if it can be undertaken without any biases. CBA compares all present and future benefits of the project with its present and future cost (Flannery *et al.,* 2004). This method was established back in 1844 by a French engineer, Jules Dupuit for bridge construction and water pricing (Gramlich, 1990). CBA is widely used and is probably the most comprehensive economic evaluation method available to avoid possible ramifications in the welfare of current and future generations (Nas, 1996). This method has been used for the past decades as an aid in decision making for economic and social policy (Robinson, 1993).

Unlike financial analysis, that is widely used in the private sector, which only looks at the outcomes that are in the best interest of that firm. CBA considers all forms of economic costs and benefits in both humans and environment. The private sector tends to measure economic efficiency through economic profit evaluation without considering possible costs to the third-party and positive unintended outcomes to the environment (Nas, 1996). However, this does not necessarily need to be valid in the private sector as the market information can be distorted or decision may be affected by new government policies. Under CBA analysis, prices are corrected for possible market distortions before they are used in the valuations. Therefore, CBA is recognized as the best approach in testing economic efficiency (Nas, 1996; Department of Trade and Industry, 2013).

The ultimate objective of each firm is to make sure that resources are put at their best-valued uses because all trade-offs are clearly stated before the implementation. The strength of CBA is the last step in the project cycle where a sensitivity analysis is undertaken to account for risk and uncertainty. This step involves changing some key and uncertain parameters such as prices of inputs and output, cost of labour, discount rate and externalities (Gramlich, 1990).

3.3 Background of gross margin analysis (GMA) in decision making

A gross marginis a sales revenue retained after the incurring variable costs associated with sales (Firth, 2002).This type of analysis became popular in the UK in early 1960 when it was mainly used by farm management advisors for planning and analysis purposes (Firth, 2002). Gross margin analysis (GMA) can be used to compare enterprise margins with figures obtained from other farms, given that those farms have similar characteristics such as topography, soil types and climatic conditions, and production systems. Comparisons give a functional indication of the production and economic enterprise of that business.

Simple gross margin analysis is a useful method in the *ex ante* impact assessment when estimating the economic profitability of technology. However, profit attributable to new technology cannot be fully captured by this analysis because the overhead costs (interest and depreciation) and return to management are excluded (Mudombi, 2010). Anandajaysekeram *et al.* (2004) concurs with Mudombi (2010) that gross margin analysis is one of the most commonly used methods when dealing with *ex ante* studies, but it has shortcomings. GMA fails to capture the social and environmental impact (both negative and positive) that are attributable to new technology. Therefore, the decision to adopt new technology cannot be made based on GMA solely as some economic costs and benefits are excluded from financial gross margin analysis (Anandajaysekeram *et al*. 2004).

3.4 A case study using representative farm models approach

Representative farm modelling using linear programming is one approach to conduct an impact assessment. The model is generally verified using a baseline scenario. The impact assessment is then conducted by re-running the model for an alternative scenario and a counterfactual. However, due to considerable uncertainty about a scenario ten years from now, when a GM cane is likely to be released, that the counterfactual is the baseline scenario, and the “with GM cane” scenario is the baseline scenario with an additional option of GM cane cultivar, *ceteris paribus*. As mentioned in Chapter 1, this study used a linear programming farm representative model and thus the detailed review of this approach is presented in the methodology section in Chapter 5.

Even though the representative farm model approach is not widely used in *ex ante* assessment of perennial organisms, the empirical evidence from the study by Griffith *et al*. (1995) in the perennial nature is briefly presented in this section. Griffith *et al.* (1995) conducted an *ex ante* assessment in Australia about adopting new technology: large, lean lamb (LLL). LLL technology was aimed at improving lamb production in Australia after the lamb sector has shown a stagnant growth rate. Farm-level economic impact of the new technology was assessed, using two methods. The first method was to calculate relative cost differences between existing technology and new technology based on the set of gross margin budgets. The method is critiqued due to its recognised limitations. Regardless, this method is known for its ability to presents more information on the more sophisticated economic approaches, and it can incorporate risk analysis to main parameters using @Risk package (Palisade Corporation,1990).

Secondly, the linear programming (LP) method was constructed for representative farms incorporating outputs from gross margin analyses. LP was chosen owing to ease of specification, operation and the joint consideration of coincidental farm activities. Also, LP indicated an opportunity cost of requiring a specific production level. The results showed that new technology would benefit both lamb producers and consumers in the country by A$4 and A$30, respectively (Griffith *et al*., 1995). Therefore, the gross margin model was used for intra-enterprise while the LP model was used for estimation of inter-enterprise adjustments. The long-term nature of an enterprise in this study can help with the current study as sugarcane is perennial and long-term in nature as well. To account for risk and uncertainties about the technology at the farm, Baumol`s model, as a fine-tuning mechanism (Hazel and Norton, 1986), was incorporated in the linear programming matrix.

3.5 Conclusions

Most of the methodologies have been criticised as they have failed to capture the full impact of the new technologies. Linear programming was identified as the best technique that is able to accurately capture the full projections of a new technology, including risks associated with that new intervention. This method was chosen for this study, and the detailed background and discussion are presented in Chapter 5. LP using representative farm models is one approach used to conduct an impact assessment by comparing the results of a verified representative farm model for a baseline scenario with the results of an alternative scenario. The empirical evidence derived from the study that was successfully conducted in Australia using LP method is presented.

Before any form of intervention is employed, the holistic understanding of challenges facing the industry is crucial to prevent unforeseen challenges inherent in the industry (Visagie *et al*., 2004). The following chapter extensively reviews the South African sugarcane industry to contextualize all methodologies and assumptions applied in this study.

Chapter 4: An Overview of the South African Sugarcane Industry

Having presented the economic theory in Chapter 3, the South African sugarcane industry and challenges facing it are reviewed in this chapter. Sugarcane as a crop is briefly described for clear understanding of its agronomic features. This is followed by a discussion of general production systems used in other sugarcane growing countries, and in the KwaZulu-Natal, South African context. Additionally, challenges facing sugarcane farmers, hindering productivity and profitability of sugarcane in South Africa are discussed. Finally, the role of sugarcane in employment creation is presented. This chapter helps to review the main activities in sugarcane farming, and therefore, the challenges that will be addressed by GM technology are identified.

The South African sugar industry is among the top, high quality and competitive producers of sugar in the world. South Africa is ranked in the top 15 out of approximately 120 producing countries globally (SASA, 2015). The supply chain of sugarcane involves various stakeholders, from cultivation, manufacturing of raw materials, sugar refining and a range of by-products produced. There are approximately 24 000 registered cane growers mainly farming in KwaZulu-Natal and in Mpumalanga contracted with 14 sugar millers as shown in Figure 4.1 (SACGA, 2018).

Even though the South African sugar industry has been discerned to be effective and efficient, there are inefficiencies and shortcomings mainly because of underlying fragmentation between millers and growers (Hildbrand *et al.*, 2014). Stakeholders with different, and sometimes conflicting aims and objectives are interdependent yet interact with each other to maximise their processes (Ndoro *et al*., 2015). Competitiveness among industries and companies is no longer centred on the consumers` satisfaction about the final product but the focus is now on improving the supply chain. Inherent disagreements between millers and cane growers can perpetuate the complexity of the sugar supply chain (Hildbrand *et al.*, 2014; Ndoro *et al.,* 2015).

According to Hildbrand *et al.* (2014), the complexity eventuates in both "hard" and "soft" issues. "Hard" issues are defined as technical and operational areas like transport optimisation, cane quality, and mill efficiency, whilst "soft" issues refer to interactional aspects such as values, goals, perceptions, relationships, communication, and behaviour of stakeholders. A large number of studies had focused more on "hard" issues with very little attention on "soft" aspects of the supply chain (Hildbrand *et al.*, 2014). The main cause of miller-grower fragmentation is that these two parties generally perceive each other as competitors instead of being partners in a mutual and symbiotic relationship. This fragmentation can be attributed, mainly to "soft" issues such as trust and communication deficits, lack of incentives and inefficient conflict resolutions. To solve the miller-grower fragmentation in South African sugar supply chain, a holistic understanding of both aspects (soft and hard) is important (Hildbrand *et a*l., 2014; Ndoro e*t al.,* 2015). Improving "soft" aspects first in the supply chain can lead to efficient and effective "hard" and structural aspects (Gerwel *et al.*, 2011).

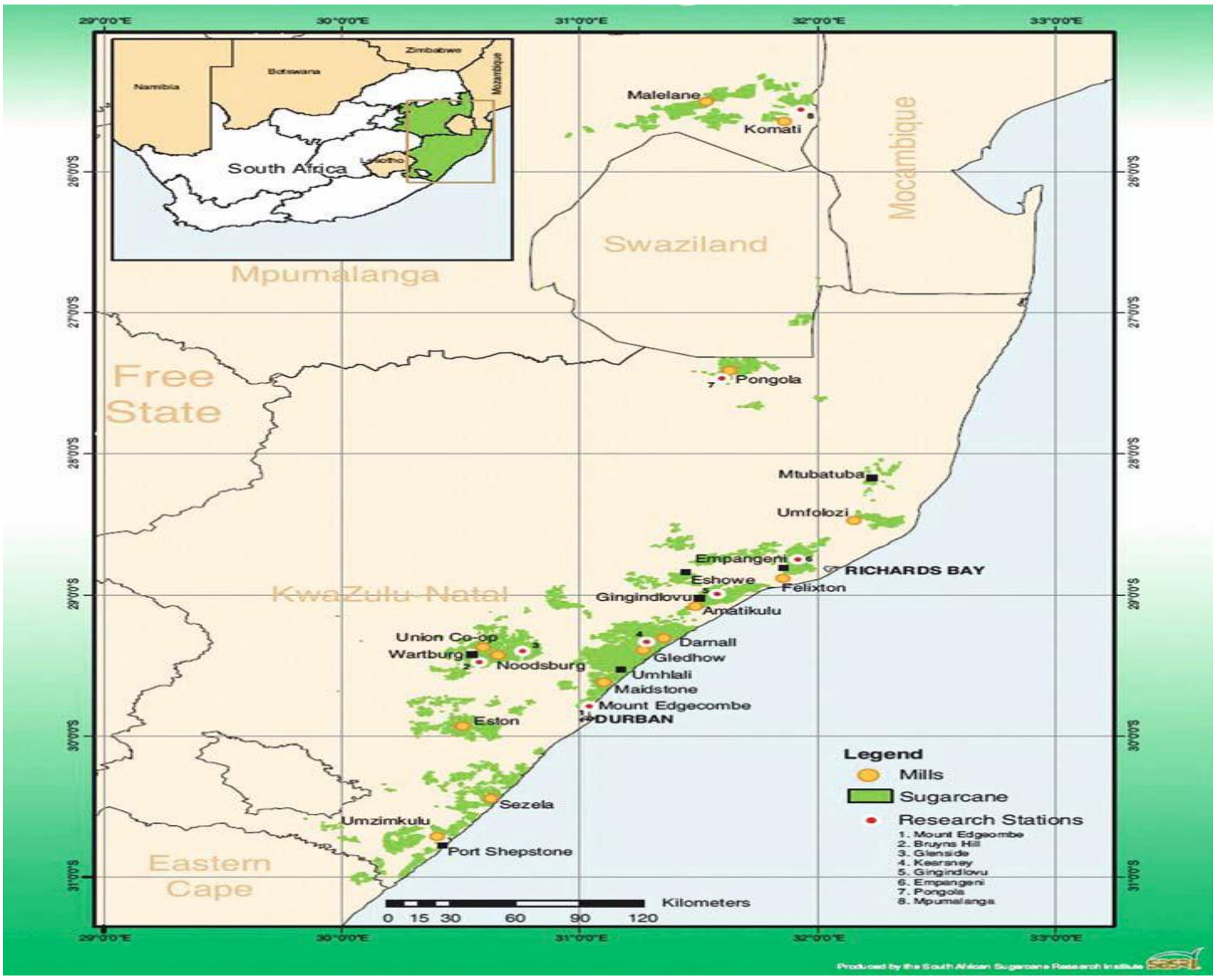

Figure 4.1: Map of the South African sugarcane industry. *Source: Snyman et al., 2008*

From the total sugar produced, 60% of that sugar is traded in the Southern African Customs Union (SACU) which is a customs union among five countries of Southern Africa: Botswana, Lesotho, Namibia, South Africa and Swaziland, and the rest is exported to other African countries, Asia and the Middle East. The sugar industry generates about R8 billion in revenue per annum (SASA, 2015).

Sugarcane producers have experienced a cost price squeeze phenomenon from the year 2010 due to lower world prices; less profit from export trades. Recent drought also contributed to lower yield, poor quality and increased input costs (DAFF, 2017). Costs that are attributed to lower profitability of sugarcane are chemicals, labour, fuel, fertilizers and maintenance and repairs (Mboyisa, 2017). Since farmers are price takers, sugarcane production became relatively less profitable than it was in the past decades due to limited alternatives for them to remain profitable. There has been a significant increase in fuel, lubricants and chemical costs in this sector lately, which can be attributed to mechanisation and higher chemical sprays needed for adamant weed and pests (DAFF, 2017). Pressure on farmers was further added by the 50% increase to the minimum wages to farmworkers in 2012 (DAFF, 2017; Mboyisa, 2017). The minimum wage policy was aimed at benefiting employees by setting a minimum amount to be paid to employees per hour. However, that resulted in a negative unintended consequence because the cost of labour became so high that employers decided to substitute manual labour with mechanisation. Most large-scale farmers have responded by reducing labour while investing more on labour-saving technologies.

Most agricultural policies are established to assist employees and farm dwellers, but the risk and uncertainties associated with them impact the sector negatively. For instance, the land reform policy has aggravated the uncertainty about the future of current white cane producers because the land is subject to redistribution or/and restitution. Therefore, long-term investment in farms has declined, so has the profitability (Goga, 2013; Ndoro *et al*.,2015).

4.1 Review of the general sugarcane crop

Sugarcane, *Saccharum officinarum,* is a perennial grass that belongs to the family Gramineae and it can grow up to 4.25 m tall (Nxumalo, 2015). The plant is adapted to a wide range of climatic conditions, but tropical and subtropical areas are well-suited for faster elongation with hot temperatures and high humidity (80-85%) (Smithers, 2014; Nxumalo, 2015). The crop can be grown in slopey or flat terrain with 0.9 to 0.15 row spacing, and it matures from 12 to 24 months period, depending on the region, cultivar and production system (Smithers, 2014). Approximately 70% of total sugarcane in South Africa is under rainfed production and the rest is under supplementary or a full irrigation system (Nxumalo, 2015). Sugarcane is vegetatively propagated through stem cutting of 8-12 months old cane. The plant can adversely be affected by various abiotic and biotic factors. The main abiotic factors are a frost, drought, soil acidity and nutrient deficiency (DAFF, 2012). This study focuses on the biotic factors that affect cane quality.

Weeds and insects have become significant pests (biotic factor) in sugarcane fields in the last decade. Creeping grass is an adamant weed that competes with sugarcane for resources, especially at an early stage of development when the cane canopy is not fully developed to shade the weed (Cheavegatti-Gianotto *et al.*, 2011). Eldana is a major biotic factor that has caused severe loss of cane yield and quality. Sugarcane grows at an average rate of 5 to 7 tonnes per month with a maturity cycle of 20 to 24 months in the inland areas. At maturity, there are two general harvesting methods used, manual or mechanical harvesting. Manual harvesting has dominated since 1848 because it is relatively cheaper, there is an abundant labour force and because the sugarcane is generally planted in steeper terrain with more than a 20% slope where mechanical harvest is not easy. With manual harvesting, burning of standing cane used to be the necessity to improve the efficiency of cane cutters. However, cane producers are now shifting to green harvest due to government regulations and other benefits of green harvest such as reduced soil erosion and protection from natural enemies of the major pests (Nxumalo, 2015).

4.2 Current sugarcane production systems in other countries

Just like any other cropping system, sugarcane production requires alternative management strategies that consider production, economic and environmental outlooks. Sugarcane can either be irrigated or rainfed depending on the climatic conditions (Keating *et al*., 1999). The first step in the establishment of a commercial sugarcane field is to obtain the vegetative planting material from the coveted commercial cultivar. For a disease-free seed cane, hot water treatment is used to control systemic infections in the stalks to be planted. Alternatively, tissue meristem culture can be used for virus and bacteria-free sugar cane (Cheavegatti-Gianotto *et al.*, 2011).

Tena *et al*. (2016) conducted a study about the sugarcane production systems in Ethiopia and found out that soil preparation is done by hand hoes, animal power (in small holder farming) and mechanical ploughing. Land preparation is done 2 to 3 times before the seed cane is planted in the farrows. Seed cane or setts harvested with 2 to 4 buds are used. However, in other regions of Ethiopia, tops are planted above the ground. In the rainfed system, swampy areas and stream beds which are not well suited for other crops are selected for optimum and efficient water use by sugarcane (Ten*a et al.,* 2016).

Cheavegatti-Gianotto *et al. (*2011) confirmed that conventional cane production is proven to dominate the sugarcane industry worldwide. Farrows are opened in the field either by hand hoes (smallholders) or mechanical ploughs and seed cane is planted. In areas that are heavily infested by pests, pesticides are applied over the cuttings before covering with soil.

4.3 The sugarcane production systems in KwaZulu-Natal

The crushing season is eight to nine months long, starting from April until November/December annually. Millers receive approximately 20-22 million tons of sugarcane, produced from 430 000 hectares per annum. Small scale farmers account for more than 90% of total cane producers, however, 90% of sugarcane supplied to the mill comes from large scale producers (Cockburn *et al.*, 2014).

On average, cane yields for small scale growers are considerably lower than of large-scale growers. The main reasons for lower yields in small scale cane growers are smaller farm sizes, less advanced technologies, family labour supply (mostly, unskilled and less educated members) and less access to modern information (SACGA, 2018). All these farmers (large and small scales) depend on 14 mills that are owned by 6 milling companies for sugarcane manufacturing (Snyman *et al.*, 2008).

4.3.1 Inland vs coastal production systems

Both coastal and inland regions are dominated by rainfed sugarcane production and methods, the main variable being the cutting cycle. In the coastal region, historically, farmers in the area have adopted relatively early maturing cane cultivars in response to increasing prevalence of eldana in the region, reducing the production cycle from 18-20 months to 12-14 months. Even though the shorter cutting cycles-cultivars are still prevalent in the coastal area, the availability of effective chemical control regimes to combat eldana has led to an increasing proportion of sugarcane in the region being produced in a 14 to 16-month cycle (Nicholson *et al.*, 2017).

Conversely, inland areas produce sugarcane under relatively longer cutting cycles owing to less rainfall and colder conditions relative to coastal areas. However, higher yields are generally produced in the inland areas than the coastal areas because the longer the cutting cycle, the higher the yield accumulation (Pilusa, 2016). Historically, eldana pest was problematic in the coastal areas. Over time, the pest even became endemic to the inland regions of KwaZulu-Natal. The region of Eston (inland) was chosen as a study area because the region was severely affected by eldana pest in the past years. Infestation of the eldana pest is positively correlated with drought and the harvest age of sugarcane

4.4 Other challenges impacting the sugarcane enterprise in South Africa

According to SACGA (2017), the crippling drought from 2015 was still present with its dramatic impact on sugarcane production in the 2016/17 season. The reduction in crop yield is a major threat in the industry, and some farmers may go out of business. The yield reduction could not only be attributed to water deficiency by drought but other opportunistic factors such as drought-tolerant weeds (creeping grass) and eldana (Rutherford, 2015) that are present in sugarcane fields.

The implementation of the Health-promotion levy by the South African government is expected to negatively impact the demand for sugar in domestic markets. Despite being internationally cost-competitive, the industry faces significant competition from imports owing to insufficient import protection for local sugar industry while input costs are increasing (DAFF, 2017). Local sugar producers are expected to face even lower profitability due to the decline in the world price of sugarcane (Mboyisa, 2017). About 600 000 tons of sugarcane were estimated to be imported in the 2017/18 season in South Africa. In 2017, South Africa lost approximately a 30% market share due to higher imports as a result of insufficient tariff protection for local producers (Mboyisa, 2017). Daff (2017) reported that income generated by sugarcane was R6 437 million in 2015/16, which was 6.5% lower than the 2014/15 season.

Besides political and regulatory issues in the South African sugarcane industry, there are other on-farm challenges, pests and labour utilisation, which affect cane yield and productivity.

4.5 Impact of eldana pest on the sugarcane production

Eldana pest, *Eldana Saccharina Walker,* has become prevalent in South African sugarcane fields. This pest was first reported at Umfolozi flats in KwaZulu-Natal, South Africa in 1939. A two-year cycle variety, POJ2725 was the first variety that experienced infestation and it remains a susceptible sugarcane variety to eldana while the Co281 cultivar was remarkably resistant to the pest (Nuss *et al.*, 1986; Rutherford, 2015).

In 1865 in Sierra Leone, sugarcane had recorded the first severe infestation before South Africa had recorded one, and hence the insect was first believed to have immigrated from the neighbouring countries such as Mozambique (Rutherford, 2015). However, the insect was proven to be indigenous in African countries, including South Africa as specimens of the moth were found in Mount Edgecombe with no larval infestation. Eldana disappeared in 1953 until 1970 where it was again reported with a new variety, NCo376 that had replaced the resistant variety, Co281 due to delayed succumbing to ratoon stunting disease (RSD). In 1975, the insect became pervasive in the whole South African sugarcane industry, when it was also reported in Swaziland sugarcane as well (Rutherford, 2015).

4.5.1 Financial impact of eldana

Eldana insect feeds extensively within sugarcane stalks which causes an increased fibre due to loss of sucrose in infected stalks (Nuss *et a*l, 1986; Rutherford, 2015). Internal tissues turn a red colour due to secondary infection by various organisms which are preceded by an eldana attack, as shown in Figure 4.2. As a result, less sugar is extracted from infected stalks in the mills because sucrose is transposed to glucose (Way & Goebel, 2003). Cane quality is measured in different ways, but the recoverable value (RV) is the latest payment system that is used by millers to pay cane producers in South Africa which refers to the recovered value of sugar and molasses from the total sugarcane delivered to the mill by individual cane growers (Ndoro *et al.*, 2015). According to Singels and Donaldson (2000) the RV payment system has created essential incentives for improving the quality of sugarcane delivered to the mill because producers are now striving for a high sucrose content while reducing fibre content and other non-sucrose materials in their deliveries. However, the eldana pest has been identified as the main counterfactual reason of those improved quality practices at the farm level.

The damage patterns in South Africa were demonstrated by Way and Goebel (2003) showing how this pest has affected the sugar industry. Even though the patterns vary by geographical location, the overall damage ranged from 0.5 to 4.0% measured by stalk length red (SLR), which is a red colour in cane stalks indicating damage caused by eldana pest. In South Africa, field surveys are conducted by the Local Pest, Disease and Variety Control Committee (LPD & VCC) seasonally to determine the extent of SLR in sugarcane fields. LPD & VC recommend the ways of mitigating losses within each area. According to Nuss *et al.* (1986), this pest can lead up to 0.1% loss in RV% for every 1% damage in stalks and they found that economic damage is even higher, depending on other factors such as water stress and cane resistance to the pest. Rutherford (2015) concurs with Nuss *et al.* (1986) about RV deterioration caused by eldana, stating that every 1% internode bored (%IB), the economic damage can be as high as 4% RV% loss. With 3% average internode bored, there was R344 000 000 per annum direct loss from 271 000 hectares harvested. This pest also leads to sizeable indirect losses. For instance, a reduced cropping period (from 18 to 14-month cycle) can lead up to 25% reduction of RV% and hence the revenue generated by a grower (Rutherford, 2015).

Figure 4.2: Red discolouration on stalk by eldana larva and F*usarium* fungus. *Source: Rutherford (2015).*

Susceptibility to eldana pest is closely associated with the age of cane; the more damage is reported by many studies on older sugarcane crops. The water stress in the cane is also an aggravating factor on crop damage (Nuss *et al.*, 1986; Way & Goebel, 2003; Rutherford, 2015).

4.5.2 Mitigating the impacts of eldana

South African sugarcane producers have adopted an integrated pest management (IPM) practice to control the adamant eldana pest. IPM is commonly defined as a broad-based method that integrates various practices for economic pest control which aims at suppressing the population of pests below the economic threshold. The main objective of IPM is to keep chemicals and other pest control at economically justified levels to minimize risks to the environment and human health. This practise encourages the use of chemical, biological, technical and physical control (Rutherford, 2015).

Biological control involves natural enemies that are introduced to the field aiming at suppressing the eldana population to a level below the threshold. In 1981, eldana predators were investigated in South Africa. Ants (*Formicidae*), spiders (*Arachnidae*), cockroaches *(Blattidae)* and earwigs (*Dermaptera*) were found in the empty tunnels made by eldana borer in the sugarcane stalks and they were identified as good biological control agents of the pest (Mazodze & Conlong, 2003).

The South African Sugarcane Research Institute (SASRI) and Sugarcane Milling Research Institute (SMRI) are working together in research and development of new technologies and innovations. SASRI is the number one sugarcane research institute in Africa, eminent for its work on development of new sugarcane varieties, efficient farming activities and advanced pest control methods in sugarcane production. On the other hand, SMRI concentrates on research and technical services in the Southern African sugarcane milling and refinery sectors. The South African Sugar Technologist`s Association (SASTA) is another research organisation that works closely with SASRI and SMRI in the sugarcane industry to promote technical aspects and processing practices. SASTA also fosters the exchange of scientific skills and knowledge among research institutes and sugarcane producers (SACGA, 2015). All these research institutions are working tirelessly to ensure sustainability in the South African sugarcane industry (South African Sugar Association (SASA), 2015).

There are about 42 cultivars that are cultivated in South Africa which have different attributes. Even though eldana is found in all commercial cane cultivars, the susceptibility varies with each cultivar, cane age, water stress, soil type and nutrients (Nuss *et al*, 1986). The other significant characteristics of cane cultivars to note are disparities in yield, maturity cycle and relative value (RV) and content in sugarcane (DAFF, 2014).

4.6 New sugarcane pest in KwaZulu-Natal sugarcane farms

Besides the endemic insect eldana in South Africa, a new insect was reported at Entumeni area in Eshowe region. Longhorn beetle was first discovered in the grub stage within damaged sugarcane stalks in 2015 (SACGA, 2017). This pest damages in both larval (grub) and adult (beetle) stages. Approximately 1752 hectares of 313 sugar cane fields were inspected at Entumeni area in 2017 and the results proved the insect to be only restricted to four farms in the area and it has since been found in a total of 391 hectares of 40 sandy fields (SA Cane growers, 2017, Way *et al.,* 2017).

Figure 4.3: Longhorn, *Cacosceles (Zelogenes) newmani,* and its mode of infection in the sugarcane plant Source: *Way et al. (2017)*

According to Way *et al.* (2017), the pest was identified as *Cacosceles (Zelogenes) newmani.* The grub was also identified at the most damaging stage to the lower section of sugarcane stalks. The SA Cane Growers Association is currently working with local pest and disease teams to contain this insect so that it does not spread to other places. The SASRI team is studying the insect to understand the full biology of an insect so that suitable control methods can be identified and used (SACGA, 2017). Conditional quarantine in affected fields is done by preventing the transportation of infected cane and banning seed canes from those farms. The other remedial action was the registration of an insecticide called WARLOCK 19.2 EC (Way *et al.,* 2017). In some fields, inflicted damage was severe with stools completely dying back where the grubs were found in every second stool. And all those fields that were severely affected had to be ploughed out completely to eradicate infection (SACGA, 2017). Even though the mode of infection by long horn is not necessarily the same as the eldana, the IR gene on the GM is expected to mitigate impacts of other insects such as long horn as well.

4.7 Effects of weeds on sugarcane production

Weed control is an essential practice in South Africa for successful sugarcane production. According to Nicholson *et al.* (2017), weeding contributes to the costs of production of sugarcane, it contributes 13% and 18% to the planting and ratoon management costs, respectively.

Weeds are the main inhibitors of sugarcane productivity as they directly compete with the crop for resources: water, light space, and nutrients. Cynodon is the major weed species in South African growing sugarcane. Cynodon has been identified as one of the highly competitive and prolific weeds that directly compete with sugarcane at early growing stages which reduces the ratooning ability of a crop (Campbell, 2008; Nicholson *et al*., 2017; Rutherford *et al.*, 2017). If not controlled, Cynodon can reduce cane tonnage to 50 tons per hectare over three maturity cycles before replanting (Nicholson *et al*., 2017). Rutherford *et al.*, (2017) also reported that Cynodon can reduce up to 40% of crop yield per season on their study that was conducted on herbicide–tolerant sugarcane in South Africa.

This weed is prevalent in marginal, acidic sandy soils (Campbell, 2008) and in droughted canewhere sugarcane is less competitive and poor canopy formation (Nicholson *et al.,* 2017). Infestation is increasing as a result of residual herbicide practices aiming to eradicate weeds, but those programs unintendedly lead to more vigorous *c. dactylon.* Burning at harvest also aggravates this weed (Campbell, 2008). Even though the cynodon grass was reported in the coastal areas where it was more problematic in the sugarcane fields (Nicholson *et al*., 2017), farmers in the inland areas such as the Eston region, have indicated that this weed has also become problematic in the sugarcane fields of Eston. Botha (2018, pers.comm), believes that the prevalence of cynodon grass weed was caused by an increased incidence of drought in the Eston area.

It is not easy to control this creeping grass without damaging the crop itself due to its similar characteristics with sugarcane plants; grass and monocotyledonous species. Therefore, there is only a limited spectrum of chemicals utilised to control it (Maphalala, 2013). Best management practices (BMPs) and cost-effective inputs help to optimise weed control on the farm. Advancement and adoption of technology has shown a significant impact in mitigating losses in crop yields due to weeds.

Currently, this weed is controlled by glyphosate chemical spraying before planting, but the application is done four months prior to planting. Therefore, the development of the GM cane with herbicide tolerance will reduce the waiting period before replanting is done. Owing to the potential resistance of cynodon grass to glyphosate herbicide and the ban of this chemical by U.S. government and Austrialia, farmers are now encouraged to use imazapyr herbicide as an alternative non-selective herbicide to eradicate sugarcane stools (Snyman, 2018, pers.comm).

4.8 Labour utilisation and employment creation by sugarcane production

Employment is among the strongest features attributable to the sugarcane industry in South Africa. The industry is believed to be creating job opportunities in deeply rural and job-starved areas where there are limited sources of income. Industrywide, sugarcane has created about 11% of the total labour force in South Africa (SASA,2015). Most of the employment opportunities comes with the harvesting process where more workers are required for manual harvesting (90% manual harvesting) due to steep topography and high supply of unskilled labours (Smithers, 2014). Agriculture is an industry that contributes positively to higher economic activities which for example, it raised the gross domestic product (GDP) by 2.5% in the second quarter of 2017 (Stats SA, 2017).

Goga (2013) analysed the labour utilisation by large-scale sugarcane farmers in KwaZulu-Natal and demonstrated that employment has been diminishing over the past years due to various reasons. The main reason for the decline in labour utilisation in sugarcane production was the minimum wage policy which increased the real costs of labour. Notwithstanding the potential of this industry to create job opportunities in the future as it is claimed by many studies and government in the literature, labourers are being replaced by capital, mechanisation and other technologies to reduce costs (Goga, 2013).

However, the sugarcane industry seems to be less affected by the current employment crisis in the agricultural sector. The long-term nature of sugarcane crops prevents the immediate reaction to changes in the industry. The plant is perennial; re-growing 5 to 8 lifecycles before ratoons and yields deteriorate significantly, warranting the stools to be ploughed out and the field replanted every 8 to 12 years. This influences the short-term decisions and adjustments required in the cane fields and therefore, requires forward-looking plans (Goga, 2013).

Sugarcane is a perennial crop that is well suited to a wide range of climatic conditions. Generally, this crop is established through vegetative propagation, and it can be grown under irrigated or rainfed farms. In KwaZulu-Natal, cutting cycles vary depending on the production system used and the location. This study is based on the Eston, a region with a longer cutting cycle (20-24 months) in the Midlands of KwaZulu-Natal, and therefore challenges faced in the shorter cutting cycle regions may differ. Eldana insect and cynodon grass were identified as the most significant pests in sugarcane farming in KwaZulu-Natal. Challenges such as the long horn beetle, land issues, drought, Health-promoting levy and the minimum wage also impact on the productivity of sugarcane in South Africa. Despite the diminishing profitability of this enterprise over time, it has contributed positively to the livelihoods of people in KwaZulu-Natal through employment creation and is expected to continue to accommodate the less educated The next chapter outlines the methods used in this study, based on the previous chapters which validated the choice of steps and methodologies used in this research.

Chapter 5: Study area and Methodology

Having presented the literature review and the various methods that have been widely used in assessing the potential impact of GMOs in Chapter 4, this chapter presents the methodology used. In this chapter the study area, selection of representative farms and stakeholders involved are described. Furthermore, the methodology used to develop the farm representative linear programming model, and the analyses executed to address objectives of the study are presented. A representative farm modelling approach was used in this study to investigate farmers' likelihood to adopt GM sugarcane cultivar if the cultivar is available using linear programming (LP).

5.1 Introduction

Based on SASRI`s recommendations, only one GM cultivar of sugarcane will be developed, and farmers will be allowed to plant no more than one third of GM cane in the farm. It is also important to note that the selected cultivar may not be a well-suited cultivar for all sugarcane production areas of KwaZulu-Natal (Rutherford, 2018, pers.comm; Snyman, 2018, pers.comm). Therefore, the cane production system must allow side-by-side production of GM cane and conventional cane. Below, are the assumptions made in the study:

- The mill will purchase the GM cane at the same price from the producers.
- There will be no change in harvesting season and in yield distribution of GM cane.
- There will be no new rules and regulations in the future that are against GM cane.
- Buyers of sugarcane do not perceive GM cane to be different from conventional cane.

In this chapter, a brief overview of linear programming and the compilation of representative farm models are presented. The criteria for disaggregation of the Eston region into four representative farms is discussed, which are governed by characteristics of each sub region. This is followed by the data collection and analytical methods used for model development. Then, a brief discussion of risks and uncertainties in agricultural decision making, and how this study incorporated the considered risks of each representative farm model. Lastly, the matrix compilation and analysis for representative farms, aimed at verifying the model outcomes in the "without GM cane" scenario is compared to preliminary results from farmers and extension staff before the GM cultivar is included in the model.

5.2. Area Selection

5.2.1 Focus Group Discussion with Umbumbulu sugarcane smallholders

Umbumbulu area is a rural area in the Eston cane supply region dominated by commercial smallholder farmers producing sugarcane. Umbumbulu is on the border of the large-scale grower farming community, Mid-Illovo in the southern area of the Midlands, under the eThekwini municipality as shown in Figure 5.1. The district contains the areas of Mbokodweni river and Mkomazi river (Landrey *et al*., 1993). Sugarcane production is very common, especially among commercial smallholder growers who have contracts with Eston mill. Based on the FGD that was held in the area, sugarcane production is dominated by adult people from 40 years upwards. According to Mdluli (2013), the age of a farmer influences the commitment and time spent on farming. The older farmers are highly committed to farming using information and experience accumulated over the years. Conversely, younger farmers spend most of their times in formal education and pursuing non-agricultural employment as their sources of income (Mdluli, 2013).

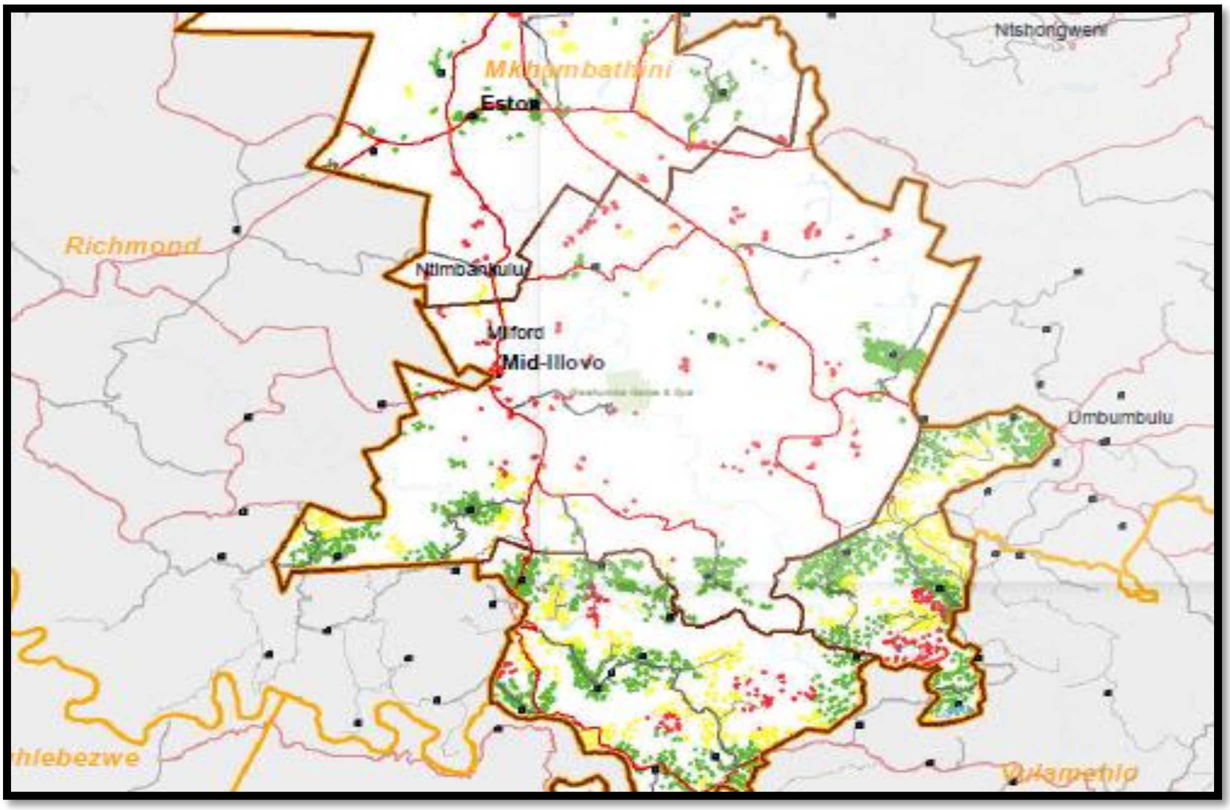

Figure 5.1: A map for representative farms and FGD study area

An FGD can be defined as a group of interacting individuals that have some common interest and characteristics to gain information about a specific or focused issue, perceptions and attitudes towards a certain intervention or technology (OECD,1993). At least, 7 to 10 participants should be involved to get a detailed discussion and views from all individuals in the group rather than having a shallow discussion with a large group (OECD,1993). The advantage of doing face-to-face interviews and focus group discussions is that it is more comprehensive and insightful than telephonic and questionnaires. The methodology of using the open-ended questions gives the interviewees and discussion participants the flexibility to respond freely, which prevents prompted answers caused by leading questions (Ndoro *et al*., 2015). However, this methodology has some shortcomings because some participants tend to dominate the discussion while others do not participate in focus group discussions.

A focus group discussion (FGD) with 12 smallholder farmers in the Umbumbulu area was conducted to obtain accurate values and activities currently undertaken on their farms, and to gauge their demand for GM cultivars of sugarcane, if and when they become available. With the assistance of the area manager and extension officer, FGDs were planned based on clearly stated inclusion criteria required from the participants. Respondents were required to be a farmer who:

- Is a smallholder sugarcane producer
- Keeps records of farm activities
- Consistently supply the cane to the mill
- Is willing to share information
- Is reliable and co-operative

The main open-ended questions during the interviews were:

- What are the main cane cultivars grown in this region?
- What are the different land categories/soil types in the area?
- What are the significant pests in the area?
- How have farmers adjusted sugarcane production to deal with the pest (eldana)?
- If eldana resistant variety becomes available that is similar to the currently grown cultivar in the area, would you be willing to buy that seed cane?

With the consent of an FGD participants, the conversations were recorded in both audio and written format. All conversations were kept private and confidential. Data collected from smallholder farmers were the common cultivars in the area, soil types, problematic pests (insects and weeds) and the type of pest control. These data were gathered to gauge the demand of the GM cultivar in the area. For instance, the prevalence of cultivars susceptible to eldana and/or chemical eradication of sugarcane using chemicals that require waiting period would potentially create demand for GM cultivar. Using excel, data were analysed, and results were presented in figures.

5.2.2 Large scale representative farms

As aforementioned, this study is a component of a broader research project for SASRI. There is a complementary study by Ntuli (2020) in the iLembe region dealing with shorter sugarcane cutting cycles. SASRI has motivated to develop GM cane that is primarily suited to coastal areas. Eston region was selected as a case study area to contrast with findings for coastal regions. This study considers the possible benefits of developing a GM cultivar that is also suited to both coastal and inland regions.

Historically, the Eston region was severely affected by eldana insect. The eldana population is positively correlated to the drought and the impact of a drought can be detrimental to the inland areas owing to lower rainfall compared to coastal areas (Rutherford, 2015). Even though this insect is still a serious threat to cane production, the collective control measures that were taken by cane producers in the area to mitigate eldana in the past years dropped the population significantly in 2016/17 season. Regional chemical control was conducted in 2015 where each farmer contributed towards the costs of aerial spray (Botha, 2018, pers.comm). Since the maturity cycle is approximately 24 months and the eldana infestation increases with the age of cane, Eston sugarcane is highly susceptible to this pest (SACGA, 2017). Eston area is mainly rainfed with very few cane growers using supplementary irrigation. Thus, the farming activities are likely to be impacted by the shortage of water.

The Eston area has been subdivided into four representative farms for the purpose of the project, namely Mid Illovo, Richmond, Eston Central and Umbumbulu areas. There is a variability within the area in terms of land categories and soil types. Sugarcane is grown in all those land categories, but the yield distribution varies across them. This warranted the selection of three representative farms (Eston central, Mid-Illovo and Richmond) based on soil fertility, rainfall variation and yield differences across the Midlands South area (Eston) because production systems are similar across the region. These three sub-regions are dominated by large commercial sugarcane farmers, and the Umbumbulu area was selected to capture smallholder farming in the Eston region as this area is dominated by smallholder sugarcane farmers. Richmond and Mid-Illovo are marked with high yielding varieties relative to Eston Central owing to their suitability and conducive climatic conditions (Botha, 2018, pers.comm).

According to SACGA, (2018), common cultivars in Eston are N12, N37, N31, N16 and N48. N12 is still the leading cultivar but its cultivation has declined from 79% in 2012/13, 53% in 2014/15 and 43% in 2016/17, and it is expected to decrease further due to greater performance of newly released cultivars such as N54, N50 and N52 (SACGA, 2017). To verify this information obtained from a literature, a review meeting with the Eston key informants and SASRI experts was held. Botha (2018, pers.comm) confirmed that newer cultivars are being adopted in Eston owing to their better performance (higher yields, RV tons, shorter maturing cycles and resistance to pests and mosaic), and adaptability to the area. Stakeholders (Farmers and area manager) also confirmed Eston Central, have three main land categories with different soil types: marginal poor soil (MP), flat land sandy soil (FS) and flat land clay soil (FC). And the main cultivars are N12, N52, N31, N48, N50, and N54. Richmond and Mid-Illovo have similar land categories with Eston Central with additional steep red soil category (SR). Common cultivars in Richmond area are N12, N31, N52, N54, N37, N35, N50 and N54. Mid-Illovo grows N12, N31, N52, N54, N48 and N50; Umbumbulu area commonly produce N12, N47, N54 and NCo376 as presented in Table 5.1

Table 5.1: Common sugarcane cultivars grown on different land categories by each representative farm

Table 5.1: The arable land resources of the large-scale representative farms in the Eston cane supply area.

		Central Eston	**Mid-Illovo**	**Richmond**
Marginal soils	Proportion of arable land	53%	6%	24%
	Cane production cycle	20-24 months	20-24 months	20-24 months
	Commonly produced cane cultivars	N12	N12, N31	N12, N31
Sandy soils	Proportion of arable land	27%	8%	19%
	Cane production cycle	20-24 Months	20-24 Months	20-24 Months
	Commonly produced cane cultivars	N31, N52	N12, N52, N54	N54, N52
Clay soils	Proportion of arable land	20%	63%	32%
	Cane production cycle	18-24 months	18-24 months	18-24 months
	Commonly produced cane cultivars	N54, N48, N50	N12, N48, N54	N35*, N37, N48, N50, N54
Steep Red soils	Proportion of arable land	-	23%	25%
	Cane production cycle	-	18-24 months	18-24 months
	Commonly produced cane cultivars	-	N50	N37, N48, N50

*Frosty area

5.3 Description of a study area

The main objective of the study is to analyse the potential impact of GM cane of South African sugarcane farming in the Eston region of South Africa. Analysis of representative farm models for scenarios of no GM cane versus with GM cane was identified as a suitable approach to study the farm-level impacts of GM cane on large commercial sugarcane farmers. Linear programming (LP) is a suitable methodology to construct the representative farm models. The main components of the LP matrix are activities and the constraints, and a background of the study area will assist in identifying these components. Furthermore, land categories, activities taking place in different sugarcane representative farms, and alternative uses of land will be identified. For the Umbumbulu area, the data did not permit the use of the LP to compile a representative farm. Lack of record keeping on smallholder farms was the main reason that prohibited the compilation of representative farm modelling, and therefore, a focus group discussion (FGD) method was used to collect data.

Eston, Midlands South, is located in the Southern-Eastern corner of Pietermaritzburg and the Midlands in KwaZulu-Natal. The area is a sub-region that covers Ixopo, Umbumbulu and Richmond to Pietermaritzburg, predominantly located in the Mkhambathini District Municipality. The area is undulating with about a 12% gradient slope, and up to 80% plus of area is accessible by farm machineries such as tractors (Pilusa, 2016). Eston is characterised by visible enterprise diversification of vegetables, timber, macadamia nuts, sugarcane and livestock. Sugarcane enterprise has shown profitability over the past 40 years. In the past decades, there has been a significant shift in land allocation, land being moved from timber to sugarcane largely accompanied by the mill being moved from Illovo to Eston. Sugarcane is now the main crop in the area, and other enterprises are used to support the sugarcane field through green manuring, crop rotation and diversification. Even though macadamia nuts are becoming popular in the area owing to its high market value at the moment, they are mainly used for diversification, replacing timber (Botha. 2018, pers. comm).

There are about 1706 and 416 small scale and large-scale commercial sugarcane producers in the Eston area, respectively. Large-scale and smallholder growers produce 95% and 5% of sugarcane, respectively (SACGA, 2018). Most of the farmers supply cane to one of the twelve sugar mills in KwaZulu-Natal that is situated in Eston. Eston mill (29°87'S 30°53'E) is the newest mill in KwaZulu-Natal and it was accredited in 1994 to replace the Illovo old mill (Kadwa & Bezuidenhout, 2015). Approximately, 1.26 million tons of sugarcane are crushed, and 125000 tons of sugar are produced in this mill annually, excluding mill cum planter (MCP) growers that deliver about 48 442 tons of sugarcane (Ndoro e*t al*., 2015; SACGA, 2017). All deliveries from cane growers to the mill are done via the road only because there is no railway linked to the mill. On average, growers supplying to Eston mill are within 0-58 km radius and the average distance of 22 km for haul from farms (Ndoro *et al.,* 2015; Kadwa & Bezuidenhout, 2015). The mill pays farmers in terms of sugar recovered from supplied cane, and sugar is measured by its recoverable value (RV) on the cane supplied to the mill (Mafunga, 2016). The Eston cane maturity cycle is approximately 24 months, however, the newer cultivars (N54) can be harvested within 18 months. The longer cycle gives sugarcane the time to develop and assemble adequate sucrose. Generally, Midlands South (Eston) is drier than the northern part of the Midlands, and hence the cane yields are lower but characterized with relative higher RV%, 13% on average per season. On average, the yield per hectare under cane is 41 tons and 85 tons from per hectare harvested, seasonally (Pilusa, 2016).

The Midlands area is marked with disparities in terms of crop growing conditions. Sugarcane performs well in Mid Illovo, Richmond and Umbumbulu, but central Eston to Pietermaritzburg has poorer conditions (Pilusa, 2016; Botha, pers. comm, 2018). Average annual rainfall ranges from 800 mm to 900 mm, even though it varies seasonally, and the average temperature is between 18^{o}C and 19^{o}C (Kadwa & Bezuidenhout, 2015).

Besides eldana being the prevalent and most damaging pest for sugarcane production, weeds and creeping grasses degrade cane plants. Creeping grasses, *Cynodon dactylon, Digitaria longiflora and Cynodon plectostachyus* have been identified as the most hindering factor in sugarcane production for both smallholders and large-scale growers in KwaZulu-Natal (Nicholson *et al*., 2017). Creeping grass weeds lead to cane desiccation, yield losses, poor cane quality and poor ratooning. Even though various weed management practices have been employed, the weeds are still prevalent in the sugarcane fields (Landrey *et al.,* 1993). The rapid spread of weeds is perpetuated by residual herbicide programmes that eradicate other weed types but invigorate this type of grass weed. Minimum tillage has shown some savings on mechanical land preparation of which those savings are then used to finance weed chemical control practices. Large-scale farmers eradicate this weed by cover spray, using “round-up” before they plant. However, there is a waiting period of four months before they can plant again which delays their production (Botha, 2018, pers.comm).

5.4 Representative Farm Modelling

The Eston area was disaggregated into four relatively homogenous groups of farms: Large-scales Eston central, Mid-Illovo, Richmond; and small scale Umbumbulu. Generally, Richmond and Mid-Illovo areas have good soils with no limited water as this area is situated on the banks of upper Illovo and Umkomaas rivers (Pilusa, 2016), therefore, higher yields are produced per season. However, these areas were disaggregated into different representative farms owing to frost inherent in the Richmond area. Thus, some cultivars tend to underperform under such conditions. Farmers mentioned that they grow N35 under a 12-month cycle instead of 24-month cycle to cope with effects of frost in the Richmond area. In the Mid-Illovo representative farm, the cane cutting cycle is 24-month. Eston central representative farm is drier than the other cane cultivars, and it is dominated by drought tolerant cultivars that thrive under drier conditions and still produce the expected tonnage. Finally, the fourth representative farm, Umbumbulu was disaggregated to ascertain information from smallholder sugarcane producers. Umbumbulu is in the border of the farming community, Mid-Illovo in the southern area of Midlands under the areas of Mbokodweni and Mkomazi rivers (Landrey *et al*., 1993). Even though the area is relatively moist with good soils, the space is a major variable in the area as this area is dominated by subsistence and smallholder farming.

Based on the methodologies used in *ex ante* impact assessments as discussed in Chapter 3, relevant methods were chosen that best suit this study. Firstly, gross margins were computed from partial enterprise budgeting for each large-scale representative farm. A simple gross margin analysis is a useful method in the *ex ante* impact assessment when estimating the economic profitability of technology (Firth, 2002).

Even though GM cane is not available for another 10 years, it is possible to predict the "with" and "without" GM cane scenarios. The baseline (or current) scenario was used as the counterfactual and the current scenario with GM cane, *ceteris paribus*, to predict the impact of GM cane. Owing to uncertainties about the future, the researcher reached the consensus with the industry experts and research funders to use the current scenario, with the historic data of seven years to incorporate the risk factor instead of future scenario for ten years from now. Following the meetings with CTS staff, farmers from different representative farms and SASRI experts, sugarcane gross margins were calculated by region, by land category and by sugarcane cultivar per representative farm. Then, the GM cultivar was hypothetically computed based on the SASRI experts` opinions.

SASRI biotechnologists recommended that N52 is the cultivar that fits the desired traits (high yields, resistance to diseases and drought tolerant) of GM cane. For the purpose of this study, N52 was hypothetically modified as GM cane by assuming a cultivar of sugarcane that is similar to N52 but has the IR and HT traits. A description of the GM cultivar was compiled which includes how its production may differ from production of non-GM 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. However, the model was constrained from allocating more than ⅓ of the total land in each representative farm. A single cultivar should not exceed 33% of total land in the farm (Botha, 2018, pers.comm).

For the small-scale representative farm, a focus group discussion was used instead of gross margin computation owing to poor record-keeping of smallholder farming. According to OECD (1993), an FGD is an efficient method of obtaining in-depth information from a small number of homogenous groups.

5.5 Linear Programming in farm decision-making

Having considered various approaches to conduct ex ante impact assessments, as identified in Chapter 3, the application of linear programming to construct representative farm models and a comparison between baseline and counterfactual was chosen over others. The next best approach identified was gross margin analysis (GMA). However, the inability of GMA to account for SASRI`s rules of limiting the area to one-third under cane for each cultivar, and risk consideration of an intervention made was the main reason the LP model was chosen over GMA.

Linear programming (LP) is a mathematical technique that is mainly used in recommendations of managerial decisions (Hazell, 1971). LP is a powerful technique in various areas of planning such as home, corporate business and farm managements. In farm planning, LP is widely used for determining optimum farm plans from different levels of capital and other inputs employed. This technique helps to establish benchmarks for specific situations due to its illustrative ability to determine only one enterprise with maximum returns from a given capital amount, however all other enterprise compositions will approximate similar returns (Love, 1956). LP deals with non-negative solutions to obtain linear equations where negative solutions are eliminated from the decision-making process (Veselovska, 2014). As applied to farm planning, LP represents a systematic approach to determine the optimum combination of enterprises in order to maximize income or to minimize costs and losses within the constraints of available resources (Igwe & Onyenweaku, 2013). There are several mathematical programming approaches useful for modelling of specific agricultural planning problems. And there is no single superior model at a farm level, it only depends on the situation (Zia, 1998). In the agricultural sector, many studies have demonstrated how the LP model is used for managerial and decision-making practices, especially resource allocation among farm enterprises (Love, 1956).

In the following section, the methods used to collect the data are presented and the reasons behind them are discussed. Prior to the construction of an LP model, components such as gross margins, constraints and other farm activities are important to understand. The computation of partial budgeting and gross margin analysis were undertaken prior to the construction of LP.

5.6 Data collection and analytical methods

After the ethical clearance approval was granted by the Research Ethics Committee of KwaZulu-Natal, the data were collected. Owing to difficulties encountered in meeting with farmers through focus group discussions (FGDs) (farmers were not available to meet), the researcher communicated with an extension officer and area manager about an alternative means of obtaining the required information. A meeting was arranged with the Eston Mill Group Board (MGB), requesting members to encourage farmers to participate in this study. MGB is a group of farmers elected by SACGA based on their skills and diversity to represent farmers in decision making based on local and strategic issues. The group ensures the values of integrity, transparency and accountability (SACGA, 2013). MGB provided the authorisation letter to access data from Cane Testing Services (CTS) from Eston Mill. Owing to confidentiality of data from CTS, each participant signed a permission letter authorising the researcher to use such information.

Raw data was accessed from CTS for the past seven years (2012-2018). The significant components of the raw data for this study were: grower code, cane cultivar, method of harvest (trashed or burnt), tons of cane, tons of RV, RV %, delivery date and tons of non-sucrose. An extension officer aided with identification of farmers for grower codes from CTS data. Cultivars supplied per representative farm were identified based on farm number and grower code. Using Excel, cultivars supplied by each grower, tons of cane and tons of RV per cultivar per grower were calculated. To verify the data received from CTS, farmers that were available and willing to participate were visited for one on one meetings. Together with SASRI cane planting cost schedules (G6-forms), data was used to compile partial enterprise budgets per cultivar for each study area. These budgets were fine tuned to represent the land categories and soil types. To account for variation within and between cane cultivars, seven-years of historical data was collected and analysed for each cultivar. This was done to determine gross margin variation, which is a measure of the risk of a cultivar.

Table 5.2 shows the Mini-Tableau for real RV and conversion using producer price indices for the past seven years (2012-2018). Based on the nominal RV prices, real prices were computed using producer price indices (PPI) extracted from an abstract of Agricultural statistics in 2019 rather than consumer price indices (CPI). PPI was chosen over CPI because it measures the value of goods and services sold over a period of time whilst CPI measures the price changes on consumer products (OECD, 2002**).**

Table 5.2: Mini-Tableau for Real RV prices over the past seven years

Season	Nominal RV Price	PPI	Real RV Price
2012/13	3017,51	110,1	4752,37
2013/14	3197,32	121,7	4555,59
2014/15	3137,87	121,1	4493,04
2015/16	3437,97	132,0	4516,24
2016/17	3979,22	145,6	4738,10
2017/18	4931,91	170,7	5009,92
2018/19	4187,11	173,4	4502,98

The formula: Real price $_i$= (PPI base year/ PPI$_i$) * Nominal Price $_i$.

Base year: 2018/19

Owing to the low RV price in 2018, growing sugarcane was not profitable, and the model was not allocating land to sugarcane. The expected real RV price was used for the year 2018, which was computed as the average price of RV for the past seven years. Section 5.5 presents partial budgets and the gross margins per cultivar. This was done to determine the variation of costs across growing cane cultivars under a different land category, which is the main component of the LP matrix.

5.7 Partial budgeting and Gross Margin compilations

From the information gathered from SACGA, SASRI experts, meetings with farmers, meetings with SASRI scientific staff and the Cane Testing Services team, partial enterprise budgets and gross margins for each representative farm: Eston central, Richmond and Mid-Illovo were obtained. Significant components of gross margin are yield, output price and variable costs (Mudombi, 2010). Even though partial budgeting and gross margin analyses fail to measure the profitability of a new technology as they exclude fixed costs, they present the evaluations among financial returns from different production systems. These tools are often used in projecting potential profitability of new technology or an intervention without including overhead costs (Anandajaysekeram *et al.,* 2004). Data from G6 forms obtained from SACGA were used to calculate planting, ratooning and harvesting costs after being fine-tuned for each likely combination of sugarcane cultivars, locality and land category. Furthermore, the enterprise budgets and gross margins were compiled for the various sugarcane cultivars for the representative farms.

To correctly capture returns on different cane cultivars, budgets were compiled on the basis of per hectare harvested per annum which allows a direct comparison of returns for opportunity costs and competing enterprises. This was recommended by different authors (Mudombi, 2010; Anandajaysekeram *et al*., 2004). The cane cutting cycle is 18 to 24 months in the Eston milling area. To compile an annual budgets and gross margins, process maps using Excel were employed to calculate the frequency of each activity (planting, ratooning, green manuring and harvesting) to proportionate costs and returns on annual basis. All other cane cultivars are harvested after 24 months except N54 which has an 18-month cutting cycle. Annual proportions for the 18-month cycle are: area harvested (66.67%), area planted (11.11%), area ploughed out (11.11%), green manured (8.33%) and ratooning (55.56%). For the 24-month cycle: area harvested (51.25%), area planted (11.25%), area ploughed out (11.25%), green manured (11.25%) and ratooning (40.00%).

Different cane cultivars are grown in different land categories, based on their suitability, and the connection between the cultivar and land type is presented by 1 under growing cultivar. This was done to represent activities on a per 1-hectare basis. Table 5.3 shows a Mini-Tableau for computation of land categories and growing cane cultivars, and opportunity costs of that land category for Eston Central.

The second part was to develop a farm representative model for three different selected regions. In building the matrix, information collected in the first part was used to correctly capture the actual production system in the ground. In both ‘with’ and ‘without’ GM cultivar, opportunity costs macadamia nuts and timber were constrained to not more than 15% and 10% of total land, respectively. This was done to prevent the model from allocating the larger proportion of land away from sugarcane cultivars. Macadamia nuts are profitable at the moment in the Eston area (Botha, 2018, pers.comm). Section 5.8 shows how the matrix was compiled for each representative farm. To avoid repetition, one representative farm, Eston Central, is presented.

As mentioned in Chapter 1, SASRI is currently developing genetically modified sugarcane to address threats of eldana pest and creeping grass weed. However, there are risks and unintended consequences associated with an intervention and they need to be addressed before such action is implemented (Visagie *et al*., 2004, Armstrong, 1999). Risks in agriculture are briefly discussed, and how farm models are used to incorporate existing risks, and new risks associated with new interventions are described in the following section.

5.8 Risks and uncertainties in agricultural sector

Risk and risk preference are important determinants of farmers` decision making, and therefore, they must be accounted for in a prediction of farmers` decisions for counterfactual.
Risk, as defined by Armstrong (1999), is the uncertain outcomes of an action and the longer the period between action and outcomes, the larger the risk attached to that decision. In the agricultural sector, there are many potential risks along the supply chain (farm level to the market level). The weather is the main source, but there are other factors of which risk can be attributed to such as volatile input and output prices, yield, technological advancements, pests and diseases and everchanging government policies (Hazell & Norton, 1986; Visagie *et al*., 2004). Agricultural risks are prevalent throughout the world, but the severity and kind of risks depend on the farming system, climate, policies and institutions. Smallholder farmers in developing countries are susceptible to almost all kinds of farm level risks (Hazell & Norton, 1986).

A fluctuating gross margin due to yield variability and volatile output prices have been the chief source of risk (Armstrong, 1999), and the fluctuations can emanate from decisions made based on asymmetric information. Farm level optimisation studies tend to focus on the best enterprise mix and efficient resource allocation with little or no attention to the risk factors associated with these activities. Oversight of risks in decision modelling at farm level may lead to the wrong attribution of impact to a new intervention. That is, the model may over-estimate yields of risky activities or/and under-value input costs without considering the risk associated with such action, and failure to acknowledge the significance of diversification in agricultural production system. Therefore, to avoid the incorrect forecast of technology choices, risk should be incorporated into decision-making for agricultural analysis at farm level (Visagie *et al*., 2004).

According to Hazell and Norton (1986) farmers` farm decisions are guided by their risk risk-aversion statuses. As such, farm plans with an adequate security level; relatively less risky than others, always get chosen by farmers even if that calls for sacrificing their income. In most cases, secure plans involve reduction of risky enterprises, diversification, and the use of advanced and efficient technologies. For sustainable profitability, crop rotation is highly recommended because it mitigates the effect of pests, weeds and diseases in the farming process (Visagie *et al.,* 2004). However, the crop rotation practice is not an option for the current sugarcane production because this enterprise is currently dominated by a monoculture system since the crop is perennial. The minimisation of total absolute deviations (MOTAD) is an LP technique that incorporates risks, as measured by variance in all expected returns from a different enterprise mix. This technique has been widely accepted for farm planning because conventional deterministic models overlook risk and uncertainties which may lead to the rejection of a farm plan. E-V boundary, a set of optimal plans with the expected income subject to risk associated with each plan, is used to determine an optimal farm plan that generates higher returns with minimum risk. The main sources of risks and uncertainties are forecasted yields and costs and prices associated with individual activities (Hazell, 1971). MOTAD`s weakness is the assumption that choice is solely affected by expected returns and attributable risks.

In a study of efficient resource allocation that was conducted in Pakistan, Zia (1998) concluded that the use of a compromise MOTAD is a powerful analytical instrument for agricultural systems. Zia (1998) also used a compromise MOTAD model as this model has a simple assumption: "farmers prefers more income over the less income and less risk over more risk". Compromise MOTAD is useful in studies with environmental issues with some regulatory restrictions, multiple and/or conflicting objectives without encountering computational difficulties because the LP algorithm can be used in this model (Zia, 1998). Compromise programming deals with weaknesses of the conventional MOTAD model in handling risk minimisation in resource allocation by incorporating hybridization of the MOTAD model (Romero *et al.,* 2009). This model offers a risk-efficient set and trade-offs of farm plans. It is a subset of those risk-efficient farm plans already identified by a conventional MOTAD model, hence the alternatives to be considered in decision making are reduced through this technique (Zia, 1998).

However, compromise MOTAD model requires time series data of various environmental conditions which rarely exist in the required form. The other disadvantage of the model is the difficulty in attaching the weights to different objectives (Zia 1998; Romero *et al.*, 2009). To account for risk and uncertainties about the technology at the farm, Baumol`s model was incorporated in the linear programming matrix in this study.

5.9 Baumol`s Model

Baumol`s model uses deviations in farm gross margin as a proxy of risk to determine maximum utility (L) associated with that enterprise (Hazel and Norton, 1986).
The equation for this model is:

$$L = E[GM] - \theta\sigma \qquad (1)$$

Where L represents income generated under a certain amount of probability which is determined by using expected income (E) minus the product of standard deviation of expected income and risk aversion coefficient (of a farmer). Under the specific confidence interval of achieving an expected income, the exact maximum utility can be determined if the farmer`s risk aversion is known. This model treats risk as a cost, meaning larger coefficients represent riskier plans. Also, Baumol`s model is often used as a fine-tuning coefficient in a representative farm model(Hazel and Norton, 1986). Even though the risk aversion coefficient of Eston farmers is unknown, the value of the coefficient was determined through adjusting for a reasonable range to get best fit with observed farms in the baseline scenario.

5.10 Model development: linear programming

In this study, the LP model was used to determine resource allocation given the essential farm activities and constraints in the Eston representative farms. Constraints in the LP matrix provide a limit to the expanse of resources to be utilized. Constraints can either be maximum, minimum or equal to, where less than or equal to (≤), greater or equal to (≥) or equal to (=) is used in the matrix, respectively. Land is binding in the Eston area and therefore, different land categories have been divided into separate constraints for three representative farms, namely Eston Central, Mid-Illovo and Richmond. To account for disparities in land categories, different land types can be separated into distinct constraints (Hazell & Norton, 1986**).** Land categories in Eston central were Marginal poor soils (MP), Flat sandy soil (FS) and Flat clay soil (FC); in Mid-Illovo and Richmond: Marginal poor soil (MP), Flat sandy soil (FS), Flat clay soil (FC) and sloped red soils (SR). And there is a maximum limit (≤) in all land categories. Even though it was assumed that capital is not binding in the Eston area, additional labour can be hired when necessary but there is a maximum limit (≤) for hours available to be utilized for farm activities per annum.

Each matrix contains farming activities taking place in each representative farm. The activities included in the model were different cane cultivars (including hypothetical genetically modified (GM) cultivar), categorised according to their land and soil types, alternative uses of land: timber and macadamia nuts, weeding, eldana control, cane yield and tons RV sold. All these activities are subject to various constraints which are hectares of land available (marginal poor soil, flat land sandy soil, flat clay soil and sloped red soil), total hours of labours: weeding, scouting (eldana control), and cane transfer (cane yield and RV tons). The size and kind of different activities that are essential to generate revenue are specified distinctly, and they are subject to certain conditions that are imposed by constrained resources and risk aversions (Love, 1956).

Sugarcane and main alternative use of land: timber and macadamia nuts are all perennial in nature. Since the focus of this study is not on macadamia and timber, only gross margins (R) per hectare per annum are shown in the matrices for timber which grown under marginal poor soils across representative farms, and for macadamia nuts, grown in the sandy and clay soils in all representative farms. For sugarcane, gross margins include costs associated with the area under cane include planting, ratoon management and harvesting costs per hectare per annum. Transfer activities are reported in tons per hectare.

The objective function rows in the matrices represent the expected gross margins, subject to risk preference of a farmer which is achieved under a certain confidence interval. Since the LP model is based on the preference axioms for the option based on underlying risk, the optimal solutions for a portfolio can be identified with respect to different risk aversion statuses (Love, 1956; Ogryczak, 2000). Matrix compilation is discussed in detail in following section.

5.11 Compilation and description of the matrix: Eston Central Representative farm

Each model was built to represent what is happening in each representative farm category. Extension staff and farmers have explained that sugarcane cultivars are often planted under specific land and soil type based on its adaptability and performance. There are four main land categories in the region: marginal poor soil, flat sandy soil, flat clay soil and steep red soil, and different sugarcane cultivars are grown under these categories. Even though marginal poor soils and steep red soils are marked with relatively low cane yields due to lower soil moisture content and organic matter. However, there are common cultivars that are grown across the three representative farm categories that are well-suited, and therefore, produce adequate cane yields. Those are N12, N31, N52, N48, N50, N54 and GM cultivars. These cultivars were specifically developed for the low potential soils in the rainfed regions of KwaZulu-Natal (SASRI, 2006). According to Botha (2018, pers.comm), growing these cultivars under high potential soils is not economical because they are susceptible to severe lodging, and therefore, cause field management issues.

The baseline scenario, “without GM cane”, representative farm model is presented in Table 5.3. The current production of various sugarcane cultivars and opportunity costs of land (timber and macadamia nuts) grown under different soil types and land categories are presented. Cane selling activities, and the objective function of the Eston central model are also presented

Table 5.3: Mini-Tableau for sugarcane production without GM cultivar in the Eston Central area.

	Cane Cultivar grown /ha						**Opportunity cost of land (R) /ha**			**Cane RV Sales (R/ton)**	**RHS**
	MP N12	FS N 52	FS N31	FC N48	FC N54	FC N50	MP Timber	FS Mac	FC Mac		
Marginal Poor Soil (MP)	1						1				L12050
Flat land Sandy soil (FS)		1	1					1			L6000
Flat land Clay soil (FC)				1	1	1			1		L4500
RV Transfer (tons)	-4,96	-5,95	-5,25	-5,81	-5,70	-6,00				1	E0
Obj: E[GM] (R)	-13117,05	-12132,05	-13642,17	-13914,77	-16864,62	-12132,05	3427,59	19060,74	36 425,80	4502,98	**Max!**

For simplicity, activities will be represented as X_i:

X_1 =N12 in Marginal poor soil, X_2 = N52 in marginal poor soil, X_3= N31 in marginal poor soil, X_4=GM in marginal poor soil X_5 =N52 in Flat clay soil, X_6 =N31 in Flat sandy soil, X_7 =GM in Flat sandy soil, X_8 =N48 in Flat clay soil, X_9 =N54 in Flat clay soil, X_{10} = N50 in

Flat clay soil, X_{11} =GM in Flat clay soil, X_{12}=Timber in marginal poor soil, X_{13} =Macadamia nuts in flat sandy soil, X_{14} =Macadamia nuts in Flat clay soil, X_{15} = weeding in conventional cane, X_{16} = weeding in GM cane, X_{17} =Scouting for eldana, X_{18} =Conventional eldana chemical control,
X_{19} =Cane transfer, X_{20}=GM eldana chemical control X_{21}=RV sales, X_{22} =labour hiring, X_{23} =expected gross margin, deviations(D): X_{24} =D1, X_{25}= D2, X_{26} = D3, X_{27} = D4, X_{28} = D5, X_{29} = D6, X_{30} =D7, X_{31} = 0,5TAD, X_{32} =Standard deviation.
Constraints are represented by R_i

Activities taking place in the marginal poor soil, sandy soil and clay soil land categories and their maximum capacities available for production of sugarcane and opportunity costs are presented in Table 5.4, Table 5.5 and Table 5.6, respectively**.**

Table 5.4: Mini-Tableau of marginal poor soil activities

	MPN12	MPN52	MPN31	MPGM	MP Timber	RHS
Marginal Poor Soil (MP)	1	1	1	1	1	L12050

R_1: Marginal poor soil (MP in ha), area under N12, N52, N31, MPGM and timber should not exceed total marginal poor soil of 12050 ha available in the Eston Central representative farm category.
MP: $X_1 + X_2 + X_3 + X_4 + X_{12} \leq 12050$ ha

Table 5.5: Mini-Tableau of sandy soil activities

	FSN52	FSN31	FSGM	FSMAC	RHS
Flat sandy soil (FS)	1	1	1	1	L6000

R_2: Flat sandy soil (FS in ha), area used to grow N52, N31, FSGM and macadamia nuts should not exceed 6000 ha of flat sandy soil that is available for Eston Central representative farmer to utilise.
FS: $X_5 + X_6 + X_7 + X_{13} \leq 6000$ ha

Table 5.6: Mini-Tableau of clay soil activities

	FCN48	FC54	FC50	FSGM	FCMac	RHS
Flat clay soil (FC)	1	1	1	1	1	L4500

R_3: Flat clay soil (FC in ha), Eston Central farmer should not exceed 4500 ha when growing N48, N54, N50, GM and macadamia nuts in Flat clay soil.

FC: $X_8 + X_9 + X_{10} + X_{14} \leq 4500$ ha

In Table 5.7, the total number of hours spent by farm workers was calculated from G6 forms obtained from SACGA. This includes time spent on planting, ratoon management and harvesting, and the hours were converted to hours per hectare per annum. It is important to note that hours on conventional cultivars are more than GM cultivar owing to reduced time spent on eldana control on the GM cultivar. A maximum of 2040 hours was computed from the product of 340 days (excluding Sundays and public holidays) and 6 hours spent on the farm per day.

Table 5.7: Mini-Tableau of the labour activities in the Eston central farm

	MP N12	MP N52	MP N31	MP GM	FS N52	FS N31	FS GM	FC N48	FC N54	FC N50	FC GM	Labour hire (R/hr)	RHS
Labour (hrs)	370	370	370	350	370	370	350	370	370	370	350	-1	L2040

R_4: Labour hiring (hr), Hours allocated for sugarcane production should not be more than maximum hours available (2040 hours) for production in the Eston Central, plus additional hours required for hired labours. There are 370 hours and 350 hours that are allocated for non-GM cultivars and for GM cultivars, respectively.

Labour (hours): $370X_1 + 370X_2 + 370X_3 + 350X_4 + 370X_5 + 370X_6 + 350X_7 + 370X_8 + 370X_9 + 370X_{10} + 350X_{11} \leq 2160 + X_{22}$

Table 5.8: Mini-Tableau of the eldana chemical control activities in the Eston central farm

	MP N12	MP N52	MP N31	MP GM	FS N52	FS N31	FS GM	FC N48	FC N54	FC N50	FC GM	CHEM_CNV	CHEM_C GM (R/Ha)	RHS
Eldana Chemical Control CONV	2	2	2		2	2		2	2	2		-1		E0
GM eldana chemical control				1			1				1		-1	E0

R_5: Eldana chemical control is done 2 times and once in non-GM and GM cultivars, and these sprays should be equal to total sprays allocated for sugarcane per year as illustrated in Table 5.8

Eldana control (Conventional): $2X_1 + 2X_2 + 2X_3 + 2X_5 + 2X_6 + 2X_8 + 2X_9 + 2X_{10} - X_{18} = 0$

GM: $X_4 + X_7 + X_{11} - X_{20} = 0$

Table 5.9: Mini-Tableau of eldana physical control in the Eston central farm

	MP N12	MP N52	MP N31	MP GM	FS N52	FS N31	FS GM	FC N48	FC N54	FC N50	FC GM	Scouting (R/ha/hr)	RHS
scouting (hrs)	24	24	24	12	24	24	12	24	24	24	12	-1	L1000

R_6: Hours allocated to eldana scouting, hours for scouting eldana in Non-GM (24 hours) and GM (12hours) cultivars should not exceed a maximum of 1000 hours allocated for physical control of eldana as illustrated in Table 5.9.

Scouting (Hour): $24X_1 + 24X_2 + 24X_3 + 12X_4 + 24X_5 + 24X_6 + 12X_7 + 24X_8 + 24X_9 + 24X_{10} + 12X_{11} = 1000 + X_{17}$

The total hours on scouting were computed from the product of days of scouting (1 day = 6 hours in the farm) and total of 2 hours allocated to scouting per day and the frequency of scouting per annum. For non-GM cultivars, 6 hours/day X scouted twice per year X 2 hours allocated to scouting per day. For GM cultivars, 6 hours/day X 2 hours X scouted once per year.

Table 5.10: Mini-Tableau of cane and RV transfer in the Eston central farm

	MP N12	MP N52	MP N31	MP GM	FS N52	FS N31	FS GM	FC N48	FC N54	FC N50	FC GM	Cane (tons)	RV (R/t)	RHS
Cane transfer (tons)	-40	-60	-48	-64	-55	-47	-64	-47	-84	-51	-71	-1		E0
RV Transfer (tons)	-4,96	-5,49	-5,93	-5,54	-5,95	-5,25	-5,94	-5,81	-5,12	-6,00	-5,54		-1	E0

R_7: Cane yield harvested per hectare per annum; tons of cane harvested from the field are transferred to the mill as shown in Table 5.10.

Cane yield (tons): $40{,}49\ X_1 + 60.00\ X_2 + 47.50\ X_3 + 64.2\ X_4 + 54.66\ X_5 + 47.20\ X_6 + 64.2\ X_7 + 46.96\ X_8 + 52.40\ X_9 + 50.61\ X_{10} + 71.33\ X_{11} - X_{19} = 0$.

R_8: Tons of RV transferred per annum: $4.96\ X_1 + 5.49\ X_2 + 5.93\ X_3 + 5.54\ X_4 + 5.94\ X_5 + 5.25\ X_6 + 5.54\ X_7 + 5.81\ X_8 + 5.70\ X_9 + 6\ X_{10} + 5.54\ X_{11} = X_{21}$

Table 5.11: Mini-Tableau of weed control in the Eston central farm

	MP N12	MP N52	MP N31	MP GM	FS N52	FS N31	FS GM	FC N48	FC N54	FC N50	FC GM	Weeding CONV	Weeding GM	RHS
Weeding Conventional	61,2	61,2	61,2		61,2	61,2		61,2	61,2	61,2		-1		E0
Weeding GM (Hours)				55			55				55		-1	E0

R_9: Hours allocated for weeding (hand-hoeing) in conventional cane, there are 61.2 hours and 55 hours of weeding spent on each non-GM cane field and GM cultivars, respectively. Hours should not exceed the maximum of 209.69 hours per annum. Approximately, 61.2 hours are spent by field workers hand-hoeing (from planting and ratoon management) per hectare per annum as shown in Table 5.11. Physical control of weeds is expected to decrease because GM cane is tolerant to herbicide (imazapyr) and therefore, post emergence spraying will supress weed for longer. Therefore, at least, 55 hours will be allocated to hand-hoeing in GM cane.

Non-GM cane weeding (hours): $61.2\ X_1 + 61.2\ X_2 + 61.2\ X_3 + 61.2\ X_5 + 61.2\ X_8 + 61.2\ X_9 + 61.2\ X_{10} - X_{15} \leq 209.69$.

Hours for weeding GM cane: $55\ X_4 + 55\ X_7 + 55\ X_{11} - X_{16} \leq 209.69$

Table 5.12: Mini-Tableau of land constraint for opportunity costs in the Eston central farm

	MP N12	MP N52	MP N31	MP GM	FS N52	FS N31	FS GM	FC N48	FC N54	FC N50	FC GM	MP Timber	FS Mac	FC Mac	RHS
Mac-consnt	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	0,85	0,85	L0
Timber-Costnt	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	0,9	-0,1	-0,1	L0

$R_{10:}$ Macadamia constraint: The area under macadamia nuts should not exceed 15% of the farm as illustrated in Table 5.12.

$-0.15\ X_1 - 0.15\ X_2 - 0.15\ X_3 - 0.15\ X_4 - 0.15\ X_5 - 0.15\ X_6 - 0.15\ X_7 - 0.15\ X_8 - 0.15\ X_9 - 0.15\ X_{10} - 0.15\ X_{11} + 0.85\ X_{13} + 0.85\ X_{14} \leq 0$.

R_{11}: Timber constraint: Eston sugarcane farmers do not plant more than 10% of timber owing to limited permits from Forestry department (Botha, 2018, pers.comm).

$0.10\ X_1 + 0.10\ X_2 + 0.10\ X_3 + 0.10\ X_4 + 0.10\ X_5 + 0.10\ X_6 + 0.10\ X_7 + 0.10\ X_8 + 0.10\ X_9 + 0.10\ X_{10} + 0.10\ X_{11} \leq 0.85\ X_{12}$

Table 5.13: Mini-Tableau of land constraint for sugarcane cultivars in the Eston central farm

	MP N12	MP N52	MP N31	MP GM	FS N52	FS N31	FS GM	FC N48	FC N54	FC N50	FC GM	MP Timber	FS Mac	FC Mac	RHS
GM Constraint	-0,33	-0,33	-0,33	0,67	-0,33	-0,33	0,67	-0,33	-0,33	-0,33	0,67				L0
N52 Constraint	-0,33	0,67	-0,33	-0,33	0,67	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33				L0
N12 Constraint	0,67	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33				L0
N31 Constraint	-0,33	-0,33	0,67	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33				L0

$R_{11:}$ GM constraint: area under GM cane should not exceed one third of the field as illustrated in Table 5.13

$-0.33\ X_1 - 0.33\ X_2 - 0.33\ X_3 - 0.33\ X_5 - 0.33\ X_6 - 0.33\ X_8 - 0.33\ X_9 - 0.33\ X_{10} + 0.67\ X_4 + 0.67\ X_7 + 0.67\ X_{11} \leq 0$

N52, N12 and N31 cultivars were significantly profitable that the model allocates more than one-third of land under these cultivars. To avoid violation of the one-third rule in sugarcane production, these cultivars were constrained so that a single cultivar does not exceed 33% of the area under cane.

$R_{12:}$: N12 constraint: area under GM cane should not exceed one third of the field

$0.67\ X_1 - 0.33\ X_2 - 0.33\ X_3 - 0.33\ X_4 - 0.33\ X_5 - 0.33\ X_6 - 0.33\ X_7 - 0.33\ X_8 - 0.33\ X_9 - 0.33\ X_{10} - 0.33\ X_{11} \leq 0$.

$R_{13:}$: N52 constraint: area under GM cane should not exceed one third of the field

$-0.33\ X_1 + 0.67\ X_2 - 0.33\ X_3 - 0.33\ X_4 + 0.67\ X_5 - 0.33\ X_6 - 0.33\ X_7 - 0.33\ X_8 - 0.33\ X_9 - 0.33\ X_{10} - 0.33\ X_{11} \leq 0$

$R_{14:}$: N31 constraint: area under GM cane should not exceed one third of the field

$-0.33\ X_1 - 0.33\ X_2 + 0.67\ X_3 - 0.33\ X_4 + 0.67\ X_5 + 0.67\ X_6 - 0.33\ X_7 - 0.33\ X_8 - 0.33\ X_9 - 0.33\ X_{10} - 0.33\ X_{11} \leq 0$.

Gross Margin deviations for the past 7 years

Coefficients were calculated and used from R_{15} to R_{21} constraint, as presented in the Table 5.14 and deviations should be greater or equal to zero (≥0)**.**

Table 5.14: Mini-Tableau for income deviations in the Eston Central farm

	Sugarcane cultivars									Opportunity costs		
Income	MP N12	MP GM	FS N52	FS N31	FS GM	FC N48	FC N54	FC N50	FC GM	MP Tm	FS Mac	FC Mac
T1 (R)	4249,49	5418,43	5140,78	4998,05	5418,43	-6116,13	2138,85	688,20	7335,29	-630,76	-6352,74	-4308,07
T2 (R)	4719,03	-2949,08	-2681,73	6469,93	-2949,08	2991,51	-365,68	10014,37	-4613,16	-415,73	-1348,21	386,82
T3 (R)	413,99	-1726,66	-1653,18	417,26	-1726,66	5549,13	-2446,87	2544,47	-2643,94	-341,17	-251,03	412,84
T4 (R)	-4991,87	-6426,64	-6092,03	-5570,61	-6426,64	-3740,53	-10269,46	-9519,49	-9267,13	76,42	900,60	921,43
T5 (R)	-3248,69	399,93	164,77	-4997,02	399,93	-1836,29	-8258,21	-2658,09	684,31	29,95	399,34	-1743,62
T6 (R)	674,78	3376,90	2686,21	2,18	3376,90	4958,31	23466,53	2481,23	5123,91	494,89	2735,89	1621,78
T7 (R)	-1816,73	1907,12	2435,18	-1319,80	1907,12	-1805,99	-4265,17	-3550,68	3380,73	786,40	3916,16	2708,83

Gross margin deviations are calculated as follows: Gross margin X= Gross margin X - Average Gross margin for seven years (2012 to 2018).

R_{22}**:** Sum (R): $X_{24} + X_{25} + X_{26} + X_{27} + X_{28} + X_{29} + X_{26} + X_{30} + X_{31} = 0$

R_{23}**:** Converting Factor (R): $X_{30} = X_{31}$

R_{24}**:** Expected Gross Margin:

(-13117,05) X_1+ (-12132.05)X_2 + (-10492.67) X_3 (-11681,14) X_4 + (-12132,05)X_5+ (-13642,17) X_6+ (-11681) X_7+ (-13914,77) X_8+ (-16864,62) X_9+ (-12132,05)X_{10}+ (-14023,59) X_{11}+ 3427,59 X_{12}+ 19060,74 X_{13}+ 36 425,80 X_{14} + (-52,18)X_{15}+ (-33,65)X_{16}+ (-211,25)X_{17}+ (-1970)X_{18}+(-985) X_{20}+ 4502,98 X_{21}+ (-18.00) X_{22} - X_{21} = 0

Objective function: Assuming 95% confidence interval

R_{25}**:** $X_{20} = 1.64X_{30}$

5.12 Model Verification

According to Robinson (1997), model verification can be defined as the process of ensuring the conceptual model is sufficiently and accurately transformed into a computer modelling. Even though 100% accurate model does not exist in reality, the purpose for which the model is to be used should be clear to increase the accuracy of the model. There are three common methods of model verification, namely: checking the code (where data coding is checked before running the model), visual checks (watch the logic behaviour of each variable against the real world), and the inspection of output reports (compare actual with the expected results) (Robinson, 1997).

If the model cannot be verified, further modification and improvement are required until it meets the required verification criteria. The raw sugarcane data from CTS was used to identify the dominant cultivars per representative farm. That was done by calculating the total tons of sugarcane and tons of RV supplied to the mill per cultivar per representative farm using Excel commands. This was done to validate that the model (without-GM scenario) is representative of what is actually happening on the ground before the GM cultivar is incorporated into the model.

5.13 Incorporation of a genetically modified (GM) cultivar into the model

The first part under Baumol`s model was to run the model 'without' GM technology in order to gauge profitability and resource allocation for non-GM cultivars. The GM cultivar was incorporated into the model after communicating with SASRI biotechnologists. The assumption made was that, output prices will remain the same even after adoption of the technology, and that input costs on the conventional cane will stay constant, ceteris paribus. At farm level, linear programming can be modelled for resource allocation under the assumption that input costs and output prices will remain the same. However, when working at sectoral level, aggregation in the model may lead to distortion of data and aggregation bias (Önal *et al*., 2009).

Main open-ended questions about the GM cane cultivar include:

- How would the sugarcane production for GM differ from non-GM cultivars?

- How would cane yield and tons RV change if N52 was modified to have IR and HT genes, ceteris paribus?
- What other changes do you anticipate in the GM scenario?
- How might the use of chemicals to control weeds and eldana, and to eradicate cane before plough-out change in the GM cane scenario?

Table 5.15: Enterprise budgets for the sugarcane (N52) cultivars for the representative farm in the Eston Central cane supply region.

		GM Cultivar (24 months)	Eston Central (24 months)	GM Cultivar (18 Months)
a	Cycle Proportions: Harvest	51,25%	51,25%	66,67%
b	Plant	11,25%	11,25%	11,11%
c	Plow out	11,25%	11,25%	11,11%
d	Green manure	11,25%	11,25%	8,33%
e	Ratoon	40,00%	40,00%	55,56%
	Enterprise budget in a typical year per hectare			
f	RV price per ton (Rands)	4502,98	4502,98	4502,98
g	Average yield cane (Tons per hectare)	128,40	120	118,8
h	RV%	0,1298	0,1285	0,1298
i	**Gross receipts Income (a*f*g*h) (Rands)**	**38448,39**	**35577,30**	**46274,79**
	*Yield per year **	64,2	60	79,2
	*RV Tons per year/Ha **	8,33	7,71	10,28
	Allocated Costs (Rands)			
	Cane planting costs- Mechanical land prep			
j	Land preparation	3253	3253	3253
k	Hand planting	2770	2770	3463
l	Seed cane	8699	8699	8520
m	Fertiliser and lime	7525	7525	4042
n	Weed control	1850,49	2588,97	1850,49

o	Sundries and contingencies	2493	2493	3354
p	**Total (j+k+l+m+n+o)**	26590,49	27328,97	24482,49
q	**Adjusted Total (b*p)**	**2991**	**3074,51**	**2720,28**
	Harvesting costs			
r	Cutting of burnt cane	7052,40	7052,40	6981,88
s	Infield-cane haulage	3033,60	3033,60	3003,26
t	Loading and transhipment of burnt cane	1682,40	1682,40	1665,58
u	**Total (r+s+t)**	11768,40	11768,40	11650,72
v	**Adjusted Total (a*u)**	**6031,31**	**6031,31**	**7767,14**
	Ratoon management costs: Dryland cane early harvest			
w	Field management	528,28	528,28	528,28
x	Fertilizer	3232,97	3233,00	3233,00
y	Weed control	181,52	730,97	181,52
z	**Total (w+x+y)**	3942,78	4492,25	3942,80
aa	**Adjusted Total (e*z)**	**1577,11**	**1796,90**	**2190,45**
ab	Green manuring	4606,87	4606,87	3106,87
ac	**Green manuring (d*ab)**	518,27	518,27	258,91
ad	**Eldana control**	985	2955	985
ae	**Total Costs**	12103	14376	13922
	Gross margin (i-ae) (Rands)	**26345**	**21201**	**32353**

Table 5.15 shows the comparisons of conventional N52 cultivar with both 18-month and 24-month GM cane cultivars in the Eston area. This was done to determine the performance of the GM cultivar compared to conventional, main foci being on weed and eldana costs. Owing to severe susceptibility to lodging of N52 cultivar if aged especially under clay soils (Ramburan, 2016), N52 can be harvested within 18 months. Thus, the GM cultivar will need to be grown for a shorter period in good soils.

Table 5.16: Comparisons of gross margins of GM cultivars and the currently most profitable conventional cultivars per representative farm in Eston Milling area.

		Eston Central	**Mid-Illovo**	**Richmond**
Marginal poor soil (MP)	**Profitable cultivar**	GM (R21175/Ha)	GM (R22007/Ha)	N12 (R21213/Ha)
	Second profitable	N12 (R16200/Ha)	N12 (R18895/Ha)	GM (R18187/Ha)
Flat land Sandy soil (FS)	**Profitable cultivar**	GM (R22645/Ha)	GM (R27960/Ha)	N54 (R45282/Ha)
	Second profitable	N52 (R17064/Ha)	N52(R23174/Ha)	GM (R23252/Ha)
Flat land Clay soil (FC)	**Profitable cultivar**	GM (R33467/Ha)	GM (R45696/Ha)	N37 (R53729/Ha)
	Second profitable	N54 (R31298/Ha)	N54 (35241/Ha)	GM (R38412/Ha)
Steep red soil (SR)	**Profitable cultivar**	-	GM (R27960/Ha)	GM (R23253/Ha)
	Second profitable	-	N50 (R22687/Ha)	N37 (R23203/Ha)

The objective function is to maximize the utility and the conversion factor (F) is incorporated in the Baumol`s model calculated as follows:

$F=2\Delta 0.5 /T$ (2)

And $\Delta=\pi T2(T-1)$ (3)

Where T is the number of years from which the gross margins were recorded, in this case T=7 because a seven-year period was considered.

Each representative farm model was verified by optimizing the mathematical programming models using a ‘current scenario’ and comparing the optimal solutions to current observations, and then repeating the analysis for a scenario in which a GM cane cultivar is available to assess the likely change in farmers’ decisions from introducing a GM cultivar of sugarcane.

Table 5.16 comparisons from the enterprise budgeting and gross margin analysis**,** shows that GM cultivar generally outcompetes non-GM cultivars. In both Eston Central and Mid-Illovo a GM cultivar is the most profitable cultivar across all land categories. Since a GM cultivar is N52 with HT and IR genes, the adaptability and suitability of N52 aids GM cane to perform well even in relatively poorer soils. This cultivar produces higher yields and good RV in limited water conditions (Ramburan, 2016), and its performance is validated as the Eston Central and Mid-Illovo are characterised by drier soils relative to Richmond area (Pilusa, 2016; Botha, 2018, pers.comm). However, non-GM cultivars in the Richmond representative farm perform better than GM cane, except in the steep red soils. The Richmond generally has good soils with no limited water as this area is situated on the banks of upper Illovo river and Umkomaas (Pilusa, 2016), and therefore GM cultivar is less superior over high yielding cultivars. The GM cultivar is susceptible to severe lodging under good soils if aged, and hence, the management costs are high (Ramburan, 2016; Botha, 2018, pers.comm). Furthermore, the GM cultivar is known for its poor performance under frosty conditions, yet the Richmond region is discernible of frosts (SACGA, 2017). Notwithstanding, the GM cane will be adopted in all the three representative farm categories, as discussed in detail in Chapter 6.

Baumol`s model was incorporated in the farm representative to account for risk, using confidence interval of 95% with the standard deviation value of 1.64, as illustrated in Table 5.17

Table 5.17: Mini-Tableau for Baumol`s matrix of Eston Central area

	Cane Cultivar grown /ha									Opportunity cost of land (R)/ha			Cane RV Sales (R/ton)	E(GM)	0.5TAD	SD	RHS
	MP N12	MP GM	FS N 52	FS N31	FS GM	FC N48	FC N54	FC N50	FC GM	MP Tim	FS Mac	FC Mac					
Marginal Poor Soil (MP)	1	1								1							L12050
Flat land Sandy soil (FS)			1	1							1						L6000
Flat land Clay soil (FC)						1	1	1				1					L4500
RV Transfer (tons)	-4,96	-5.54	-5,95	-5,25	-5.94	-5,81	-5,70	-6,00	-6.05				1				E0
Conv															-0.39	1	E0
Obj: E[GM] (R)	-13117	-11681	-12132	-13642	-11681	-13914	-16864	-12132	-14023	3427	19061	36426	4503	-1			Max!
OBJ: L														1		-1.64	E0

Furthermore, the sensitivity analysis was conducted. The purpose of doing sensitivity analysis was to test the stability of Eston farms` plan subject to changes in key variables. The key variables are the fall in RV price, the area under GM cane constraint and the yield advantage of GM cultivar. It is important to note that “fall in RV price” rather than “increase in RV price” was considered in this analysis owing to the volatility of the RV price in the past years, and the worst case scenario that can happen is further RV price fall in the future. Furthermore, a “increase in RV price” is expected to increase the adoption rate since this cultivar has cost savings advantage relative to non-GM cultivars. Also, the removal of relative higher yield advantage from the GM cultivar was done to test whether the adoption will solely be driven by the higher yields or not. NB: when varying each variable, everything else will be held constant (ceteris paribus).

5.14 Conclusion

Eston region was chosen as a study area because the region was severely affected by the eldana pest in past years. Infestation of eldana pest is positively correlated with drought and the age of sugar. On the other hand, cynodon grass also thrive in the marginal soils where it vigorously competes with ratooning sugarcane especially on drought seasons. Therefore, impacts of eldana and cynodon can be detrimental in this region owing to relatively low rainfall and longer sugarcane cutting cycles in the Eston area. The region was subdivided into three large scale representative farms (Eston, Mid-Illovo and Richmond) and one smallholder farm (Umbumbulu) to gauge the socio-economic impact of GM cane. Partial budgeting and gross margin analysis methods were used to develop the LP and Baumol`s model for the three representative farms. Risk consideration in the impact assessment studies is crucial to prevent negative unintended consequences. An understanding of the study area and current production systems helped to construct the conceptual model that is sufficiently and accurately transformed into a computer model. Model verification under the baseline scenario was done to test the model`s robustness before the new technology is incorporated into the model. The results obtained in this research are discussed in detail in the next chapter, aiming to address the main objective of this research which is to determine the likelihood of GM sugarcane adoption in the Eston region.

Chapter 6: Results and Discussions

The results for the three representative farms in the Eston cane supply area are presented and discussed in this chapter. The discussion explains how these results can be used in farm-level decision-making related to essential resource allocation. It is centred on the main study objective of analysing the likelihood of GM cane adoption and its potential impact on the Eston sugarcane growers. Results generated through enterprise budgets and gross margin analysis developed in Chapter 5 were used in the computation of the Linear programming: Baumol`s matrix. The representative farm models were optimised for each of the solver add-in “without GM” scenario and the “with GM cane” scenario using Microsoft Excel. The answer reports generated by the solutions are presented in Appendices.

6.1 Model verification of results

Using the inspection of the output reports method (Robinson, 1997), results generated by the LP model under the baseline scenario and under “with GM” scenario were compared with the preliminary results calculated from the raw data as presented in Table 6.1.

Table 6.1: The sugarcane cultivars that were chosen by an LP model under different land categories in the Eston region.

Eston central			Mid-Illovo			Richmond		
Raw Data	**Without GM**	**With GM**	**Raw Data**	**Without GM**	**With GM**	**Raw Data**	**Without GM**	**With GM**
N12	MPN31	MPN31	N12	FSN52	FSGM	N48	MPN31	MPN31
N31	MPN12	MPGM	N48	FCN12	FCN12	N12	FSN52	FSN52
N48	FSN31	FSGM	N50	FCN48	FCN48	N31	FCN48	FCN48
N54	FSN52	FSN52	N54	SRN50	SRN50	N52	FCN35	SRGM
N50	FCN48	FCN48	N31		SRGM	N37	SRN48	
N16			N37			N35	SRN37	
N52			N16			N54		
			N52			N50		

The model was further verified by comparing the land proportion and shift of area under each cultivar, and under opportunity costs in both ‘without’ and ‘with’ GM cane scenarios. That was done to determine the robustness of the model used.

As shown in Table 6.2, N12 is completely replaced by GM cane. Even though N12 is still a reliable cultivar for most of the sugarcane farms, Botha (2018, pers.comm), and other farmers have indicated that the area under N12 has declined significantly owing to newer cultivars such as N54, N52, and N48 that outperform older cultivars. The substantial reduction from 26% to 0% area under N12 can be further explained by the lag in the replanting of sugarcane; cane is generally replanted after eight years. Therefore, even if the cultivar has become less profitable farmers are less likely to plough it out before it has reached its full lifespan. DAP statistics (statistical software designed to perform data management, analysis and graphics) from the LP model shows that most of the existing non-GM cultivars will remain in the Eston central representative farm even after the adoption of GM cultivars. However, there is a slight decline in the area under N31 from 33% to approximately 28% in marginal poor soil. The replacement of N31 by GM cane can be attributed to its relative susceptibility to the eldana (SASRI, 2006) compared to GM cane

Table 6.2: Land allocation among sugarcane cultivars and opportunity costs of land under baseline and with GM cane scenarios in the Eston central representative farm

Without GM CANE			**With GM CANE**		
Growing	**Land (Ha)**	**Proportion (%)**	**Growing**	**Land (Ha)**	**Proportion (%)**
MPN31	5692,8	33,0	MPN31	4747,8	27,5
MPN12	4440,5	25,7	MPGM	5385,5	31,2
FSN52	5692,7	33,0	FSN52	5692,7	33,0
FSN31	307,3	1,8	FSGM	307,3	1,8
FCN48	1117,5	6,5	FCN48	1117,5	6,5
MP Timber	1916,8	8,5	MP Timber	1916,8	8,5
FCMac	3382,5	15,0	FCMac	3382,5	15,0

In the Mid-Illovo representative farm category, there is no significant land displacement from sugarcane cultivars, timber and macadamia nuts.. However, N52 grown under flat sandy soil prior to the adoption of GM technology was completely replaced by a GM cultivar while other the land under other cane cultivars e.g. N12 and area under opportunity costs remained relatively unchanged, as shown in Table 6.3. This can be justified by the similarities between the two cultivars, GM cane is N52 with IR and HT genes.

Table 6.3: Land allocation among sugarcane cultivars and opportunity costs of land under baseline and with GM cane scenarios in the Mid-Illovo representative farm.

WITHOUT GM CANE			**WITH GM CANE**		
Growing	**Land (ha)**	**Proportion (%)**	**Growing**	**Land (ha)**	**Proportion (%)**
FSN52	1000	9,9	FSGM	1000	9,9
FCN12	3326,4	33,0	FCN12	3326,4	33,0
FCN48	2231,706	22,1	FCN48	2753,6	27,3
FCN54	521,8941	5,2	SRN50	673,6	6,7
SRN50	3000	29,8	SRGM	2326,4	23,1
MP Timber	800	6,2	MP Timber	800	6,2
FCMac	1920	15,0	FCMac	1920	15,0

Table 6.4 shows the reduction of area under timber and an increase in area under N31 of marginal poor soil and increase red soils in steep slopes was allocated to GM cultivar. Timber has become less profitable, and timber permits are no longer issued in the area (Botha, 2018, pers.comm), and the fact that the GM cultivar is primarily developed to thrive under poor soils where other cane cultivars struggle.

Table 6.4: Land allocation among sugarcane cultivars and opportunity costs of land under baseline and with GM cane scenarios in the Richmond representative farm.

WITHOUT GM			**WITH GM**		
Growing	**Land (ha)**	**Proportion (%)**	**Growing**	**Land (ha)**	**Proportion (%)**
MPN31	435	18,4	MPN31	496,7	20,5
FSN52	600	25,4	FSN52	600	24,7
FCN35	527,5	22,3	FCN48	527,5	21,8
SRN37	20,4	0,9	SRGM	800	33,0
SRN48	779,6	33,0	MP Timber	253,3	8,0
MP Timber	315	10,0	FCMac	472,5	15,0
FCMac	472,5	15,0			

Based on the results presented, the model was verified and validated because of land allocation among the cultivars and opportunity costs generally in consensus with *priori* expectations discovered during data collection. A detailed discussion of the results obtained is presented in the next section.

6.2 Results and discussion from commercial large-scale sugarcane producers in the Eston sugarcane supply region

The analysis shows that farmers will benefit from adopting GM cane in the Eston supply area through increased utilities. Higher utilities are attributed to major savings on costs of eldana chemical control on the GM cane as shown in the partial budget in Chapter 3.

Table 6.5: Comparisons of utilities between without and with GM technology in the Eston area.

	Utility without GM cane	**Utility with GM cane**	**Change**
Eston Central	65 736 618.58	115 308 872.90	43%
Mid-Illovo	32 163 587.649	50 206 887.8	36%
Richmond	17 010 894.94	20 442 891.16	17%

The significant increase in the objective function value (utility) in all the three representative farm categories is attributed to the adoption of GM sugarcane. Across all the representative farm categories, the area under GM cane has exhausted the maximum land constraints which is land under a single cultivar should not exceed one-third of the area under sugarcane on the farm as shown by Table 6.6. This concurs with a *priori* expectation as Rutherford (2018, pers.comm) reported that the GM cultivar will produce 1% and 7% RV tons and cane yield higher than the non-GM cultivars, respectively and therefore, produces higher revenues.

The technology will help in reversing the declining area under sugarcane that has been experienced recently owing to low productivity of sugarcane (Donnelly, 2017). In relative profitability of sugarcane, the results show that GM technology is not sufficient to change the current enterprise mix in the Eston central and Mid-Illovo representative farm categories. Therefore, increased utilities are due to relatively higher profitability of GM cane relative to existing non-GM cultivars. The area under cane is expected to increase by 3% following the adoption of GM cane while the area under timber has declined in the Richmond representative farm. Timber has become relatively less profitable, and most farmers are considering reducing their areas under timber and replace it with more profitable enterprises such as macadamia nuts and new cane cultivars (Botha, 2018, pers.comm).

Table 6.6: Area under GM cane in the Eston supply region by representative farm

Representative farm categories	Total arable land per farm category (Ha)	Area under cane-without GM cane (Ha)	Area under cane-with GM cane (Ha)	Change in Area under cane	Proportion of GM per Area under cane
Eston Central	22 550	17 250,75	17 250,75	0%	33%
Mid-Illovo	12 800	10 080	10 080	0%	33%
Richmond	3 150	2 362,50	2424,242	3%	33%
Total	**38 500**	**29 693**	**29 755**	**3%**	33%

Since sugarcane producers in South Africa are paid based on the recoverable value of the cane yield supplied to the mill (Ndoro *et al*., 2015), higher RV tons are expected to improve utility. Figure 6.1 shows a general increase in the tons RV in the Eston central and Mid-Illovo representative farm categories while the Richmond farm has experienced a slight reduction in both tons cane and tons RV. Even though there will be no significant shift in terms of yields following the adoption, GM cultivar shows will increase utilities owing to low costs incurred in its production relative to other cultivars.

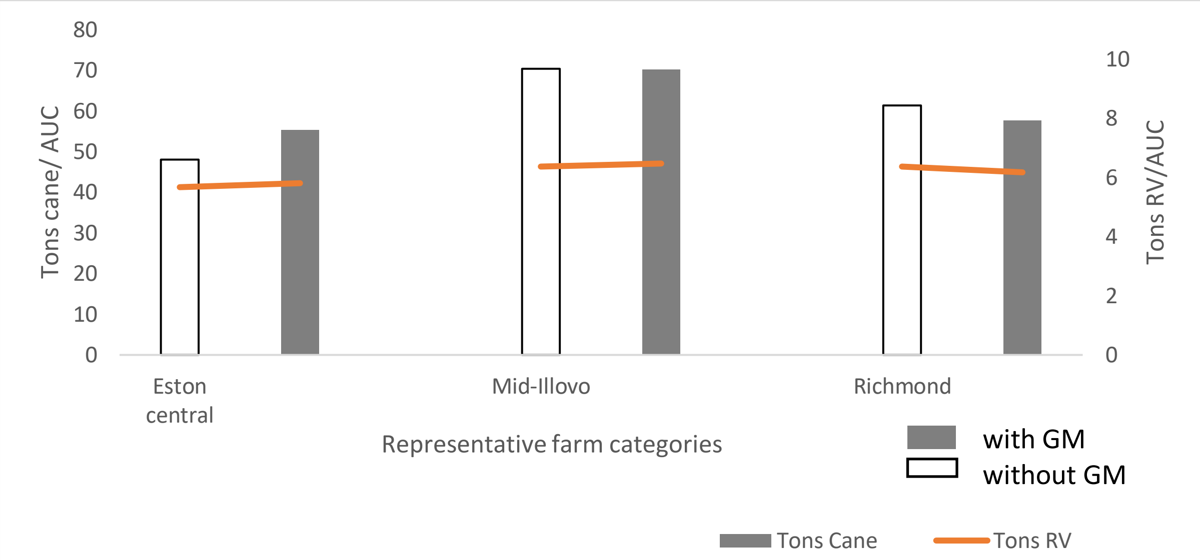

Figure 6.1: A summary of the Cane and RV yield distributions in three representative farms before and after the adoption of GM cane.

Eston central is characterized by lower sugarcane yields owing to less favourable climatic conditions and dominance of marginal poor soils relative to Mid-Illovo and Richmond regions (Botha, 2018, pers.comm). Even though N12 has been completely taken out of the farm following the GM adoption as shown in Figure 6.2, the overall tonnage has increased in Eston central. Displacement of land under N12 was expected to reduce the tonnage in this farm owing to its distinguished performance under different soils types and climatic conditions. According to SASRI (2006), N12 is the most prevalent cultivar in the rainfed regions which performs well in poor soils, even during dry seasons. This cultivar produces high yields of both cane and tons RV when harvested older than 16 months, and it is distinguished with its resistance to pests and common diseases.

However, the extension officer have indicated that the area under N12 in the Eston region have declined significantly over time owing to new cultivars that are better suited to the area than N12. Results show that the GM cultivar has sufficiently compensated the decline of area under N12 and N31. N31 is also a cultivar marked with high cane yield and tons RV if grown in sandy or marginally poor soils (similar features to GM cultivar) of the Midlands (SASRI, 2006). Figure 6.2 shows that adopting the GM cultivar has boosted both tons of RV and tons of cane in the farm category by 2% and 13%, respectively. The adaptability and performance of the GM cane under poor soil are pronounced in this farm, and the larger proportion of area under GM cane is marginal poor soil land category.

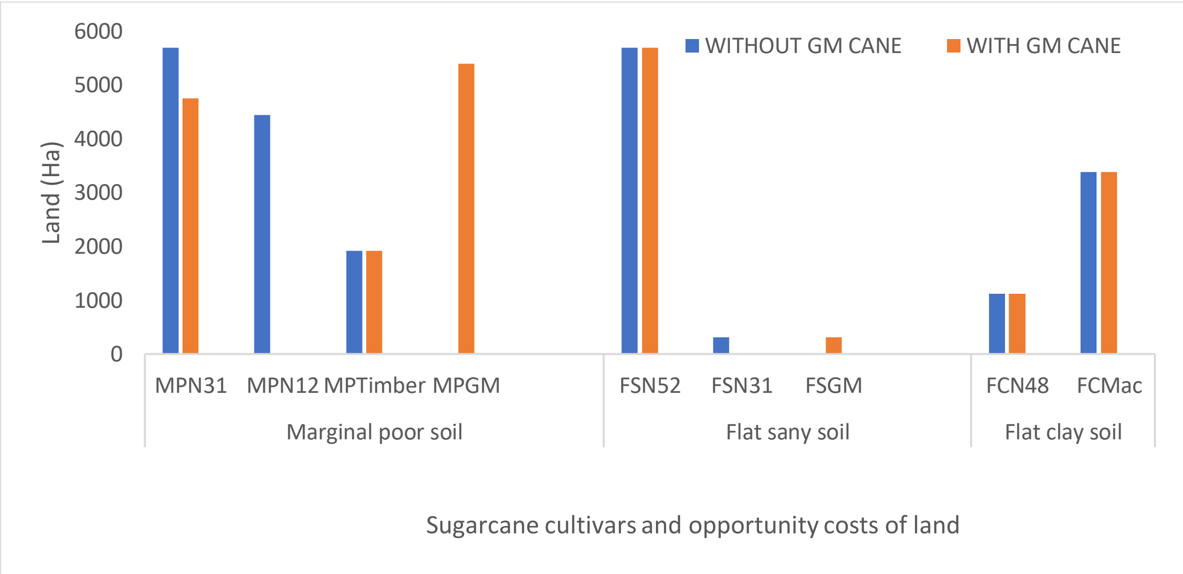

Figure 6.2: Land allocation among sugarcane cultivars and opportunity costs in Eston Central representative farm, with GM cultivar

In the Mid-Illovo representative farm, GM technology will not affect the cane yield in any way. However, the overall tons RV per area under cane have increased by 2% post GM cane adoption. Despite the redistribution of area under cane among sugarcane cultivars, the performance of cultivars (GM and N48) that are replacing other cultivars is fairly similar. N54 and N52 cultivars were taken out of the enterprise mix following the GM adoption as shown in Figure 6.3. These are new, high yielding cultivars with good RV content that are well-suited to sandy and humic soils of the

Midlands (Zhou, 2010). These cultivars were replaced by GM and N48, which are also high yielding cultivars, characterised by high quality RV yields; and the GM cultivar produces 1% tons of RV higher than non-GM cultivars (Rutherford, 2018, pers.comm).

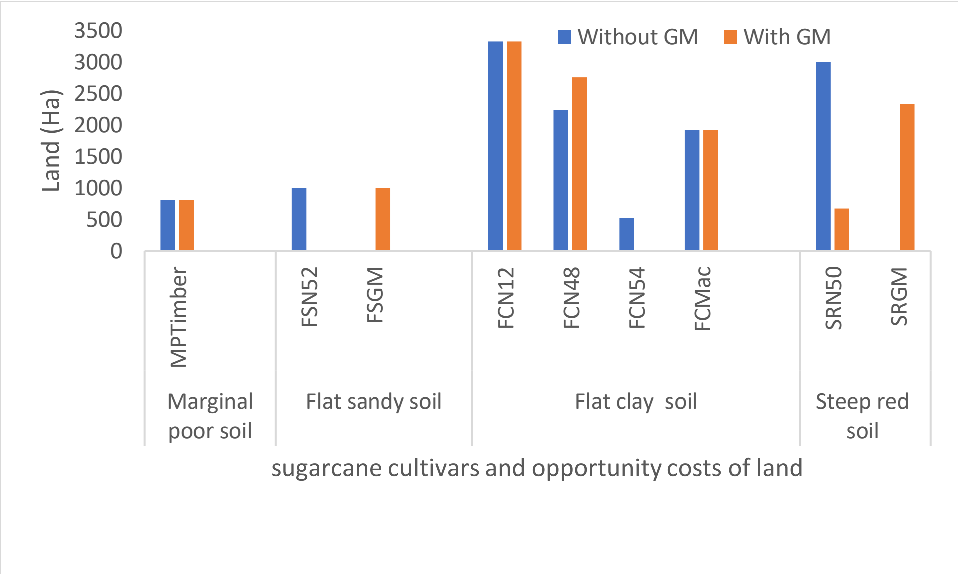

Figure 6.3: Land allocation to sugarcane cultivars and opportunity costs in the Mid-Illovo representative farm after adopting GM cane.

HT and IR genes in GM cane produce 7% and 1% cane yield and RV higher relative to non-GM cultivars, respectively (Rutherford, 2018, pers.comm). Contrary to the prior expectations, there is a downturn in the overall tons cane and tons RV produced on the Richmond representative farm category. The overall reduction on cane yield can be attributed to land displacement from high yielding cultivars (N37; N48; N35) after the adoption of the GM cultivar as shown in Figure 6.4. The land under N48 cultivar has declined by 32% post the GM technology adoption, a high yielding cultivar with intermediate resistance to eldana (Zhou, 2010). This shift can be explained by the similarities between N48 and GM cultivars which include high tons of RV, high cane yield and resistant to the adverse impacts of pests and diseases. In the “without GM technology” the model would choose more steep red soils under N48, but when the GM cane becomes available the model allocated the entire land category the GM. This shows that, even though these cultivars are similar, the GM cultivar would always have superior characteristics over N48 which includes cost savings on eldana and weed control.

Even though there is still a discernible N48 cultivar under flat clay soil replacing N35, this cultivar performs well in poor soils and sandy soils because it is prone to lodging under good soils (Zhou, 2010), which affects sugarcane quality. Conversely, N35 produces high tons RV in high potential soils (SASRI, 2006). Even though the cultivar is susceptible to eldana, it is adapted to the frosty areas of Richmond. Farmers grow N35 cultivar under the 12-month cycle to mitigate eldana infestation since the eldana population increases with the age of sugarcane (Rutherford, 2015; Botha, 2018, pers.comm). Farmers indicated that this cultivar produces higher overall yields in 2 years because it is harvested twice while most cultivars are harvested after 24 months.

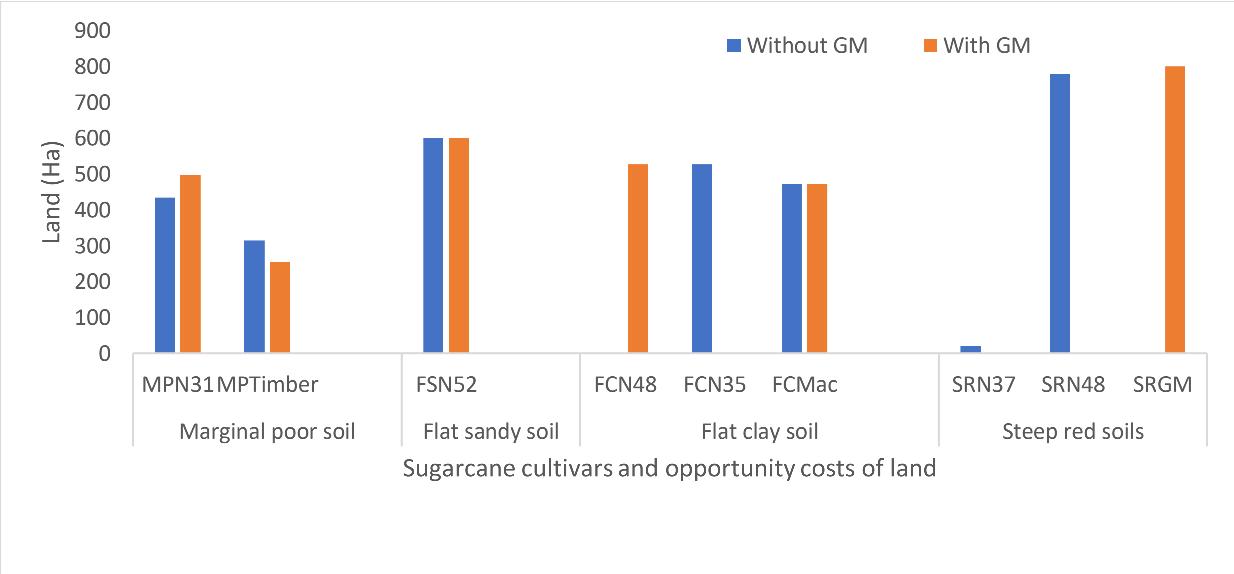

Figure 6.4: Land allocation to sugarcane cultivars and opportunity costs in the Richmond representative farm after the adoption of GM cane

Therefore, the overall yields have slightly declined because higher yields produced by GM cane is not likely to fully compensate the reductions because the area under this cultivar must not exceed the one-third of the area under sugar cane in the farm. Furthermore, the Richmond representative farm currently grows high yielding non-GM cultivars which produce higher revenues than the GM cultivar as shown in Table 5.16 in Chapter 5. Therefore, adoption of GM cane would not necessarily increase the overall cane yield, rather the cost savings on eldana and weed control are sufficient to drive the adoption. These results concur with Cheavegatti-Gianotto *et al.,* (2011) and Rutherford (2018, pers.comm) that the benefits of GM IR and HT cane are mainly attributed to the decreased costs of pesticides and increased gross income owing to the improvement of cane quality.

Figure 6.5 shows that there has been a decline in costs of eldana chemical control per hectare in all the three representative farms after GM cane has been adopted which agrees with a priori expectations. Based on the agricultural economics literature (Klümper & Qaim, 2014; Brookes & Barfoot 2016; Cheavegatti-Gianotto *et al*., 2011), adoption of HT and IR GM crops generally reduce overall input costs on the farm. Currently, chemical spray for eldana is conducted twice a year in Eston (Botha, 2018, Pers.com), but in the 'With-GM' cane scenario, there is going to be a single spray. The analysis shows that farmers stand to achieve up to 49.3% cost savings on eldana chemical costs. Reduction in the number of eldana chemical sprays is expected to address environmental conservation and biodiversity protection (Cheavegatti-Gianotto *et al.*, 2011) in the Eston region because the untargeted organisms will be less exposed to insecticides.

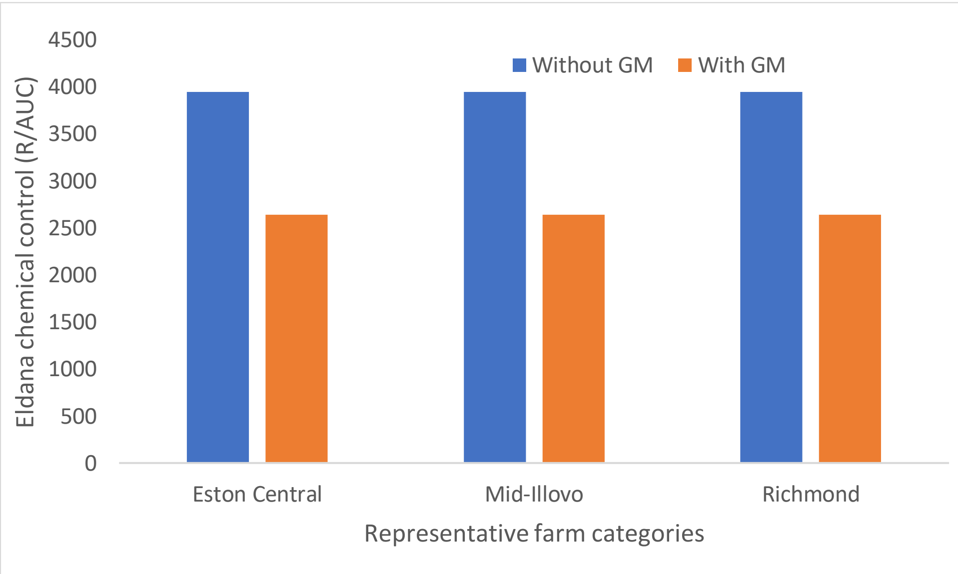

Figure 6.5: Comparisons of costs of eldana chemical control before and after the GM cane adoption across all representative farm categories.

The overall time spent on sugarcane weeding is expected to decrease in the three representative farms, as shown in Table 6.7. According to Nicholson *et al*. (2017), by adopting GM the cane farmers are expected to save costs and time spent on controlling the weeding. Herbicide tolerance of the GM cane helps farmers with the early onset of the production season without having to wait for four months after chemical eradication of old sugarcane. Thus, fewer chemical sprays to control post emergence (ratoon stage) weeds because of the chemical residues in the soil that would still be present.

Instead of using various herbicides that are currently used for non-GM cane cultivars, Format 250 SL herbicide (commercial non-selective herbicide that has an imazapyr active ingredient with ingredient) will be used for both cover spray and spot spray for the GM cane cultivar (Snyman, 2018, pers.comm). Even though a litre of an imazapyr herbicide is relatively more costly than common herbicides that are used under non-GM cultivars, the reduced application rates and less labour required per hectare per annum are the main contributors to the relatively lower total costs which is expected to increase the adoption (Nicholson *et al.,* 2017).

Table 6.7: The weeding hours spent on the Eston farms in both without and with GM cane

	Weeding Without GM (Hours/ha)	Weeding With GM (Hours/ha)	Change
Richmond	69	65	-6%
Mid-Illovo	66	64	-3%
Eston central	62	60	-3%

Analysis presented in Table 6.9 shows a slight reduction in hours (1,8% lesser) spent by farmworkers in the Eston central and Mid-Illovo representative farm categories, contrary to *priori expectation*. Experts and biotechnologists in sugarcane have indicated that field workers will spend fewer hours on eldana pest control as the spray programs will be reduced to a single spray per annum after the adoption of GM cane. Rutherford (2018, pers.comm), however, indicated that reduced hours on eldana control are not expected to result in less labour usage on farm owing to higher yields and adaptability of GM cane which will demand more field workers for ratoon management and harvesting. Therefore, farmworkers are not likely to lose their jobs as a result of GM cane adoption.

According to Goga (2013), land under sugarcane and yield per hectare are the significant determinants of demand for labourers in large scale sugarcane farms in KwaZulu-Natal. The statement is validated by Table 6.7 which shows that Richmond farm will allocate 0.8% more hours on the farm activities after adopting GM cane. An increase in hours spent by labourers on the farm is caused by the shift of land under timber to sugarcane post-adoption of GM cane as shown in Figure 6.3. The positive correlation between land under sugarcane and hours spent on the field is expected to boost the demand for labours in sugarcane farms because sugarcane enterprise appears to be more labour-intensive than timber, hence, there is a higher labour utilisation after the land has shifted from timber to sugarcane. Furthermore, technologies that address protection of health for farmworkers improve both supply and demand for labours in sugarcane farms and thus improving productivity. Therefore, the productivity is expected to advance owing to less exposure of farm workers to eldana chemicals (Goga, 2013).

Table 6.8 Labour utilisation in the Eston area, before and after GM technology

	Without GM cane (Hours)	With GM cane (Hours)	
Eston Central	6380617,5	6266762,55	-1,8%
Mid-Illovo	3727440	3660912	-1,8%
Richmond	871965	878809,697	0,8%

6.3 Sensitivity Analysis

As aforementioned, the purpose of this section was to test the stability of Eston farms` plan subject to changes in key variables. The key variables that were tested are the fall in RV price, the area under GM cane constraint and the yield advantage of GM cultivar.

Table 6.9 shows that farmers stand to gain more utility from an additional hectare of land per representative farm. In the Mid-Illovo representative farm, one additional hectare of marginal poor soil can produce an additional value of utility amounting to 9137,69 as represented by shadow price value. Shadow price, in linear programming, can be defined as an additional value to an optimised objective function resulting from increasing the right-hand side (RHS) of a constraint by one unit (Igwe & Onyenweaku, 2013). This potential increase can be explained by the dominance of GM cane, total land is devoted to GM cultivar, yet this land category only constitutes approximately 6% of the total farm. The profitability of this cultivar under relative poorer soils was demonstrated when the marginal poor soil under timber was entirely taken away and was devoted to GM cultivar in both Mid-Illovo and Richmond farms.

Table 6.9: Sensitivity analysis report for land potential from the three representative farms

Land categories (Ha)	Eston Central		Mid-Illovo		Richmond	
	Final Value	**Shadow Price**	**Final Value**	**Shadow Price**	**Final Value**	**Shadow Price**
Marginal Poor Soil (MP)	12050	3942,75	800	**9137,69**	750	8826,31
Flat land Sandy soil (FS)	6000	5744,30	1000	4791,75	600	7255,40
Flat land Clay soil (FC)	4500	7398,67	8000	2961,36	1000	4729,21
Steep red soils	-	-	3000	4791,75	800	5877,28

6.3.1 Fall in sugarcane RV price

The range of decreasing an RV price from 5% to 25% was chosen based on the past trend of real RV price volatility over the past seven years. The common trend is a 5% decline/increment in the price of RV, and the maximum reduction in RV price was 20% that was experienced in 2018. 25% was included to test the unforeseen worst-case scenario in the future.

The original price of RV was R4502,98/ton which yielded a solution with utility (L) value of 115 308 872,90, with 4747,755 ha of marginal poor soil under N31, 5385,50 ha of marginal poor soil under GM cultivar, 5692,75 ha of flat sandy soil under N52, 307,25 ha of flat sandy soil under GM cultivar, 1117,50 ha of flat clay soil under N48, 1916,75 ha of marginal poor soil under timber and 3382,50 ha of flat clay soil under macadamia nuts in the Eston central representative farm. A 5 percent decrease in RV price resulted in a solution with 92 739 176,17 value of utility (L) but the land allocation among cane cultivars and opportunity costs did not change. In the Richmond farm category, a 5 percent decline in RV reduced the value of utility by 16%, from 20 442 891 to 17 146 011, and there was a slight displacement of land from sugarcane to timber in the Richmond representative farm category. Marginal poor soil category under N31 declined by 12,4%, and timber has reached its maximum land constraint (10%) increasing from 253.28 ha to 315 ha of marginal poor soil. The value of the utility declined by 22% (50206888 to 38968253) in the Mid-Illovo representative farm category when the RV price reduced by 5%, but there was no change in land allocation among the sugarcane cultivars and opportunity costs. Across all three representative farm categories, the area under GM cane reached the full capacity of 33% in each farm.

Reducing the RV price by 10% resulted in the solution with an L value of 70 169 479,44 (~39% reduction) with no change in land allocation among sugarcane cultivars and opportunity costs in the Eston central farm. There was approximately a 58,5% reduction in the utility Mid-Illovo while Richmond`s utility declined by 32%. A drop in the RV price by up to 20% reduced the value of the utility by 74%, but the land allocation was not affected.

Further reduction of the RV price by 25% (R3377,23/ton) yielded a solution with the utility value of 11 396 754,06 which is 90% lower than the original solution. And only 49% (10972,93 ha out of 22550 ha) of land is utilised in the Eston central representative farm, 932,70 ha of marginal poor soil is allocated to timber, 2770,12 ha of sandy soil is under GM cultivar and 2770,12 ha of sandy soil is under N52 (33% of the area under cane by each of the two cultivars), 1884 ha of clay soil is under N48, 969,85 ha of clay soil is under N50 and 1645,94 ha of clay is devoted to macadamia nuts. No marginal poor soil is allocated to sugarcane, only timber which takes 8,5% of the utilized land, and N50 under clay soil is only chosen when the RV price is 25% lower than the original price. N50 is recognized by its good ratooning ability, and therefore, producing high yields of both cane and tons RV under average to good soils of the Midlands region (Zhou, 2010). Even though the total farm is not fully utilized, the land devoted to the GM cultivar reached the maximum constraint (one-third) allowed per cultivar. Thus, GM cane would still be adopted in the Eston central farm even when the price is 25% lower than the original price.

Reducing the RV price by 25% yielded the solution with 80% lower than the original utility value in the Richmond representative farm category. However, the land allocated to sugarcane cultivars and opportunity costs remained the same, and unlike the Eston farm, the land was fully utilized. Mid-Illovo representative farm experienced a reduction in the utility value of 95% when the RV price dropped by more than 20%. Sandy soil was displaced from GM cane (1000 ha) to N12 (725 Ha) and N52 (275 ha) and steep red soil was allocated to GM cane (1141 ha) and N50 (900 ha). However, the area under sugarcane declined leaving other parts of the farm unplanted which led to a slack of 7322 ha and 959 ha of clay and steep red soils, respectively. Even though the land under timber did not increase, but the proportion of timber in the farm has increased from approximately 6,25% to 8,5% because of the unutilized land on the farm.

Regardless of lower RV prices and therefore lower revenues, the sugarcane enterprise is not excluded from the enterprise mix, and GM cultivar is among sugarcane cultivars that remain in the farm enterprise mix across all the three representative farm categories. This shows that the model is sensitive to RV price fluctuations, however, the temporary fall in RV price has little impact on land under sugarcane owing to the perennial nature of this enterprise.

6.3.2 Relaxation of the area under the GM cane constraint

A single sugarcane cultivar must not take more than one-third of the total land under sugar cane (Botha, 2018, pers.comm). Increasing the maximum area under GM from 33% to 40% produced the solution with the utility value of 120059685 which is 4% higher than the utility produced under the one-third scenario (115 308 873). The land under GM reached the maximum constraint (40%), the land under N31 and N52 declined by 6% and 20%, respectively while the land under GM sugarcane increased by 80%. Further relaxation of land constraint under GM cultivar to a maximum of 50% yielded to solution with 126 230 257 utility (9% higher than the original utility). The sandy soil under N52 declined by 90% while the land under GM cane increased by the same magnitude of 90% making the total land under GM equal to 50%.

Complete removal of one-third constraint yielded the solution with the utility value of 136 758 752, which is approximately a 15% increment from the solution produced under the one-third constraint, and 72% of the area under cane was GM cane. The area under non-GM cultivars declined to 28%. However, the land under timber and macadamia nuts remained the same under different scenarios of GM constraints. Contrarily, a 40% relaxation of the constraint for the area under the GM cultivar caused the complete shift of land out of timber to a GM cultivar in both Mid-Illovo and Richmond representative farm categories. This implies that farmers would want to plant more than one-third of GM to increase utility. Therefore, regulations for compliance should be strict to avoid unintended consequences of this technology.

6.3.3 GM cultivar with no yield advantage

According to Rutherford (2018, pers.comm), HT and IR genes in the GM cane is expected to produce 7% and 1% cane yield and an RV higher than the non-GM cane cultivars, respectively. To test the responsiveness of the model to this variable, a 7% yield advantage was removed from partial budgets and gross margin schedules of the GM cultivar. For all the three representative farms, the enterprise remained unchanged, implying that even if the GM cane has no yield advantage relative to non-

GM cultivars, it would still be adopted in the Eston region. Even though the value of utility (L) declined by 12%, 19%, and 2% for Richmond, Mid-Illovo and Eston central, respectively but the L values are 44%, 19% and 38% higher than the values in the "without GM" scenario. This validates that the adoption of this technology depends heavily on the cost savings.

The changes made in the model are possible in reality, and therefore, the stability and robustness of GM cane technology are tested. Even though the model demonstrated the susceptibility to these changes, the GM cane would still be adopted under such volatilities in the long-run.

6.3.4 Other enterprises

The main opportunity costs of sugarcane are macadamia nuts and timber in the Eston region. To promote diversification, the land under a single enterprise is constrained to a certain proportion per farm; the area under macadamia nuts and under timber should not exceed 15% and 10% of the total farm area, respectively (Botha, 2018, pers.comm). The profitability of the macadamia nuts is pronounced in the land allocation in both scenarios (With and without GM). Macadamia nuts have exhausted the maximum land constraint of 15% in all the three representative farms in the Eston area, outperforming non-GM cultivars and timber in both 'with' and 'without' scenarios. Macadamia nuts are among the most profitable enterprises in South Africa, export-driven and there has been a significant shift of land from other enterprises to macadamia since 2010 (DAFF, 2017).

Nevertheless, farmers have indicated that this enterprise is less likely to replace sugarcane in the near future despite its profitability. Uncertainties about the future and competition from other countries are the main reasons farmers in the Eston area have not shifted land away from sugarcane, and hence farmers allocate no more than 15% (Botha, 2018, Pers.com). Owing to severe lodging of high yielding cultivars if grown in clay soils, farmers allocate some portions of flat clay soil to macadamia to take advantage of its performance and adaptability under this soil type. Even though the analysis shows dynamic allocation of land under timber following the adoption of the

GM technology, timber was not completely taken out of the enterprise mixes across all the three representative farm categories.

In Mid-Illovo and Eston central representative farms, the adoption of GM cane had no effect on the land under timber. However, in the Richmond representative farm, an area under timber dropped by 20% following the adoption of GM technology being replaced by increased marginal poor soil under N31. An area under N31 was increased to prevent significant reduction of sugarcane tonnage in this farm after adoption of GM cane technology. N31 produces high tons of cane and tons of RV under sandy and marginal poor soils (SASRI, 2006). Therefore, timber is still a good diversifier in sugarcane production regardless of it being less profitable, especially in the marginal areas where growing of sugarcane is less profitable.

6.5 Findings from the focus group discussion with smallholders

The N12 cultivar is the dominant cultivar, accounting for approximately 67% of the total area under cane for smallholder farmers in Umbumbulu area, followed by N54 (17%), N47 (8%) and NCo376 (8%) as shown in Figure 6.6. The area allocated to N12 is declining as farmers increasingly adopt new cultivars, such as N54, which according to the farmers have advantages that include higher yields, RV tons, shorter cutting cycles and resistance to pests and diseases. Participants of the focus group agreed that N54, which has been available since 2017, will probably replace N12 as the dominant cultivar in the region in the long run due to its ability to ratoon and yield even when produced on poor soils.

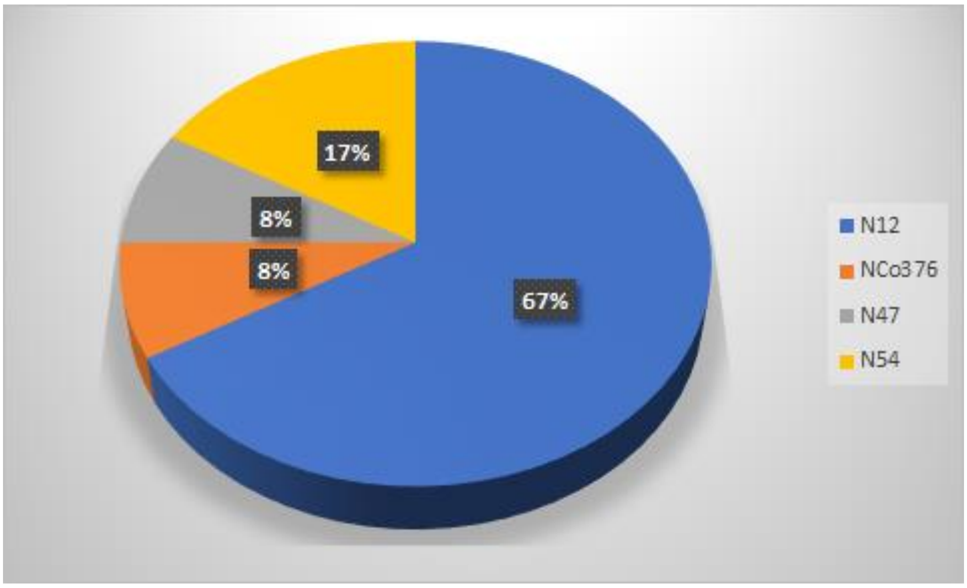

Figure 6.6: Common sugarcane cultivars in the smallholder farming at Umbumbulu region

The farmers agreed that weeds are a problem in sugarcane production in the Umbumbulu area, including various broadleaf weeds and grass species. The most prevalent weed species are Bug weed (*Solanum mauritianum*), Common blackjack (*Bidens Pilosa*), creeping grass (*Cynodon dactylon*) and Guinea grass (*Panicum maximum*). However, they generally disagreed that eldana is a problem in their fields. Botha (2018, pers. comm) contended that eldana probably is an important pest in the area, however, the farmers are not aware of it because they are often reluctant to have their cane tested.

Participants indicated that smallholder farmers are willing to adopt any strategy that may assist in mitigating the impact of weeds and pests, including the adoption of new cane cultivars, subject to their pervasive liquidity constraints. Although many of the smallholders seem to be relatively unaware of the eldana problem, adoption of GM cane with IR traits is likely to have a favourable yield response and to increase the farmers' resilience to drought. Smallholders tend to benefit the most from GM technologies in South Africa as the magnitude of cost savings by IR and HT genes are relatively substantial compared to those of large-scale farmers (Cloete *et al.,* 2006; Azadi *et al.,* 2016). However, Gouse *et al*. (2005) argued that the benefits of GM technologies are not fully captured by smallholding producers owing to their averseness to adopt new technologies.

6.6 Summary of the Results and discussion

The development of a herbicide tolerant (HT) and insect resistant (IR) genetically modified sugarcane cultivar was advocated as a solution in mitigating the impact of eldana insect and cynodon grass in sugarcane production in KwaZulu-Natal. Eldana and cynodon are the most damaging pests in sugarcane production which deteriorate the quality of sugarcane, therefore reducing revenue. This study aimed at determining the likelihood of the adoption of HT and IR sugarcane cultivar when it becomes available, using *ex ante* assessment with the LP model, in the Eston region of KwaZulu-Natal. Preliminary findings indicated that sugarcane is the main crop in the Eston area, and macadamia nuts and timber are the main opportunity costs of land in the area. The maturity cycle of sugarcane ranges from 18 to 24 months, and maturity cycles for opportunity costs are longer than 3 years. The perennial nature of the enterprise mixes in the region calls for proper and long-term planning in farm decision making. These findings attained the first objective which aimed at grasping the current sugarcane production system and opportunity costs of land.

The LP analysis showed that subject to risk considerations, sugarcane producers in the Eston area will adopt this technology to maximize the utility. This technology stands to increase the area under cane, replacing timber, owing to its profitability from higher yields, low eldana costs and lower riskiness relative to non-GM cultivars. Across all the three representative farm categories, the GM cultivar outcompeted non-GM cultivars under poorer soil (marginal poor soils and steeper red soils). Tons of RV have increased in Eston central and Mid-Illovo representative farms after the adoption of GM, as predicted by Cheavegatti-Gianotto *et al.* (2011) study and (Rutherford, 2018, pers.comm). Even though the Richmond representative farm category experienced a downturn in both cane yield and tons of RV, the adoption leads to higher utility values in all the three farms. The findings revealed that cost savings are sufficient to cause the adoption of the GM cultivar in the Eston area. That was further proven through a sensitivity analysis test which was conducted to examine the possibility of GM adoption if there is no yield advantage in the GM cultivar. The analysis showed that farmers would still adopt this cultivar even with no evidence of higher yield characteristics.

Based on the analysis, there is a prevalence of N48 in the clay soil across the region following the adoption of GM technology. N48 is characterised by high yield under high potential soils when harvested after 20 months. This cultivar is relatively resistant to pests and diseases such as eldana and smut (Zhou, 2010). The performance is similar, but the GM cultivar is well suited to low potential soils owing to severe lodging problems under good soils (Botha, 2018, pers.comm). Findings concur with a priori expectations that GM cane will perform better under marginal and poorer soils in the Eston supply area. A larger proportion of land under GM cane is visible in marginal poor soils and steeper areas of the farms across all the three large scale representative farm categories.

Smallholder farmers will also benefit from this technology. This stands to boost sugarcane yields and quality in smallholder farming owing to resilience of the GM cultivar against pests and diseases that are inherent in the Umbumbulu farms. However, smallholder farmers are generally unable to capture the full benefits of new technologies owing to their reluctance towards the change. Therefore, proper training and information dissemination about new cultivars, including GM cultivars should be strengthened in smallholder farming so that farmers will also benefit fully from these high performing cultivars. The main purpose of developing GM cane is to produce a cultivar that can withstand the impact of cynodon and eldana even when grown in low potential soils.

Conclusions and recommendations

The main objective of this study was to determine the likelihood of genetically modified sugarcane adoption and its socio-economic impact on South African rainfed sugarcane production, using an *ex ante* assessment. A literature review showed that GMOs play a significant role in improving the agricultural industry worldwide. South Africa has pioneered the adoption of GMOs in Africa, and GM crops have dominated those enterprises. However, there is little information about the genetical modification of perennial crops, and therefore, studies on perennial crops tend to extrapolate the impact on annual crops owing to inadequate data. Sugarcane is a perennial crop with a complex genome, making it difficult to modify and hence there is currently no commercialised GM sugarcane in the world. In literature, various methods for an *ex ante* assessment were reviewed, identifying their strengths and weaknesses so that this study would choose a robust methodology with no biases.

Even though ex ante assessments are highly recommended for new technologies and new policy implementations, this type of assessment is known for its susceptibility to biases. The bias conclusions are normally associated with overestimations of the impact owing to exclusion of irrelevant variables in the analysis, and vice versa. This study strived to avoid the overestimation of GM cane benefits by using Baumol`s model which incorporates the time frame and deviations of income from expected income over time and therefore, measures the riskiness associated with new technology. However, the primary limitation of this study was 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, and there was no adequate historical information on new sugarcane cultivars and GM cultivar.

This study successfully conducted an *ex ante* analysis of GM sugarcane in the Eston region using the data collected from relevant stakeholders through focused group discussions, interviews, and establishment visits (CTS offices, farms and mills). Using partial enterprise budgeting, gross margin analysis, and the LP model, results show that the GM cultivar will be adopted in the Eston area, across all three representative farm categories: Eston central, Mid-Illovo and Richmond. As predicted by biotechnologists, GM cane performs well under marginal poor soils, steep red soils, and sandy soils and not under high potential soils such as clay soils owing to its susceptibility to lodging under good soils. This technology is likely to replace non-GM cultivars such as N12 and N52 which are currently well-suited to relatively poorer soils in the Eston area owing to its relative better performance under such soil types.

Farmers stand to benefit the most on cost savings on eldana and weed chemical control, and the reduced variation of income over time. The cost savings of 29%, 75% and 49,3% on weed costs at planting, weed costs at ratoon management, and on eldana control will help to improve revenues and utilities on large-scale farming. Farmworkers are also expected to benefit from this technology through the improved health due to less chemical spraying on eldana. This technology stands to reverse the current displacement of land under sugarcane to other opportunity costs owing to less profitability of sugarcane. And the job creation for less-skilled is expected to improve due to higher tons of cane produced, and more land under sugarcane which require more field workers.

The sensitivity analysis further revealed that GM cane adoption is possible even under different volatilities in this enterprise. The fall in RV price and the removal of high yielding advantage would not cause a decline in the area under this cultivar. Rather, the relaxation of the area under this cultivar to more than 33% of the area under cane increased the adoption up to 100% area under GM cane. This shows that the cost savings and lower riskiness of this GM cultivar compared to the non-GM cultivars are sufficient to adopt it. Therefore, there is a high possibility of sugarcane producers allocating the entire area under the GM cultivar, which is an unintended consequence associated with this cultivar. The land constraint under a single sugarcane cultivar was established to mitigate risks associated with the pest's susceptibility of a cultivar. This calls for strict regulations and enforcement of compliance to prevent farmers from exposing themselves to unforeseen risks associated with growing a single cultivar; GM cultivar.

Even though the benefits of GM cane in the smallholder farming was not quantified owing to a lack of record-keeping, respondents have indicated that the GM cultivar will benefit producers through cost savings on pest control and therefore, improving revenue. Literature showed that resource-poor farmers, especially smallholders in developing countries benefit the most from GM crops that enhance cost savings because they tend to produce relatively poorer quality products owing to less effective pest control practices they use. Therefore, strict regulations should be enforced for both large-scale and smallholder sugarcane producers not to allocate 100% area under cane to a GM cultivar.

Furthermore, the time spent on sugarcane weeding is expected to decline by 3% across all the three large scale farmers in the Eston area. However, GM cane with herbicide tolerance is likely to lead to a relatively higher agro-chemical usage. Now that GM cane can withstand imazapyr, a herbicide that covers a wide spectrum of weeds (from broadleaf to grass), farmers are most likely to shift away from the common method of weeding, hand-hoeing to solely chemical control in the post-emergence stage and ratoon management stages of sugarcane production. Therefore, strict compliance requirements should be enforced so that farmers do not exceed the threshold of herbicides to avoid chemical residues.

Future research recommendations include an extensive study of small-scale sugarcane producers on how GM cane would benefit them. The training and information dissemination to small scale extension officers and farmers about newly developed sugarcane cultivars and their benefits will play a significant role in addressing pests and low revenue inherent in smallholder farming.

References

- Abidoye, B.O. and Mabaya, E., 2014. Adoption of genetically modified crops in South Africa: Effects on wholesale maize prices. *Agrekon*, *53*(1), pp.104-123.
- African Centre for Biodiversity (ACB). 2012.Genetically modified crops in South Africa, 2008 – 2012. Available from: www.biosafetyafrica.org.za (Accessed date: 27 October 2018).
- African Centre for Biodiversity (ACB). 2013. Feeding the Dragon: Durban conference to promote massive GM soya push in Africa. Available from: https://www.acbio.org.za/en/feeding-dragon-durban-conference-promote-massive-gm-soya-push-africa (Accessed Date: 15 July 2018)
- Adenle, A.A., Morris, E.J. and Parafilm, G., 2013. Status of development, regulation and adoption of GM agriculture in Africa: Views and positions of stakeholder groups. *Food Policy*, *43*, pp.159-166.
- Aerni, P., 2005. Stakeholder attitudes towards the risks and benefits of genetically modified crops in South Africa. *Environmental Science & Policy*, *8*(5), pp.464-476.
- Aerni, P. and Bernauer, T., 2006. Stakeholder attitudes toward GMOs in the Philippines, Mexico, and South Africa: The issue of public trust. *World development*, *34*(3), pp.557-575.
- Ainembabazi, J.H., Tripathi, L., Rusike, J., Abdoulaye, T. and Manyong, V., 2015. *Ex ante* economic impact assessment of genetically modified banana resistant to Xanthomonas wilt in the Great Lakes Region of Africa. *PLoS one*, *10*(9), p.e0138998.
- Anandajaysekeram, P., Van Rooyen, C.J. and Liebenberg, F., 2004. Agricultural project planning and analysis. *International Food Policy Research Institute (IFPRI)*, pp.390-393.
- Andanda, P., 2009. Status of biotechnology policies in South Africa. *Asian Biotechnology and Development Review*, *11*(3), pp.35-47.
- Armstrong, D.H., 1999. Enterprise Comparison: Risk Programming Analysis. South African Cane Growers' Association, Malelane Cane Growers Association Building. Proc S Afr Sug Technol Ass (1999) 73
- Azadi, H., Samiee, A., Mahmoudi, H., Jouzi, Z., Rafiaani Khachak, P., De Maeyer, P. and Witlox, F., 2016. Genetically modified crops and small-scale farmers: main opportunities and challenges. *Critical reviews in biotechnology*, *36*(3), pp.434-446.
- Baker, J.L., 2000. *Evaluating the impact of development projects on poverty: A handbook for practitioners*. The World Bank.
- Bhogal, T.S., 2017. Unit-5 Farm Investment Analysis. IGNOU.

- Bio-watch South Africa (BWSA). 2016. Fact Sheet: GMOs in South Africa. Available from https://biowatch.org.za/download/fact-sheet-gmos-in-south-africa/. (Accessed date 16 March 2018).
- Botha, P. 2018. Personal Communication. SASRI Extension officer at the Eston region.
- Brookes, G. and Barfoot, P., 2014. Economic impact of GM crops: the global income and production effects 1996–2012. *GM Crops & Food*, *5*(1), pp.65-75.
- Brookes, G. and Barfoot, P., 2016. GM crops: global socio-economic and environmental impacts 1996–2014. *Dorchester, UK: PG Economics*.
- Campbell, P.L., 2008. Efficacy of glyphosate, alternative post-emergence herbicides and tillage for control of Cynodon dactylon. *South African Journal of Plant and Soil*, *25*(4), pp.220-228.
- Cheavegatti-Gianotto, A., de Abreu, H.M.C., Arruda, P., Bespalhok Filho, J.C., Burnquist, W.L., Creste, S., di Ciero, L., Ferro, J.A., de Oliveira Figueira, A.V., de Sousa Filgueiras, T. and de Fátima Grossi-de-Sá, M., 2011. Sugarcane (Saccharum X officinarum): a reference study for the regulation of genetically modified cultivars in Brazil. *Tropical plant biology*, *4*(1), pp.62-89.
- Cloete, T.E., Nel, L.H. and Theron, J., 2006. Biotechnology in South Africa. *Trends in Biotechnology*, *24*(12), pp.557-562.
- Cockburn, J., Coetzee, H., Van den Berg, J. and Conlong, D., 2014. Large-scale sugarcane farmers' knowledge and perceptions of Eldana saccharina Walker (Lepidoptera: Pyralidae), push–pull and integrated pest management. *Crop protection*, *56*, pp.1-9.
- Cuhra, M., 2015. Review of GMO safety assessment studies: glyphosate residues in Roundup Ready crops is an ignored issue. *Environmental Sciences Europe*, *27*(1), p.20.
- DAFF. 2014. Sugarcane Production Guidelines. Available from: https://www.daff.gov.za/Daffweb3/Portals/0/Brochures%20and%20Production%20guidelines/sugar%20cane (Accessed Date: 15 September 2018).
- DAFF. 2017. Trends in Agriculture. South Africa. Available from: www.daff.gov.za (Accessed Date: 2 August 2018).
- Demont, M., Cerovska, M., Daems, W., Dillen, K., Fogarasi, J., Mathijs, E., Muška, F., Soukup, J. and Tollens, E., 2008. *Ex ante* impact assessment under imperfect information: biotechnology in new member states of the EU. *Journal of Agricultural Economics*, *59*(3), pp.463-486.

- Department of Trade and Industry (DTI). 2013. DTI Annual report 2012-2013. Available from: https://www.gov.za/sites (Accessed date: 3 March 2018)
- Donnelly, L. 2017. SA's sugar industry under assault. Mail and Guardian. Available from: https://mg.co.za/article/2017-09-22-00-sas-sugar-industry-under-assault (Accessed date: 10 March 2018).
- Finger, R., El Benni, N., Kaphengst, T., Evans, C., Herbert, S., Lehmann, B., Morse, S. and Stupak, N., 2011. A meta-analysis on farm-level costs and benefits of GM crops. *Sustainability*, *3*(5), pp.743-762.
- Firth, C., 2002. The use of gross and net margins in the economic analysis of organic farms. In *Proceedings of the UK Organic Research 2002 Conference* (pp. 285-288). Organic Centre Wales, Institute of Rural Studies, University of Wales Aberystwyth.
- Flannery, M.L., Thorne, F.S., Kelly, P.W. and Mullins, E., 2004. An economic cost-benefit analysis of GM crop cultivation: An Irish case study.
- Gerwel, C.N., Hildbrand, S., Bodhanya, S.A. and Bezuidenhout, C.N., 2011. Systemic approaches to understand the complexities at the Umfolozi and Felixton mill areas. In *Proceedings of the Annual Congress-South African Sugar Technologists' Association* (No. 84, pp. 177-181). South African Sugar Technologists' Association.
- Gittinger, J.P.,1984. *Compounding and discounting tables for project analysis: with a guide to their applications*. World Bank Publications.
- Goga, A.M., 2013. *Factors Affecting the Demand for Labour in Large-scale Sugarcane Farming in Three Regions of KwaZulu-Natal, 1984-2008* (Masters dissertation, University of KwaZulu-Natal, Pietermaritzburg).
- Gouse, M., 2005. Aspects of biotechnology and genetically modified crops in South Africa. *Science, Technology and Globalization Project. Agricultural Biotechnology for Development–socioeconomic issues and institutional challenges. Belfer Center STPP. Kennedy School of Government*, *21*, p.2006.
- Gramlich, E.M. 1990. A Guide to Benefit-Cost Analysis. Second Edition, Waveland Press Inc. ISBN 0-88133-988-1 United States of America
- Griffith, G.R., Vere, D.T. and Bootle, B.W., 1995. An integrated approach to assessing the farm and market level impacts of new technology adoption in Australian lamb production and marketing systems: the case of large, lean lamb. *Agricultural systems*, *47*(2), pp.175-198.
- Hazell, P.B. and Norton, R.D. 1986. *Mathematical programming for economic analysis in agriculture*. Macmillan. New York

- Hazell, P.B., 1971. A linear alternative to quadratic and semi variance programming for farm planning under uncertainty. *American Journal of Agricultural Economics*, *53*(1), pp.53-62.
- Hildbrand, S., Bezuidenhout, C.N., Bodhanya, S., Hurly, K.M. and Grantham, E.J.O., 2014. Miller-Grower Fragmentation: A Core Challenge in The South African Sugarcane Production and Supply Systems. In *86th Annual Congress of the South African Sugar Technologists' Association (SASTA 2013), Durban, South Africa, 6-8 August 2013* (pp. 93-99). South African Sugar Technologists' Association.
- Igwe, K.C. and Onyenweaku, C.E., 2013. A Linear programming approach to food crops and livestock enterprises planning in Aba agricultural zone of Abia State, Nigeria. *American Journal of Experimental Agriculture*, *3*(2), p.412.
- Jaiprakash, B. 2016. Economic Surplus Model: A Tool for *Ex Ante* Impact Assessment. Division of Agricultural Economics, Indian Agricultural Research Institute https://www.slideshare.net/JAIPRAKASHBISEN/economic-surplus-model 2016
- James, C.2012. ISAAA Brief 44–2012 Global Status of Commercialized Biotech/GM Crops Google Scholar
- James, C. 2015. 20th Anniversary (1996to 2015) of the Global Commercialization of Biotech Crops and Biotech Crop Highlights in 2015. ISAAA Brief 51. ISAAA, Ithaca, NY, USA. http://www.isaaa.org.
- Kadwa, M. and Bezuidenhout, C.N., 2015. Modelling sugarcane supply consistency at a sugar mill. *Computers and Electronics in Agriculture*, *111*, pp.107-111.
- Keating, B.A., Robertson, M.J., Muchow, R.C. and Huth, N.I., 1999. Modelling sugarcane production systems I. Development and performance of the sugarcane module. *Field crops research*, *61*(3), pp.253-271.
- Khandker, S.R. Koolwal G.B. Samad, H.A. 2010**.** Handbook on Impact evaluation: Quantitative Methods and Practices. The World Bank, Washington, DC.
- Klümper, W. and Qaim, M., 2014. A meta-analysis of the impacts of genetically modified crops. *PloS one*, *9*(11), pp.111629.
- Landrey, O.P., Eichler, G.G. and Chedzey, J., 1993. Control of creeping grasses in small grower cane in the Umbumbulu district. *Proc S Afr Sugarcane Technol Ass*, *67*, pp.33-38.
- Love, H.C., 1956. An application of linear programming to farm and home planning.
- Mabaya, E., Fulton, J., Simiyu-Wafukho, S. and Nang'ayo, F., 2015. Factors influencing adoption of genetically modified crops in Africa. *Development Southern Africa*, *32*(5), pp.577-591.

- Majeke, F., Mubvuma, M.T., Makaza, K. and Mutambara, J., 2013. Optimum combination of crop farm activities: application of a linear programming model to a rural farmer in Zimbabwe. *Greener Journal of Economics and Accountancy*, *2*(2), pp.058-061.
- Maphalala, K.Z., 2013. *Field Assessment of Agronomic Traits and in Vitro Acetolactate Synthase Characterisation of Imazapyr Herbicide Tolerant Sugarcane* (Doctoral dissertation, University of KwaZulu-Natal, Durban).
- Marra, M.C., Pardey, P.G. and Alston, J.M., 2002. The payoffs to transgenic field crops: An assessment of the evidence. AgBioForum, 5(2), pp.43-50.
- Mazodze, R. and Conlong, D.E., 2003. Eldana saccharina (Lepidoptera: Pyralidae) in sugarcane (Saccharum hybrids), sedge (Cyperus digitatus) and bulrush (Typha latifolia) in south-eastern Zimbabwe. In *Proceedings of the South African Sugar Technologists' Association* (Vol. 77, pp. 256-274).
- Mboyisa, C. 2017. Influx of sugar imports pose threat to industry. Available from: www.sasugar.co.za (Accessed date: 25 March 2018). Publication for South African Sugar Association (SASA).
-
- Mdluli, F. 2013. Investigation of selected hygiene parameters of Umbumbulu small-scale farmers' organic produce (leafy salad vegetables) and subsequent identification of factors affecting farmer practices and food security (Masters dissertation in Food Security, University of KwaZulu-Natal**)**
- Mudombi, C.R., 2010. *An ex ante economic evaluation of genetically modified cassava in South Africa* (Doctoral dissertation, University of Pretoria).
- Nas, T. 1996. Cost-Benefit Analysis, Theory and Applications, Sage Publications
- Ndoro, F.M., Dzapatsva, P., Mafunga, W.P., Lagerwall, G. and Bezuidenhout, C.N., 2015. Application of the LOMZI model at six mills in the South African sugar industry. In *Proceedings of the Annual Congress-South African Sugar Technologists' Association* (No. 88, pp. 396-402). South African Sugar Technologists' Association.
- Nicholson, R.J., Ducasse, G., Rutherford, R.S. and Campbell, P.L., 2017. Cost-benefit analysis of a herbicide tolerant and insect resistant genetically modified sugarcane variety under coastal conditions. In *Proceedings of the Annual Congress-South African Sugar Technologists' Association* (No. 90, pp. 236-245). South African Sugar Technologists' Association.
- Nxumalo, B.N.G., 2015. *Growth and yield responses of commercial sugarcane cultivars to residue mulching in different environments* (Doctoral dissertation, University of Pretoria).

- Nuss KJ, Bond RS and Atkinson PR (1986). Susceptibility of sugarcane to the borer Eldana saccharina Walker and selection for resistance. Proc S Afr Sug Technol Ass 60: 153-155.
- OECD, 1993. OECD. Safety Evaluation of Foods Derived by Modern Biotechnology Concepts and Principles. Available from: http://ftp.fao.org/docrep/fao/006/y5316E/y5316E00.pdf (Accessed date: 21 May 2018)
- OECD Statistics Sources & Methods, 2002, Producer price Indices – Comparative Methodological Analysis *Supplement 2*. Methodological, O.M.E.I.C., 2002
- Ogryczak, W., 2000. Multiple criteria linear programming model for portfolio selection. *Annals of Operations Research*, *97*(1-4), pp.143-162.
- Önal, H., Chen, X., Khanna, M. and Huang, H., 2009. Mathematical Programming Modelling of Agricultural Supply Response (No. 319-2016-9864).
- Ortmann, G.F., 2005. Promoting the competitiveness of South African agriculture in a dynamic economic and political environment. *Agrekon*, *44*(3), pp.286-320.
- Palisade Corporation (1990). *@ Risk - Risk Analysis and Simulation Add-In for Microsoft Excel.* Newfield, New YorkParthasarathy, M. and Bhattacherjee, A., 1998. Understanding post-adoption behavior in the context of online services. *Information systems research*, *9*(4), pp.362-379.
- Pilusa, T.R., 2016. *A demand analysis of farm labour employment in the south coast and midlands commercial sugarcane farming by labour categories: implications of the sectoral determination* (Doctoral dissertation).
- Qaim, M. and Traxler, G., 2005. Roundup Ready soybeans in Argentina: farm level and aggregate welfare effects. *Agricultural economics*, *32*(1), pp.73-86.
- Qaim, M. and Zilberman, D., 2003. Yield effects of genetically modified crops in developing countries. *Science*, *299*(5608), pp.900-902.
- Ramburan, S. 2016. Information sheet: Variety N52. Available from:
- https://sasri.org.za/storage/Information_Sheets/IS_13.37-Variety-N52.pdf. South African Sugarcane Research Institute (SASRI), Durban, South Africa (Accessed date: 20 February 2017)
- Rendel, J.M., Mackay, A.D. and Smale, P., 2015. Valuing on-farm investments. *Journal of New Zealand Grasslands*, *77*, pp.83-88.
- Robinson, R., 1993. Cost-benefit analysis. *Bmj*, *307*(6909), pp.924-926.
- Robinson, S., 1997. Simulation model verification and validation: increasing the users' confidence. In *Winter Simulation Conference* (pp. 53-59).

- Rogers, A., Bear, C., Hunt, M., Mills, S. and Sandover, R., 2014. Intervention: The impact agenda and human geography in UK higher education.Creative Commons Licence: Attribution-Non-commercial-No Derivative Works.
- Romero, E.R., Scandaliaris, J., Digonzelli, P.A., Alonso, L.G., Leggio, F., Giardina, J.A., Casen, S.D., Tonatto, M.J. and Fernández de Ullivarri, J., 2009. Effect of variety and cane yield on sugarcane potential trash. *Rev. ind. y Agríc. de Tucumán*, *86*(1), pp.9-13.
- Rutherford, S. 2015. An Integrated Pest Management (IPM) approach for the control of the stalk borer *Eldana saccharina* Walker (*Lepidoptera: Pyralidae*). South African Sugarcane Research Institute Website: www.sugar.org.za/sasri ISBN: 1-874903-41-7
- Rutherford, R.S., Maphalala, K.Z., Koch, A.C., Snyman, S.J. and Watt, M.P., 2017. Field and laboratory assessments of sugarcane mutants selected in vitro for resistance to imazapyr herbicide. *Crop Breeding and Applied Biotechnology*, *17*(2), pp.107-114.
- Rutherford, S. 2018. Personal Communication. Senior Pathologist and leader of the Crop Protection Programme at the Crop Biology Resource Centre in SASRI. Tel: (031) 508 7400
- SACGA. 2013. Report of the board of directors of the South African Cane Growers Association 2012/13. [Internet]. SACGA, Mount Edgecombe, Durban, South Africa. Available from: http://www.sacanegrowers.co.za/wp-content/uploads/2011/02/CG-Annual-Report-2013e.pdf. (Accessed date: 1 March 2018).
- SACGA. 2017. Report of the board of directors of the South African Cane Growers Association 2016/17. SACGA, Mount Edgecombe, Durban, South Africa. Available from: http://www.sacanegrowers.co.za/ (Accessed date: 20 May 2018).
- SACGA. 2018. Report of the board of directors of the South African Cane Growers Association 2017/18. Available from: http://www.sacanegrowers.co.za/ (Accessed date: 18 March 2019).
- SASRI. 2006. Variety N12 Information Sheet. South African Sugar Research Institute, Mount Edgecombe, Durban, South Africa. http://www.sugar.org.za/sasri/variety/index.htm
- Sihlobo, W. and Kapuya, T., 2018. Why Land Expropriation without Compensation is a bad idea. Africa Portal Roundup Newsletter. Availablee from: https://www.africaportal.org/publications , Accessed date: 5 September 2018.
- Simbi, T. and Aliber, M., 2000. *Agricultural employment crisis in South Africa*. Trade and Industrial Policy Secretariat.
- Singels, A. and Donaldson, R.A., 2000. A simple model of unstressed sugarcane canopy development. *Proc. S. Afr. Sugar Technol. Assoc*, *74*, pp.151-154.

- Singels, A., McFarlane, S.A., Nicholson, R., Way, M. and Sithole, P., 2017. Review of South African sugarcane production in the 2016/2017 season: light at the end of the tunnel. In *Proceedings of the Annual Congress-South African Sugar Technologists' Association* (No. 90, pp. 1-19). South African Sugar Technologists' Association.
- Smithers, J., 2014. Review of sugarcane trash recovery systems for energy cogeneration in South Africa. *Renewable and Sustainable Energy Reviews*, *32*, pp.915-925.
- Snyman, S.J., 2018. Personal Communication. SASRI principal scientist and Variety Improvement manager. Email: sandy.snyman@sugar.org.za. SARI Mount Edgecombe, Durban, South Africa
- Snyman, S.J., Baker, C., Huckett, B.I., McFarlane, S.A., Van Antwerpen, T., Berry, S., Omarjee, J., Rutherford, R.S. and Watt, D.A., 2008. South African Sugarcane Research Institute: embracing biotechnology for crop improvement research. *Sugar Tech*, *10*(1), pp.1-13.
- South African Sugar Association (SASA). 2015. South African Sugar Industry Directory. Available from: https://www.sasugarindustrydirectory.co.za/static (Accessed date: 15 July 2018).
- Swanby, H., 2008. GMOs in South Africa. The African Centre for Biosafety. http://www.biosafetyafrica.net/ ISBN: 978-0-620-42898-9.
- Tena, E., Mekbib, F., Shimelis, H. and Mwadzingeni, L., 2016. Sugarcane production under smallholder farming systems: Farmers preferred traits, constraints and genetic resources. *Cogent Food & Agriculture*, *2*(1), p.1191323.
- Veselovska, L., 2014. Linear programming model of production process optimization: a case study. *The Business & Management Review*, *5*(1), p.211.
- Virgin, I., Bhagavan, M., Komen, J., Kullaya, A., Louwaars, N., Morris, E.J., Okori, P. and Persley, G., 2007. Agricultural biotechnology and small-scale farmers in eastern and southern Africa. *Stockholm Environment Institute, Stockholm*, *62*.
- Visagie, S.E., De Kock, H.C. and Ghebretsadik, A.H., 2004. Optimising an integrated crop-livestock farm using risk programming. *ORiON*, *20*(1), pp.29-54.
- Wander, A.E., Magalhaes, M.C., Vedovoto, G.L. and Martins, E.C., 2004. Using the economic surplus method to assess economic impacts of new technologies: case studies of Embrapa. In *Embrapa Caprinos e Ovinos-Artigo em anais de congresso (alice)*. in: conference on international agricultural research for development, 2004, Berlin. Book of abstracts... Berlin: International Research on Food Security, Natural Resource Management and Rural Development, 2004. 10 f. Available in: http://www.tropentag.de/2004/proceedings

- Way, M.J. and Goebel, F.R., 2003. Patterns of damage from Eldana saccharina (Lepidoptera: Pyralidae) in the South African sugar industry. In *Proc S Afr Sug Technol Ass* (Vol. 77, pp. 239-240).
- Way MJ., Conlong DE, Rutherford RS, Sweby DL, and Gillespie DY. 2017. Cacosceles (Zelogenes) newmannii (Thomson) (Cerambycidae: Prioninae), a new pest in the South African sugarcane industry.
- Zhou, M. Information Sheet: Variety N48. Available from: https://sasri.org.za/storage/2019/09/IS_13.33-Variety-N48.pdf. SASRI. Durban, South Africa (Accessed date: 15 March 2018)

  Zia, S.M., 1998. *Risk efficient resource allocation in agricultural systems of Pakistan: A farm level analysis*. Sustainable Development Policy Institute.

APPENDICES

Appendix 1: Eston central Representative farm matrix

Sugacane Production system 1

Objective	
Maximise Revenue	0
Decision variables	
MPN31	0
MPN52	0
MPN12	0
MPGM	0
FSN52	0
FSN31	0
FSGM	0
FCN48	0
FCN54	0
FCN50	0
FCGM	0
	0
GM ELDANA CHEMIC.	0
MPTimber	0
FSMac	0
FCMac	0
Mac constraint 1	0
WEEDING CONVENTI	0
WEEDING GM	0
ELDANA CONTROL M	0
ELDANA CHEMICAL C	0
CANE SALES (tons)	0
GM CANE chemical c	0
RV SALES (tons)	0
GM RV SALES	0
LABOUR HIRING	0
D1 (Rands)	0
D2 (Rands)	0
D3 (Rands)	0
D4 (Rands)	0
D5 (Rands)	0
D6 (Rands)	0
D7 (Rands)	0
0.5TAD	0
SD (Rands)	0
EGM	0

Constraints

Marginal Poor Soil (M	0	≤	12050
Flat land Sandy soil (F	0	≤	6000
Flat land Clay soil (FC	0	≤	4500
Labour (hours)	0	≤	2160
Eldana Chemical Cont	0	=	0
GM CHEMICAL CONT	0	=	0
a Physical control: scc	0	≤	1000
GM Constraint	0	≤	0
Mac Constraint 1	0	≤	0
Cane transfer (tons)	0	=	0
Timber Constraint	0	≤	0
Weeding Convention	0	=	0
Weeding GM	0	=	0
RV Transfer (tons)	0	=	0
N52 constraint	0	≤	0
N12 constraint	0	≤	0
N31 Constraint	0	≤	0
T1 (Rands)	R0,00	≥	0
T2(Rands)	R0,00	≥	0
T3(Rands)	R0,00	≥	0
T4(Rands)	R0,00	≥	0
T5(Rands)	R0,00	≥	0
T6(Rands)	R0,00	≥	0
T7(Rands)	R0,00	≥	0
Sum (Rands)	0	=	0
Conv (Rands)	0	=	0
EGM	R0,00	=	0
GM=0	0	=	0

	Cane Cultivar grown /ha											**Opporunity cost of land (R) /ha**		
	MPN12	MPN52	MPN31	MPGM	FSN52	FSN31	FSGM	FCN48	FCN54	FCN50	FCGM	MPTimber	FSMac	FCMac
Marginal Poor Soil (MP)	1	1	1	1								1		
Flat land Sandy soil (FS)					1	1	1						1	
Flat land Clay soil (FC)								1	1	1	1			1
Labour (hours)	370	370	370	350	370	370	350	370	370	370	350			
Eldana Chemical Control CC	2	2	2		2	2		2	2	2				
GM ELDANA CHEMICAL CONT				1			1				1			
Eldana Physical control: scouti	24	24	24	12	24	24	12	24	24	24	12			
Cane transfer (tons)	-40,49	-60,00	-47,50	-64,2	-54,655	-47,20	-64,2	-46,96	-84,00	-50,61	-71,33			
Weeding Conventional	61,2	61,2	61,2		61,2	61,2		61,2	61,2	61,2				
Weeding GM (Hours)				55			55				55			
RV Transfer (tons)	-4,96	-5,49	-5,93	-5,54	-5,95	-5,25	-5,94	-5,81	-5,12	-6,00	-5,54			
Mac constraint 1	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	0,85	0,85
GM Constraint	-0,33	-0,33	-0,33	0,67	-0,33	-0,33	0,67	-0,33	0,67	-0,33	0,67			
N52 Constraint	-0,33	0,67	-0,33	-0,33	0,67	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33			
Timber Constraint	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	0,9		
N12 Constraint	0,67	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33			
N31 Constraint	-0,33	-0,33	0,67	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33			
GM deviations													Julies low	Julies Average
T1 (Rands)	4249,49	5140,78	4453,68	5418,43	5140,78	4998,05	5418,431963	-6116,13	12540,97	688,20	7335,29	-630,76	-6352,74	-4308,07
T2(Rands)	4719,03	-2681,73	6548,87	-2949,08	-2681,73	6469,93	-2949,081524	2991,51	13294,27	10014,37	-4613,16	-415,73	-1348,21	386,82
T3(Rands)	413,99	-1653,18	2610,53	-1726,66	-1653,18	417,26	-1726,6552	5549,13	7588,01	2544,47	-2643,94	-341,17	-251,03	412,84
T4(Rands)	-4991,87	-6092,03	-9913,19	-6426,64	-6092,03	-5570,61	-6426,636831	-3740,53	-11969,54	-9519,49	-9267,13	76,42	900,60	921,43
T5(Rands)	-3248,69	164,77	-7424,53	399,93	164,77	-4997,02	399,9279884	-1836,29	-15703,56	-2658,09	684,31	29,95	399,34	-1743,62
T6(Rands)	674,78	2686,21	2679,21	3376,90	2686,21	2,18	3376,89534	4958,31	1950,52	2481,23	5123,91	494,89	2735,89	1621,78
T7(Rands)	-1816,73	2435,18	1045,44	1907,12	2435,18	-1319,80	1907,118263	-1805,99	-7700,66	-3550,68	3380,73	786,40	3916,16	2708,83
Sum (Rands)														
Conv (Rands)														
E[GM] Acc Constraint	-13117,05	-12132,05	-10492,67	-11681,14	-12132,05	-13642,17	-11681	-13914,77	-20381,55	-12132,05	-14023,59	3427,59	19060,74	R 36 425,80
OBJ: L= E[GM]-θσ														

	Weeding conventional (manday/ha)	Weeding in GM cane (manday/ha)	**Eldana control** scouting (hours/ha)	Chemical control (R/ha)	GM Chemical control	**Cane Sales (tons)** cane (tons)	Gm Cane(tons)	**Cane RV Sales (tons)** Conventional cane	Labour hire (days)	E[GM] (Rands)	D1 (Rands)	D2 (Rands)	D3 (Rands)	D4 (Rands)	D5 (Rands)	D6 (Rands)	D7 (Rands)	0.5TAD	SD (Rands)		RHS
Marginal Poor Soil (MP)																				≤	12050
Flat land Sandy soil (FS)																				≤	6000
Flat land Clay soil (FC)																				≤	4500
Labour (hours)									-1											≤	2040
Eldana Chemical Control CC				-1																=	0
GM ELDANA CHEMICAL CONT					-1															=	0
Eldana Physical control: scouti			-1																	≤	1000
Cane transfer (tons)						1														=	0
Weeding Conventional	-1																			=	0
Weeding GM (Hours)		1						-1												=	0
RV Transfer (tons)																				=	0
Mac constraint 1																				≤	0
GM Constraint																				≤	0
N52 Constraint																					
Timber Constraint																				≤	0
N12 Constraint																					
N31 Constraint																					0
																					0
GM deviations																					0
T1 (Rands)											1									≥	0
T2(Rands)												1								≥	0
T3(Rands)													1							≥	0
T4(Rands)														1						≥	0
T5(Rands)															1					≥	0
T6(Rands)																1				≥	0
T7(Rands)																	1			≥	0
Sum (Rands)								4502,98			-1	-1	-1	-1	-1	-1	-1	1		=	0
Conv (Rands)																		-0,39	1	=	0
E[GM] Acc Constraint	52,18	33,65	-211,25	-1970	-985			4502,98	-18	-1											Max!
OBJ: L= E[GM]-θσ										1									-1,64		

6025 0,267184

22550

Information	
F=(2Δ^0,5)/T	
Δ=ΠT/2(T-1)	
Δ	1,83
F	0,39

Risk preference	θ
Risk neutral	0
	0,25
	0,5
75% confidence of achieving E[GM]	0,674
80% confidence of achieving E[GM]	0,842
85% confidence of achieving E[GM]	1,036
90% confidence of achieving E[GM]	1,282
95% confidence of achieving E[GM]	1,645
99% confidence of achieving E[GM]	2,326

Appendix 2: An LP output for the Eston central representative farm under the "without" GM cane scenario

Microsoft Excel 16.0 Answer Report

Worksheet: [Correct Eston Matrices.xlsx]Eston Central Matrix

Report Created: 2019/08/08 12:51:36 PM

Result: Solver found a solution. All Constraints and optimality conditions are satisfied.

Solver Engine

Engine: Simplex LP

Solution Time: 0,609 Seconds.

Iterations: 50 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	Maximise Revenue	0	R65 736 618,58

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$12	MPN31	0	5692,7475	Contin
$B$13	MPN52	0	0	Contin
$B$14	MPN12	0	4440,5025	Contin
$B$15	MPGM	0	0	Contin
$B$16	FSN52	0	5692,7475	Contin
$B$17	FSN31	0	307,2525	Contin
$B$18	FSGM	0	0	Contin
$B$19	FCN48	0	1117,5	Contin
$B$20	FCN54	0	0	Contin
$B$21	FCN50	0	0	Contin
$B$22	FCGM	0	0	Contin
$B$23		0	0	Contin
$B$24	GM ELDANA CHEMICAL CONT	0	0	Contin
$B$25	MPTimber	0	1916,75	Contin
$B$26	FSMac	0	0	Contin
$B$27	FCMac	0	3382,5	Contin
$B$28	Mac constraint 1	0	0	Contin
$B$29	WEEDING CONVENTIONAL	0	1071823	Contin
$B$30	WEEDING GM	0	0	Contin
$B$31	ELDANA CONTROL MANUAL	0	413018	Contin
$B$32	ELDANA CHEMICAL CONTROL	0	34501,5	Contin
$B$33	CANE SALES (tons)	0	828298,2862	Contin
$B$34	GM CANE chemical control)	0	0	Contin
$B$35	RV SALES (tons)	0	97813,65505	Contin
$B$36	GM RV SALES	0	0	Contin
$B$37	LABOUR HIRING	0	6380617,5	Contin
$B$38	D1 (Rands)	0	0	Contin
$B$39	D2 (Rands)	0	0	Contin
$B$40	D3 (Rands)	0	0	Contin
$B$41	D4 (Rands)	0	115908528,8	Contin
$B$42	D5 (Rands)	0	65181588,02	Contin
$B$43	D6 (Rands)	0	0	Contin
$B$44	D7 (Rands)	0	0	Contin
$B$45	0.5TAD	0	181090116,9	Contin
$B$46	SD (Rands)	0	70056336,38	Contin
$B$47	EGM	0	180629010,2	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$50	Marginal Poor Soil (MP)	12050	$B$50<=$D$50	Binding	0
$B$51	Flat land Sandy soil (FS)	6000	$B$51<=$D$51	Binding	0
$B$52	Flat land Clay soil (FC)	4500	$B$52<=$D$52	Binding	0
$B$54	Labour (hours)	2160	$B$54<=$D$54	Binding	0
$B$55	Eldana Chemical Control	3,83807E-10	$B$55=$D$55	Binding	0
$B$56	GM CHEMICAL CONT	0	$B$56=$D$56	Binding	0
$B$57	Eldana Physical control: scouting	1000	$B$57<=$D$57	Binding	0
$B$58	GM Constraint	-5692,7475	$B$58<=$D$58	Not Binding	5692,7475
$B$59	Mac Constraint 1	9,51388E-10	$B$59<=$D$59	Binding	0
$B$60	Cane transfer (tons)	-1,05356E-08	$B$60=$D$60	Binding	0
$B$61	Timber Constraint	2,37264E-10	$B$61<=$D$61	Binding	0
$B$62	Weeding Conventional	-1055745,9	$B$62<=$D$62	Not Binding	1055955,59
$B$63	Weeding GM	0	$B$63<=$D$63	Not Binding	209,69
$B$64	RV Transfer (tons)	-1,14233E-09	$B$64=$D$64	Binding	0
$B$65	N52 constraint	-9,09495E-11	$B$65<=$D$65	Binding	0
$B$66	N12 constraint	-1252,245	$B$66<=$D$66	Not Binding	1252,245
$B$67	N31 Constraint	6,9349E-12	$B$67<=$D$67	Binding	0
$B$69	T1 (Rands)	R52 408 534,66	$B$69>=$D$69	Not Binding	R52 408 534,66
$B$70	T2(Rands)	R48 812 020,91	$B$70>=$D$70	Not Binding	R48 812 020,91
$B$71	T3(Rands)	R14 360 128,49	$B$71>=$D$71	Not Binding	R14 360 128,49
$B$72	T4(Rands)	R0,00	$B$72>=$D$72	Binding	R0,00
$B$73	T5(Rands)	R0,00	$B$73>=$D$73	Binding	R0,00
$B$74	T6(Rands)	R45 516 120,88	$B$74>=$D$74	Not Binding	R45 516 120,88
$B$75	T7(Rands)	R19 993 311,92	$B$75>=$D$75	Not Binding	R19 993 311,92
$B$76	Sum (Rands)	0	$B$76=$D$76	Binding	0
$B$77	Conv (Rands)	0	$B$77=$D$77	Binding	0
$B$78	EGM	R0,00	$B$78=$D$78	Binding	0
$B$79	GM=0	0	$B$79=$D$79	Binding	0

Appendix 3: An LP output for the Eston central representative farm under the “with” GM cane scenario

Microsoft Excel 16.0 Answer Report

Worksheet: [Correct Eston Matrices.xlsx]Eston Central Matrix

Report Created: 2019/08/08 12:48:35 PM

Result: Solver found a solution. All Constraints and optimality conditions are satisfied.

Solver Engine

Engine: Simplex LP

Solution Time: 0,531 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$7	Maximise Revenue	0	R115 308 872,90

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$12	MPN31	0	4747,755	Contin
$B$13	MPN52	0	0	Contin
$B$14	MPN12	0	0	Contin
$B$15	MPGM	0	5385,495	Contin
$B$16	FSN52	0	5692,7475	Contin
$B$17	FSN31	0	0	Contin
$B$18	FSGM	0	307,2525	Contin
$B$19	FCN48	0	1117,5	Contin
$B$20	FCN54	0	0	Contin
$B$21	FCN50	0	0	Contin
$B$22	FCGM	0	0	Contin
$B$23		0	0	Contin
$B$24	GM ELDANA CHEMICAL CONT	0	0	Contin
$B$25	MPTimber	0	1916,75	Contin
$B$26	FSMac	0	0	Contin
$B$27	FCMac	0	3382,5	Contin
$B$28	Mac constraint 1	0	0	Contin
$B$29	WEEDING CONVENTIONAL	0	686902	Contin
$B$30	WEEDING GM	0	353701,59	Contin
$B$31	ELDANA CONTROL MANUAL	0	344705,03	Contin
$B$32	ELDANA CHEMICAL CONTROL	0	23116,005	Contin
$B$33	CANE SALES (tons)	0	954609,4703	Contin
$B$34	GM CANE chemical control)	0	5692,7475	Contin
$B$35	RV SALES (tons)	0	100243,4878	Contin
$B$36	GM RV SALES	0	0	Contin
$B$37	LABOUR HIRING	0	6266762,55	Contin
$B$38	D1 (Rands)	0	0	Contin
$B$39	D2 (Rands)	0	0	Contin
$B$40	D3 (Rands)	0	0	Contin
$B$41	D4 (Rands)	0	119247849,9	Contin
$B$42	D5 (Rands)	0	39927612,52	Contin
$B$43	D6 (Rands)	0	0	Contin
$B$44	D7 (Rands)	0	0	Contin
$B$45	0.5TAD	0	159175462,4	Contin
$B$46	SD (Rands)	0	61578455,7	Contin
$B$47	EGM	0	216297540,2	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$50	Marginal Poor Soil (MP)	12050	$B$50<=$D$50	Binding	0
$B$51	Flat land Sandy soil (FS)	6000	$B$51<=$D$51	Binding	0
$B$52	Flat land Clay soil (FC)	4500	$B$52<=$D$52	Binding	0
$B$54	Labour (hours)	2160	$B$54<=$D$54	Binding	0
$B$55	Eldana Chemical Control	3,71074E-10	$B$55=$D$55	Binding	0
$B$56	GM CHEMICAL CONT	0	$B$56=$D$56	Binding	0
$B$57	Eldana Physical control: scouting	1000	$B$57<=$D$57	Binding	0
$B$58	GM Constraint	-1,32786E-10	$B$58<=$D$58	Binding	0
$B$59	Mac Constraint 1	1,42063E-09	$B$59<=$D$59	Binding	0
$B$60	Cane transfer (tons)	-1,12341E-08	$B$60=$D$60	Binding	0
$B$61	Timber Constraint	9,12905E-11	$B$61<=$D$61	Binding	0
$B$62	Weeding Conventional	-707349,753	$B$62<=$D$62	Not Binding	707559,443
$B$63	Weeding GM	-313101,1125	$B$63<=$D$63	Not Binding	313310,8025
$B$64	RV Transfer (tons)	-1,226E-09	$B$64=$D$64	Binding	0
$B$65	N52 constraint	-5,82077E-11	$B$65<=$D$65	Binding	0
$B$66	N12 constraint	-5692,7475	$B$66<=$D$66	Not Binding	5692,7475
$B$67	N31 Constraint	-944,9925	$B$67<=$D$67	Not Binding	944,9925
$B$69	T1 (Rands)	R58 640 053,05	$B$69>=$D$69	Not Binding	R58 640 053,05
$B$70	T2(Rands)	R2 892 238,80	$B$70>=$D$70	Not Binding	R2 892 238,80
$B$71	T3(Rands)	R97 248,07	$B$71>=$D$71	Not Binding	R97 248,07
$B$72	T4(Rands)	R0,00	$B$72>=$D$72	Binding	R0,00
$B$73	T5(Rands)	R0,00	$B$73>=$D$73	Binding	R0,00
$B$74	T6(Rands)	R59 211 086,57	$B$74>=$D$74	Not Binding	R59 211 086,57
$B$75	T7(Rands)	R38 334 835,91	$B$75>=$D$75	Not Binding	R38 334 835,91
$B$76	Sum (Rands)	3,8743E-07	$B$76=$D$76	Binding	0
$B$77	Conv (Rands)	-1,86265E-07	$B$77=$D$77	Binding	0
$B$78	EGM	R0,00	$B$78=$D$78	Binding	0

Appendix 4: Mid-Illovo Representative farm matrix

Sugarcane Production system 1

Objective

Maximise Revenue	0

Decision variables

MPN12	0
MPN31	0
MPGM	0
FSN12	0
FSN52	0
FSN54	0
FSGM	0
FCN12	0
FCN48	0
FCN54	0
FCGM	0
SRN50	0
SRGM	0
MPTimber	0
FSMac	0
FCMac	0
Mac constraint 1	0
WEEDING CONVENTIONAL	0
WEEDING GM	0
ELDANA CONTROL MANUAL	0
ELDANA CHEMICAL CONTROL	0
CANE SALES (tons)	0
GM CANE SALES (tons)	0
RV SALES (tons)	0
GM RV SALES	0
LABOUR HIRING	0
D1 (Rands)	0
D2 (Rands)	0
D3 (Rands)	0
D4 (Rands)	0
D5 (Rands)	0
D6 (Rands)	0
D7 (Rands)	0
0.5TAD	0
SD (Rands)	0
EGM	0
GM chemical control	0

Constraints

Marginal Poor Soil (MP)	0	≤	800
Flat land Sandy soil (FS)	0	≤	1000
Flat land Clay soil (FC)	0	≤	8000
Slopey Red soil (SR)	0	≤	3000
Labour (hours)	0	≤	2160
Eldana Chemical Control	0	=	0
Eldana Physical control: scouting	0	≤	1000
GM Constraint	0	≤	0
Mac Constraint 1	0	≤	0
Cane transfer (tons)	0	=	0
Timber Constraint	0	≤	0
Weeding Conventional	0	≤	209,7
Weeding GM	0	≤	209,7
RV Transfer (tons)	0	=	0
Eldana GM Chemicals	0	=	0
N12 Constraint	R0,00	≤	0
T1 (Rands)	R0,00	≥	0
T2(Rands)	R0,00	≥	0
T3(Rands)	R0,00	≥	0
T4(Rands)	R0,00	≥	0
T5(Rands)	R0,00	≥	0
T6(Rands)	R0,00	≥	0
T7(Rands)	R0,00	≥	0
Sum (Rands)	0	=	0
Conv (Rands)	R -	=	0
EGM	R -	=	0
GM=0	0	=	0

	Cane Cultivar grown/ha													Opporunity cost of land/ha		
	MPN12	MPN31	MPGM Cane	FSN12	FSN52	FSN54	FSGM	FCN12	FCN48	FCN54	FCGM	SRN50	SRGM	MPTimber	FSMac	FCMac
Marginal Poor Soil (MP)	1	1	1											1		
Flat land Sandy soil (FS)				1	1	1	1								1	
Flat land Clay soil (FC)								1	1	1	1					1
Slopey Red soil (SR)												1	1			
Labour (hours)	370	370	350	370	370	370	350	370	370	370	350	370	350			
Eldana Chemical Control (sprays)	2	2		2	2	2		2	2	2		2				
Eldana GM Chemicals			1				1				1		1			
Eldana Physical control: scouting	24	24	12	24	24	24	12	24	24	24	12	24	12			
Cane transfer (tons)	-63,31	-45,00	-59,14	-63,31	-64,00	-86,43	-68,48	-71,918	-70,88	-86,43	-79,02	-67,50	-68,48			
Weeding Conventional (Hours)	61,2	61,2		61,2	61,2	61,2		61,2	61,2	61,2		61,2				
Weeding GM (Hours)			55				55				55		55			
RV Transfer (tons)	-6,46	-5,86	-6,43	-6,46	-6,43	-6,36	-6,50	-6,46	-6,54	-6,36	-6,50	-6,08	-6,50			
Mac constraint 1	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	0,85	0,85
GM Constraint	-0,33	-0,33	0,67	-0,33	-0,33	-0,33	0,67	-0,33	-0,33	-0,33	0,67	-0,33	0,67	-0,33	-0,33	-0,33
Timber constraint	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	0,9	-0,1	-0,1
N12 Constraint	0,67	-0,33	-0,33	0,67	-0,33	-0,33	-0,33	0,67	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33
GM deviations																
															Julies low	Julies Average
T1 (Rands)	4505,53	2017,37	2288,64	5017,08	2627,06	-2036,74	2315,69	5531,52	3775,54	-2036,74	2932,53	4839,01	2315,69	-630,76	-6352,74	-4308,07
T2(Rands)	-795,88	5414,14	4006,93	-998,63	4323,31	-5154,79	4413,91	-1251,6	8325,46	-5154,79	6190,09	-798,47	4413,91	-415,73	-1348,21	386,82
T3(Rands)	879,31	1603,37	-2580,21	984,00	-2953,86	-7879,51	-3147,25	1075,53	-3029,77	-7879,51	-4989,94	-3044,22	-3147,25	-341,17	-251,03	412,84
T4(Rands)	-4021,29	-8831,03	-1209,38	-4744,59	-1735,57	-7163,23	-1558,59	-5374,8	-6596,87	-7163,23	-2614,42	7456,12	-1558,59	76,42	900,60	921,43
T5(Rands)	-2511,30	-8624,02	-6625,68	-2720,55	-7718,47	7817,48	-7728,22	-3032,2	-5017,04	7817,48	########	########	-7728,22	29,95	399,34	-1743,62
T6(Rands)	2448,71	13186,72	3709,96	2913,36	3288,74	5177,51	4514,02	3417,09	-283,43	5177,51	6855,21	-6744,88	4514,02	494,89	2735,89	1621,78
T7(Rands)	-505,08	-4766,54	409,75	-450,68	2168,80	9239,28	1190,44	-365,6	2826,11	9239,28	3313,37	11886,01	1190,44	786,40	3916,16	2708,83
Sum (Rands)																
Conv (Rands)																
E[GM] Acc Constraint	########	########	-13100,16	########	########	-20716	-13100,16	-15468	########	########	########	########	########	3427,59	19060,74	R 36 425,80
OBJ: L= E[GM]-θσ																

	Weeding conventional (R/ha/Hr)	Weeding in GM cane (R/ha/Hr)	Eldana control			cane (tons)	**Cane RV Sales (R/ton)**	Labour hire (hours)	E[GM] (Rands)	D1 (Rands)	D2 (Rands)	D3 (Rands)	D4 (Rands)	D5 (Rands)	D6 (Rands)	D7 (Rands)	0.5TAD	SD (Rands)		RHS	
			scouting (hours/ha)	Chemical control (R/ha)	GM Chemical control (R/Ha)																
Marginal Poor Soil (MP)																			≤	800	6%
Flat land Sandy soil (FS)																			≤	1000	8%
Flat land Clay soil (FC)																			≤	8000	63%
Slopey Red soil (SR)																			≤	3000	23%
Labour (hours)								-1											≤	2040	
Eldana Chemical Control (sprays)				-1															=	0	
Eldana GM Chemicals					-1														=	0	
Eldana Physical control: scouting			-1																≤	1000	
Cane transfer (tons)						1													=	0	
Weeding Conventional (Hours)	-1																		=	0	
Weeding GM (Hours)		-1																	=	0	
RV Transfer (tons)							1												=	0	
Mac constraint 1																			≤	0	
GM Constraint																			≤	0	
Timber constraint																					
N12 Constraint																			≥	0	
																			≥	0	
GM deviations																			≥	0	
																			≥	0	
T1 (Rands)										1									≥	0	
T2(Rands)											1								≥	0	
T3(Rands)												1							≥	0	
T4(Rands)													1						≥	0	
T5(Rands)														1					≥	0	
T6(Rands)							4502,97515								1				≥	0	
T7(Rands)																1			≥	0	
Sum (Rands)										-1	-1	-1	-1	-1	-1	-1	1		=	0	
Conv (Rands)																	-0,39	1	=	0	
E[GM] Acc Constraint	52,18	33,65	-211,25	-1970	-985		4502,98	-18	-1											Max!	
OBJ: L= E[GM]-θσ									1									-1,645			

#####

Information	
F=(2Δ^0,5)/T	
Δ=ΠT/2(T-1)	
Δ	###
F	###

Risk preference	θ
Risk neutral	0
	0,25
	0,5
75% confidence of achieving E[GM]	0,67
80% confidence of achieving E[GM]	0,84
85% confidence of achieving E[GM]	1,04
90% confidence of achieving E[GM]	1,28
95% confidence of achieving E[GM]	1,65
99% confidence of achieving E[GM]	2,33

Appendix 5: An LP output for the Mid-Illovo representative farm under the “without” GM cane scenario

Microsoft Excel 16.0 Answer Report

Worksheet: [Correct Eston Matrices.xlsx]Mid-Illovo Matrix

Report Created: 2019/08/16 1:38:02 PM

Result: Solver found a solution. All Constraints and optimality conditions are satisfied.

Solver Engine

Engine: Simplex LP

Solution Time: 0,484 Seconds.

Iterations: 52 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	Maximise Revenue	0	R32 163 587,65

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$12	MPN12	0	0	Contin
$B$13	MPN31	0	0	Contin
$B$14	MPGM	0	0	Contin
$B$15	FSN12	0	0	Contin
$B$16	FSN52	0	1000	Contin
$B$17	FSN54	0	0	Contin
$B$18	FSGM	0	0	Contin
$B$19	FCN12	0	3326,4	Contin
$B$20	FCN48	0	2231,705938	Contin
$B$21	FCN54	0	521,8940616	Contin
$B$22	FCGM	0	0	Contin
$B$23	SRN50	0	3000	Contin
$B$24	SRGM	0	0	Contin
$B$25	MPTimber	0	800	Contin
$B$26	FSMac	0	0	Contin
$B$27	FCMac	0	1920	Contin
$B$28	Mac constraint 1	0	0	Contin
$B$29	WEEDING CONVENTIONAL	0	665856	Contin
$B$30	WEEDING GM	0	0	Contin
$B$31	ELDANA CONTROL MANUAL	0	240920	Contin
$B$32	ELDANA CHEMICAL CONTROL	0	20160	Contin
$B$33	CANE SALES (tons)	0	709029,7767	Contin
$B$34	GM CANE SALES (tons)	0	0	Contin
$B$35	RV SALES (tons)	0	64073,77118	Contin
$B$36	GM RV SALES	0	0	Contin
$B$37	LABOUR HIRING	0	3727440	Contin
$B$38	D1 (Rands)	0	0	Contin
$B$39	D2 (Rands)	0	0	Contin
$B$40	D3 (Rands)	0	18863004,35	Contin
$B$41	D4 (Rands)	0	13876380,17	Contin
$B$42	D5 (Rands)	0	69025784,17	Contin
$B$43	D6 (Rands)	0	0	Contin
$B$44	D7 (Rands)	0	0	Contin
$B$45	0.5TAD	0	101765168,7	Contin
$B$46	SD (Rands)	0	39368768,51	Contin
$B$47	EGM	0	96925211,85	Contin
$B$48	GM chemical control	0	0	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$52	Marginal Poor Soil (MP)	800	$B$52<=$D$52	Binding	0
$B$53	Flat land Sandy soil (FS)	1000	$B$53<=$D$53	Binding	0
$B$54	Flat land Clay soil (FC)	8000	$B$54<=$D$54	Binding	0
$B$55	Slopey Red soil (SR)	3000	$B$55<=$D$55	Binding	0
$B$57	Labour (hours)	2160	$B$57<=$D$57	Binding	0
$B$58	Eldana Chemical Control	4,72937E-11	$B$58=$D$58	Binding	0
$B$59	Eldana Physical control: scouting	1000	$B$59<=$D$59	Binding	0
$B$60	GM Constraint	-3326,4	$B$60<=$D$60	Not Binding	3326,4
$B$61	Mac Constraint 1	-3,22302E-11	$B$61<=$D$61	Binding	0
$B$62	Cane transfer (tons)	0	$B$62=$D$62	Binding	0
$B$63	Timber Constraint	-288	$B$63<=$D$63	Not Binding	288
$B$64	Weeding Conventional	-616896	$B$64<=$D$64	Not Binding	617105,69
$B$65	Weeding GM	0	$B$65<=$D$65	Not Binding	209,69
$B$66	RV Transfer (tons)	-1,09139E-10	$B$66=$D$66	Binding	0
$B$67	Eldana GM Chemicals	0	$B$67=$D$67	Binding	0
$B$68	N12 Constraint	R0,00	$B$68<=$D$68	Binding	0
$B$71	T1 (Rands)	R34 130 975,00	$B$71>=$D$71	Not Binding	R34 130 975,00
$B$72	T2(Rands)	R14 064 423,93	$B$72>=$D$72	Not Binding	R14 064 423,93
$B$73	T3(Rands)	R0,00	$B$73>=$D$73	Binding	R0,00
$B$74	T4(Rands)	R0,00	$B$74>=$D$74	Binding	R0,00
$B$75	T5(Rands)	R0,00	$B$75>=$D$75	Binding	R0,00
$B$76	T6(Rands)	R0,00	$B$76>=$D$76	Binding	R0,00
$B$77	T7(Rands)	R53 569 769,77	$B$77>=$D$77	Not Binding	R53 569 769,77
$B$78	Sum (Rands)	1,93715E-07	$B$78=$D$78	Binding	0
$B$79	Conv (Rands)	R -	$B$79=$D$79	Binding	0
$B$80	EGM	R -	$B$80=$D$80	Binding	0
$B$82	GM=0	0	$B$82=$D$82	Binding	0

Appendix 6: An LP output for the Mid-Illovo representative farm under the “with” GM cane scenario

Microsoft Excel 16.0 Answer Report

Worksheet: [Correct Eston Matrices.xlsx]Mid-Illovo Matrix

Report Created: 2019/08/16 1:31:08 PM

Result: Solver found a solution. All Constraints and optimality conditions are satisfied.

Solver Engine

Engine: Simplex LP

Solution Time: 0,531 Seconds.

Iterations: 50 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	Maximise Revenue	0	R50 206 887,81

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$12	MPN12	0	0	Contin
$B$13	MPN31	0	0	Contin
$B$14	MPGM	0	0	Contin
$B$15	FSN12	0	0	Contin
$B$16	FSN52	0	0	Contin
$B$17	FSN54	0	0	Contin
$B$18	FSGM	0	1000	Contin
$B$19	FCN12	0	3326,4	Contin
$B$20	FCN48	0	2753,6	Contin
$B$21	FCN54	0	0	Contin
$B$22	FCGM	0	0	Contin
$B$23	SRN50	0	673,6	Contin
$B$24	SRGM	0	2326,4	Contin
$B$25	MPTimber	0	800	Contin
$B$26	FSMac	0	0	Contin
$B$27	FCMac	0	1920	Contin
$B$28	Mac constraint 1	0	0	Contin
$B$29	WEEDING CONVENTIONAL	0	446123,52	Contin
$B$30	WEEDING GM	0	197472	Contin
$B$31	ELDANA CONTROL MANUAL	0	201003,2	Contin
$B$32	ELDANA CHEMICAL CONTROL	0	13507,2	Contin
$B$33	CANE SALES (tons)	0	707675,4127	Contin
$B$34	GM CANE SALES (tons)	0	0	Contin
$B$35	RV SALES (tons)	0	65209,42756	Contin
$B$36	GM RV SALES	0	0	Contin
$B$37	LABOUR HIRING	0	3660912	Contin
$B$38	D1 (Rands)	0	0	Contin
$B$39	D2 (Rands)	0	0	Contin
$B$40	D3 (Rands)	0	16765022,4	Contin
$B$41	D4 (Rands)	0	34375620,81	Contin
$B$42	D5 (Rands)	0	62088666,13	Contin
$B$43	D6 (Rands)	0	0	Contin
$B$44	D7 (Rands)	0	0	Contin
$B$45	0.5TAD	0	113229309,3	Contin
$B$46	SD (Rands)	0	43803774,17	Contin
$B$47	EGM	0	122264096,3	Contin
$B$48	GM chemical control	0	3326,4	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$52	Marginal Poor Soil (MP)	800	$B$52<=$D$52	Binding	0
$B$53	Flat land Sandy soil (FS)	1000	$B$53<=$D$53	Binding	0
$B$54	Flat land Clay soil (FC)	8000	$B$54<=$D$54	Binding	0
$B$55	Slopey Red soil (SR)	3000	$B$55<=$D$55	Binding	0
$B$57	Labour (hours)	2160	$B$57<=$D$57	Binding	0
$B$58	Eldana Chemical Control	1,45519E-11	$B$58=$D$58	Binding	0
$B$59	Eldana Physical control: scouting	1000	$B$59<=$D$59	Binding	0
$B$60	GM Constraint	0	$B$60<=$D$60	Binding	0
$B$61	Mac Constraint 1	-2,54516E-11	$B$61<=$D$61	Binding	0
$B$62	Cane transfer (tons)	0	$B$62=$D$62	Binding	0
$B$63	Timber Constraint	-288	$B$63<=$D$63	Not Binding	288
$B$64	Weeding Conventional	-413320,32	$B$64<=$D$64	Not Binding	413530,01
$B$65	Weeding GM	-182952	$B$65<=$D$65	Not Binding	183161,69
$B$66	RV Transfer (tons)	-1,30967E-10	$B$66=$D$66	Binding	0
$B$67	Eldana GM Chemicals	-6,82121E-12	$B$67=$D$67	Binding	0
$B$68	N12 Constraint	R0,00	$B$68<=$D$68	Binding	0
$B$71	T1 (Rands)	R30 982 736,94	$B$71>=$D$71	Not Binding	R30 982 736,94
$B$72	T2(Rands)	R33 316 356,68	$B$72>=$D$72	Not Binding	R33 316 356,68
$B$73	T3(Rands)	R0,00	$B$73>=$D$73	Binding	R0,00
$B$74	T4(Rands)	R0,00	$B$74>=$D$74	Binding	R0,00
$B$75	T5(Rands)	R0,00	$B$75>=$D$75	Binding	R0,00
$B$76	T6(Rands)	R24 567 978,53	$B$76>=$D$76	Not Binding	R24 567 978,53
$B$77	T7(Rands)	R24 362 237,20	$B$77>=$D$77	Not Binding	R24 362 237,20
$B$78	Sum (Rands)	0	$B$78=$D$78	Binding	0
$B$79	Conv (Rands)	R -	$B$79=$D$79	Binding	0
$B$80	EGM	R -	$B$80=$D$80	Binding	0

Appendix 7: Richmond representative farm matrix

Sugacane Production system 1

Appendix 3: Richmond Representative farm matrix

Objective	
Maximise Revenue	0
Decision variables	
MPN12	0
MPN31	0
MPGM	0
FSN52	0
FSN54	0
FSGM	0
FCN37	0
FCN35	0
FCN48	0
FCN54	0
FCN50	0
FCGM	0
SRN50	0
SRN37	0
SRN48	0
SRGM	0
	0
	0
	0
MPTimber	0
FSMac	0
FCMac	0
Mac constraint 1	0
WEEDING CONVENTIONAL	0
WEEDING GM	0
ELDANA CONTROL MANUAL	0
ELDANA CHEMICAL CONTROL	0
CANE SALES (tons)	0
GM CANE Chemical control	0
RV SALES (tons)	0
GM RV SALES	0
LABOUR HIRING	0
D1 (Rands)	0
D2 (Rands)	0
D3 (Rands)	0
D4 (Rands)	0
D5 (Rands)	0
D6 (Rands)	0
D7 (Rands)	0
0.5TAD	0
SD (Rands)	0
EGM	0

	Cane Cultivar grown/ha															
	MPN12	MPN31	MPGM	FSN52	FSN54	FSGM	FCN37	FCN35	FCN48	FCN54	FCN50	FCGM	SRN50	SRN37	SRN48	SRGM
Marginal Poor Soil (MP)	1	1	1													
Flat land Sandy soil (FS)				1	1	1										
Flat land Clay soil (FC)							1	1	1	1	1	1				
Slopey Red soil (SR)													1	1	1	1
Labour (hours)	370	370	350	370	370	350	370	370	370	370	370	350	370	370	370	350
Eldana Chemical Control CONV	2	2		2	2		2	2	2	2	2		2	2	2	
GM Chemical cont			1			1						1				1
Eldana Physical control: scouting	24	24	12	24	24	12	24	24	24	24	24	12	24	24	24	12
Cane transfer (tons)	-64,01	-52,06	-50,83	-55,00	-68,25	-54,65	-60,69	-62,5	-70,58	-68,25	-80,01	-50,83	-83,23	-60,69	-70,58	-54,65
Weeding Conventional	61,2	61,2		61,2	61,2		61,2	61,2	61,2	61,2	61,2		61,2	61,2	61,2	
Weeding GM (Hours)			55			55						55				55
RV Transfer (tons)	-6,09	-6,47	-6,37	-6,37	-5,981648	-5,95	-6,24	-6,88339	-5,95	-5,98	-5,85	-6,37	-5,54	-6,24	-5,95	-5,95
Mac constraint 1	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15	-0,15
GM Constraint	-0,33	-0,33	0,67	-0,33	-0,33	0,67	-0,33	-0,33	-0,33	-0,33	-0,33	0,67	-0,33	-0,33	-0,33	0,67
Timber Constraint	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1
N48 Constraint	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	-0,33	0,67	-0,33	-0,33	-0,33	-0,33	-0,33	0,67	-0,33
GM deviations																
T1 (Rands)	3533,13	4747,96	3879,06	4144,91	-4393,37	4171,26	9117,57	-212,00	-401,84	4335,14	4093,8879	5644,67	-1952,59	5778,97	-401,84	4171,26
T2(Rands)	3639,84	-2682,56	3112,83	3326,51	2021,94	3378,76	8328,50	875,86	747,37	-3594,73	4578,7175	4635,13	-217,09	4959,64	747,37	3378,76
T3(Rands)	7805,29	162,87	-1838,70	-2004,33	-2145,08	-2236,32	2621,77	-2056,92	499,44	-1772,70	10457,613	-3533,09	823,21	1588,09	499,44	-2236,32
T4(Rands)	-13553,58	-4231,55	-802,54	-872,84	-10509,45	-914,28	-15169,87	-6550,58	-2304,03	-6832,97	-17129,87	-1342,39	-4655,49	-7458,07	-2304,03	-914,28
T5(Rands)	-8636,92	-2206,28	-4158,51	-4517,08	-2313,40	-4790,95	-9706,20	-5119,76	-3093,38	-4346,29	-10547,17	-7061,16	-8954,99	-5106,44	-3093,38	-4790,95
T6(Rands)	6020,38	2667,10	28,80	18,49	8214,37	207,03	5735,88	9361,59	3882,97	12105,75	7563,8805	610,53	10587,10	2103,46	3882,97	207,03
T7(Rands)	1191,86	1542,47	-220,94	-95,66	9124,99	184,49	-927,65	3701,80	669,47	105,80	982,94533	1046,31	4369,85	-1865,66	669,47	184,49
Sum (Rands)																
Conv (Rands)																
E[GM] Acc Constraint	-14769,34	-12945,73	-12132,05	-13338,62	-20715,80	-12132,05	-14487,52	-14412,05	-15592,31	-15257,52	-12132,05	-14023,59	-16752,91	-14487,52	-15592,31	-12132,05
OBJ: L= E[GM]-θσ																

	Opportunity cost of land/ha				Weeding conventional (manday/ha)	Weeding in GM cane (manday/ha)	Eldana control																		
	MPTimber	FSMac	FCMac				scouting (hours/ha)	Chemical control (sprays/year)	GM chemical (R/Ha)	cane (tons)	Cane RV Sales (tons)	Labour hire (days)	E[GM] (Rands)	D1 (Rands)	D2 (Rands)	D3 (Rands)	D4 (Rands)	D5 (Rands)	D6 (Rands)	D7 (Rands)	0.5TAD	SD (Rands)		RHS
Marginal Poor Soil (MP)	1																						≤	750
Flat land Sandy soil (FS)		1																					≤	600
Flat land Clay soil (FC)			1																				≤	1000
Slopey Red soil (SR)																							≤	800
Labour (hours)												-1											≤	2040
Eldana Chemical Control CONV								-1															=	0
GM Chemical cont									-1															
Eldana Physical control: scouting							-1																≤	1000
Cane transfer (tons)										1													=	0
Weeding Conventional					-1																		=	0
Weeding GM (Hours)						-1																	=	0
RV Transfer (tons)											1												=	0
Mac constraint 1	-0,15	0,85	0,85																				≤	0
GM Constraint	-0,33	-0,33	-0,33																				≤	0
Timber Constraint	0,9	-0,1	-0,1																					
N48 Constraint																							≥	0
																							≥	0
GM deviations																							≥	0
		Julies low	Julies Average																				≥	0
T1 (Rands)	-630,76	-6352,74	-4308,07											1									≥	0
T2(Rands)	-415,73	-1348,21	386,82												1								≥	0
T3(Rands)	-341,17	-251,03	412,84													1							≥	0
T4(Rands)	76,42	900,60	921,43														1						≥	0
T5(Rands)	29,95	399,34	-1743,62															1					≥	0
T6(Rands)	494,89	2735,89	1621,78																1				≥	0
T7(Rands)	786,40	3916,16	2708,83								4502,97515									1			≥	0
Sum (Rands)														-1	-1	-1	-1	-1	-1	-1	1		=	0
Conv (Rands)																					-0,39	1	=	0
E[GM] Acc Constraint	3427,59	19060,74	R 36 425,80	-2677,27	52,18	33,65	-211,25	-1635	-985		4502,98	-18	-1											Max!
OBJ: L= E[GM]-θσ													1									-1,64		

3150

Information	
F=(2Δ^0,5)/T	
Δ=ΠT/2(T-1)	
Δ	1,75
F	0,26

Risk preference	θ
Risk neutral	0
	0,25
	0,5
75% confidence of achieving E[GM]	0,674
80% confidence of achieving E[GM]	0,842
85% confidence of achieving E[GM]	1,036
90% confidence of achieving E[GM]	1,282
95% confidence of achieving E[GM]	1,645
99% confidence of achieving E[GM]	2,326

Constraints

Marginal Poor Soil (MP)		0	≤	750
Flat land Sandy soil (FS)		0	≤	600
Flat land Clay soil (FC)		R0,00	≤	1000
Slopey Red soil (SR)		0	≤	800
Labour (hours)		R0,00	≤	2160
Eldana Chemical Control		R0,00	=	0
GM Chemical cont		0	=	0
Eldana Physical control: scouting		R0,00	≤	1000
GM Constraint		R0,00	≤	0
Mac Constraint 1		R0,00	≤	0
Cane transfer (tons)		0	=	0
Timber constraint		0	≤	0
Weeding Conventional	R	-	≤	209,69
Weeding GM		0	≤	209,69
RV Transfer (tons)	R	-	=	0
N48 Constraint		0	≤	0
Gross Margin ®				

1 1 1 1

T1 (Rands)		0	≥	0
T2(Rands)		0	≥	0
T3(Rands)		0	≥	0
T4(Rands)		0	≥	0
T5(Rands)		0	≥	0
T6(Rands)		0	≥	0
T7(Rands)		0	≥	0
Sum (Rands)		0	=	0
Conv (Rands)		0	=	0
EGM	R	-	=	0
		0	=	0
GM=0		0	=	0

Appendix 8: An LP output for the Richmond representative farm under the "without" GM cane scenario

Microsoft Excel 16.0 Answer Report

Worksheet: [Correct Eston Matrices.xlsx]Richmond Matrix

Report Created: 2019/08/16 2:21:35 PM

Result: Solver found a solution. All Constraints and optimality conditions are satisfied.

Solver Engine

Engine: Simplex LP

Solution Time: 0,532 Seconds.

Iterations: 44 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	Maximise Revenue	0	R17 010 894,95

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$15	MPN12	0	0	Contin
$B$16	MPN31	0	435	Contin
$B$17	MPGM	0	0	Contin
$B$18	FSN52	0	600	Contin
$B$19	FSN54	0	0	Contin
$B$20	FSGM	0	0	Contin
$B$21	FCN37	0	0	Contin
$B$22	FCN35	0	527,5	Contin
$B$23	FCN48	0	0	Contin
$B$24	FCN54	0	0	Contin
$B$25	FCN50	0	0	Contin
$B$26	FCGM	0	0	Contin
$B$27	SRN50	0	0	Contin
$B$28	SRN37	0	20,375	Contin
$B$29	SRN48	0	779,625	Contin
$B$30	SRGM	0	0	Contin
$B$31		0	0	Contin
$B$32		0	0	Contin
$B$33		0	0	Contin
$B$34	MPTimber	0	315	Contin
$B$35	FSMac	0	0	Contin
$B$36	FCMac	0	472,5	Contin
$B$37	Mac constraint 1	0	0	Contin
$B$38	WEEDING CONVENTIONAL	0	163863	Contin
$B$39	WEEDING GM	0	-1,55E-08	Contin
$B$40	ELDANA CONTROL MANUAL	0	55700	Contin
$B$41	ELDANA CHEMICAL CONTROL	0	4725	Contin
$B$42	CANE SALES (tons)	0	144877,8	Contin
$B$43	GM CANE Chemical control	0	0	Contin
$B$44	RV SALES (tons)	0	15035,37401	Contin
$B$45	GM RV SALES	0	0	Contin
$B$46	LABOUR HIRING	0	871965	Contin
$B$47	D1 (Rands)	0	0	Contin
$B$48	D2 (Rands)	0	0	Contin
$B$49	D3 (Rands)	0	1707438,683	Contin
$B$50	D4 (Rands)	0	7308652,2	Contin
$B$51	D5 (Rands)	0	9700795,692	Contin
$B$52	D6 (Rands)	0	0	Contin
$B$53	D7 (Rands)	0	0	Contin
$B$54	0.5TAD	0	18716886,57	Contin
$B$55	SD (Rands)	0	7240795,493	Contin
$B$56	EGM	0	28885799,55	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$59	Marginal Poor Soil (MP)	750	$B$59<=$D$59	Binding	0
$B$60	Flat land Sandy soil (FS)	600	$B$60<=$D$60	Binding	0
$B$61	Flat land Clay soil (FC)	R1 000,00	$B$61<=$D$61	Binding	0
$B$62	Slopey Red soil (SR)	800	$B$62<=$D$62	Binding	0
$B$64	Labour (hours)	R2 160,00	$B$64<=$D$64	Binding	0
$B$65	Eldana Chemical Control	R0,00	$B$65=$D$65	Binding	0
$B$66	GM Chemical cont	0	$B$66=$D$66	Binding	0
$B$67	Eldana Physical control: scouting	R1 000,00	$B$67<=$D$67	Binding	0
$B$68	GM Constraint	-R779,63	$B$68<=$D$68	Not Binding	779,625
$B$69	Mac Constraint 1	R0,00	$B$69<=$D$69	Binding	0
$B$70	Cane transfer (tons)	0	$B$70=$D$70	Binding	0
$B$71	Timber constraint	2,18705E-11	$B$71<=$D$71	Binding	0
$B$72	Weeding Conventional	R (144 585,00)	$B$72<=$D$72	Not Binding	144794,69
$B$73	Weeding GM	0	$B$73<=$D$73	Not Binding	209,69
$B$74	RV Transfer (tons)	R -	$B$74=$D$74	Binding	0
$B$75	N48 Constraint	1,56888E-11	$B$75<=$D$75	Binding	0
$B$79	T1 (Rands)	2010682,656	$B$79>=$D$79	Not Binding	2010682,656
$B$80	T2(Rands)	2026550,016	$B$80>=$D$80	Not Binding	2026550,016
$B$81	T3(Rands)	9,45292E-08	$B$81>=$D$81	Binding	0
$B$82	T4(Rands)	-7,45058E-09	$B$82>=$D$82	Binding	0
$B$83	T5(Rands)	0	$B$83>=$D$83	Binding	0
$B$84	T6(Rands)	10101819,96	$B$84>=$D$84	Not Binding	10101819,96
$B$85	T7(Rands)	4577833,945	$B$85>=$D$85	Not Binding	4577833,945
$B$86	Sum (Rands)	0	$B$86=$D$86	Binding	0
$B$87	Conv (Rands)	0	$B$87=$D$87	Binding	0
$B$88	EGM	R -	$B$88=$D$88	Binding	0
$B$90	GM=0	0	$B$90=$D$90	Binding	0

Appendix 9: An LP output for the Richmond representative farm under the "with" GM cane scenario

Microsoft Excel 16.0 Answer Report

Worksheet: [Correct Eston Matrices.xlsx]Richmond Matrix

Report Created: 2019/08/28 1:21:37 PM

Result: Solver found a solution. All Constraints and optimality conditions are satisfied.

Solver Engine

Engine: Simplex LP

Solution Time: 0,578 Seconds.

Iterations: 55 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	Maximise Revenue	0	R20 442 891,16

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$15	MPN12	0	0	Contin
$B$16	MPN31	0	496,7424242	Contin
$B$17	MPGM	0	0	Contin
$B$18	FSN52	0	600	Contin
$B$19	FSN54	0	0	Contin
$B$20	FSGM	0	0	Contin
$B$21	FCN37	0	0	Contin
$B$22	FCN35	0	0	Contin
$B$23	FCN48	0	527,5	Contin
$B$24	FCN54	0	0	Contin
$B$25	FCN50	0	0	Contin
$B$26	FCGM	0	0	Contin
$B$27	SRN50	0	0	Contin
$B$28	SRN37	0	0	Contin
$B$29	SRN48	0	0	Contin
$B$30	SRGM	0	800	Contin
$B$31		0	0	Contin
$B$32		0	0	Contin
$B$33		0	0	Contin
$B$34	MPTimber	0	253,2575758	Contin
$B$35	FSMac	0	0	Contin
$B$36	FCMac	0	472,5	Contin
$B$37	Mac constraint 1	0	0	Contin
$B$38	WEEDING CONVENTIONAL	0	109788,21	Contin
$B$39	WEEDING GM	0	48596,625	Contin
$B$40	ELDANA CONTROL MANUAL	0	47581,81818	Contin
$B$41	ELDANA CHEMICAL CONTROL	0	3248,484848	Contin
$B$42	CANE SALES (tons)	0	139815,3852	Contin
$B$43	GM CANE Chemical control	0	800	Contin
$B$44	RV SALES (tons)	0	14938,73447	Contin
$B$45	GM RV SALES	0	0	Contin
$B$46	LABOUR HIRING	0	878809,697	Contin
$B$47	D1 (Rands)	0	0	Contin
$B$48	D2 (Rands)	0	0	Contin
$B$49	D3 (Rands)	0	2538624,279	Contin
$B$50	D4 (Rands)	0	4117767,075	Contin
$B$51	D5 (Rands)	0	10086994,29	Contin
$B$52	D6 (Rands)	0	0	Contin
$B$53	D7 (Rands)	0	0	Contin
$B$54	0.5TAD	0	16743385,64	Contin
$B$55	SD (Rands)	0	6477328,951	Contin
$B$56	EGM	0	31065710,64	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$59	Marginal Poor Soil (MP)	750	$B$59<=$D$59	Binding	0
$B$60	Flat land Sandy soil (FS)	600	$B$60<=$D$60	Binding	0
$B$61	Flat land Clay soil (FC)	R1 000,00	$B$61<=$D$61	Binding	0
$B$62	Slopey Red soil (SR)	800	$B$62<=$D$62	Binding	0
$B$64	Labour (hours)	R2 160,00	$B$64<=$D$64	Binding	0
$B$65	Eldana Chemical Control	R0,00	$B$65=$D$65	Binding	0
$B$66	GM Chemical cont	1,11413E-11	$B$66=$D$66	Binding	0
$B$67	Eldana Physical control: scouting	R1 000,00	$B$67<=$D$67	Binding	0
$B$68	GM Constraint	R0,00	$B$68<=$D$68	Binding	0
$B$69	Mac Constraint 1	R0,00	$B$69<=$D$69	Binding	0
$B$70	Cane transfer (tons)	-6,66478E-09	$B$70=$D$70	Binding	0
$B$71	Timber constraint	-61,74242424	$B$71<=$D$71	Not Binding	61,74242424
$B$72	Weeding Conventional	R (99 403,64)	$B$72<=$D$72	Not Binding	99613,32636
$B$73	Weeding GM	-44000	$B$73<=$D$73	Not Binding	44209,69
$B$74	RV Transfer (tons)	R -	$B$74=$D$74	Binding	0
$B$75	N48 Constraint	-272,5	$B$75<=$D$75	Not Binding	272,5
$B$79	T1 (Rands)	5775184,82	$B$79>=$D$79	Not Binding	5775184,82
$B$80	T2(Rands)	3838098,869	$B$80>=$D$80	Not Binding	3838098,869
$B$81	T3(Rands)	9,56468E-07	$B$81>=$D$81	Binding	0
$B$82	T4(Rands)	-1,6042E-06	$B$82>=$D$82	Binding	0
$B$83	T5(Rands)	-1,12131E-06	$B$83>=$D$83	Binding	0
$B$84	T6(Rands)	4441473,553	$B$84>=$D$84	Not Binding	4441473,553
$B$85	T7(Rands)	2688628,399	$B$85>=$D$85	Not Binding	2688628,399
$B$86	Sum (Rands)	-6,70552E-08	$B$86=$D$86	Binding	0
$B$87	Conv (Rands)	0	$B$87=$D$87	Binding	0
$B$88	EGM	R -	$B$88=$D$88	Binding	0