DEVELOPMENT OF A FRUGAL CROP PLANNING DECISION SUPPORT SYSTEM FOR SUBSISTENCE FARMERS

By

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DECLARATION

I, Adam Friedland declare that this dissertation is a representation of my own work both in conception and execution. This work has not been submitted in any form for another degree at any university or institution of higher learning. All information cited from published or unpublished works have been acknowledged.

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DEDICATION

This dissertation is dedicated to my family for their support, encouragement and motivation throughout the period of this study.

A special thank you to my loving partner, Janine Rutsch. Your constant positivity, engagement and support fortified my resolve whenever problems arose for me.

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ABSTRACT

This dissertation reports on the original study that undertakes the development of a frugal information system to support subsistence farmers through the use of the Agricultural Production Systems Simulator (APSIM) as a support tool to assist them in optimal strategic decisions making. The field of agriculture is vast and in-depth and a number of critical factors like soil type, rainfall and temperature are involved that farmers have to take into account. Farmers persistently face the challenges of increasing and sustaining yields to meet with the populaces demand with often limited resources, which makes strategic decisions on what to plant, when to plant, where to plant and how to plant in a particular season imperative.

The way in which this study attempts to solve this agricultural decision making problem is with the use of the APSIM. This technology platform provides an advanced simulation of agricultural systems that can enable subsistence farmers to simulate a number of variables ranging from plant types, soil, climate and even management interactions. This research presents a frugal web-based crop planning decision support system that subsistence farmers can take advantage with the use of the APSIM. The APSIM platform was used to run simulations for various regions with the results containing the expected level of success along with other useful information for a specified crop in the vicinity, using state of the art software platforms and tools ranging from Google Maps application programming interfaces, Microsoft's model view controller framework, JavaScript and others. The validity of this system was tested through a number of design science methods including structural testing and illustrative scenarios, show capability of the information system. The results obtained from this evaluation show a small but powerful tool that has the capability of servicing a multitude of farmers with crop management decisions.

CHAPTER 1

INTRODUCTION

This dissertation focuses on the development of a crop planning decision support system based on the Agriculture Production System Simulator (APSIM) as a way of assisting the decision process made by farmers concerning crop planning. The primary goals associated with an agricultural decision support tool is to ensure that the population not only has sufficient sustenance in order to survive, but that it can continue to grow and support itself. Elevated food prices due to commodity inflation have resulted in 110 million people being poverty stricken along with 44 million more being left malnourished, worldwide. Implications of food unavailability have had dramatic repercussions ranging from livelihood degradation, increased infant and child mortality rates, and the amount of expenditure required to secure food, which is set to be 70-80% of total income (Nellemann 2009). By alleviating the issues associated with food availability and accessibility; effectively means that other sectors like industrialisation will boom due to the surplus in labour leading to people saving money more, personal investing taking place and more food being available to meet the demand of our ever-growing population (Diao *et al.* 2007).

Agriculture is arguably one of the most attractive fields that every country strives to achieve better and more efficient solutions for in order to produce sufficient food for an ever-growing population. Agriculture and agricultural products play important roles in sustaining lives on the planet earth (Adekanmbi and Olugbara 2015). Currently in South Africa, we are facing the problem of food scarcity, lack of income, resources and agriculture information. In a recent survey conducted, it was found that 6-10% of children and 12.2% adults were sometimes or always hungry in South Africa (Statistics South Africa 2014).

Food production in developing countries such as South Africa relies heavily on mechanized farming, which uses advanced tools, implements and machinery to increase agricultural productivity (Folaranmi 2014). To massively increase agricultural productions in developing countries such as South Africa, the role of subsistence farmers is very important. Subsistence farming focuses

on crop production, livestock rearing and other activities that are conducted mainly for personal consumption (Berdegué and Fuentealba 2011). If the promises of subsistence farming are well tapped, it could boost the Gross Domestic Product (GDP) of a country, provide sufficient food to feed the nation and solve hunger problems. It provides the nourishment for which people rely on to survive with the limited resources they have.

1.1. Problem statement

Subsistence farmers are incessantly faced with decision challenges of what to plant, when to plant, where to plant and how much to plant in order to yield maximum output (Adekanmbi and Olugbara 2015). Moreover, subsistence farmers are currently facing the challenge of increasing and sustaining yields to meet with the current and future demand with often limited resources, which makes strategic decision making in the agriculture domain imperative (Chirwa and Matita 2012). It provides the nourishment for which people rely on to survive with the limited resources they have, thus incurring a great deal of risk when investing in subsistence farming (Parton 2009; Masere and Duffy 2014). In South Africa and even in many other developing countries, there is a wide digital divide between commercial and subsistence farmers, with ICT being more difficult to penetrate in the latter because of a lack of resources (Townsend *et al.* 2013). Another major impediment to subsistence farming is inadequate telecommunication infrastructure to access relevant agricultural information (Ramoroka 2014).

Achieving food security is a very serious issue throughout the countries of the modern world. The challenges are greater for developing nations such as those in Africa because of a number of socioeconomic problems, which result in poor agricultural productivity. Small scale farming in Africa has been shown to often have low crop yields and this is linked with widespread poverty and lack of agricultural input (Shumba 1994; Godfray *et al.* 2010). Specifically, one such reason for poor crop yields is a need for relevant and adequate information essential to making informative crop management decisions (Masere 2011). These decisions include crop variety, planting date, sowing density, fertiliser investment, and weeding frequency and are key to getting optimal crop yields (Masere and Duffy 2014). By eliminating the knowledge requirement that is posed

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by agronomy, subsistence farmers are able to take advantage of tools that were before, unusable and inaccessible. With this, farmers are able to obtain optimum crop yields, alleviating the tension caused by food insecurity and enhancing overall livelihoods.

Sub-Saharan Africa is well known and documented for suffering from food scarcity, a lack of income, resources and agriculture knowledge. In a general household survey that was conducted in South Africa 2014, it was found that 6-10% of children and 12.2% of adults were sometimes or always hungry (Statistics South Africa 2014). Currently, food production in developing countries such as South Africa relies heavily on mechanized farming. Mechanized farming is described as using advanced tools, implements and machinery to increase productivity (Folaranmi 2014). Due to the commonly found problems mentioned in the above, mechanized farming is a very difficult market to penetrate unless you possess the resources, skills and knowledge to be able to function as a famer – with underlying risks still being applicable, such as climate erraticism. To increase agricultural production massively in developing countries, the role of subsistence farmers is very significant and cannot be overlooked.

The research question to be addressed in this study is enunciated as follows: 'What form of agricultural information system can be developed to support subsistence farmers in the process of strategic decision making such that additional costs are not incurred?'

1.2.   Study aim and objectives

Crop planning and critical decisions surrounding it can be an arduous task in nature as there are many non-static variables that a subsistence farmer has to cognisant about. The types of crop to plant, the correct soil for the chosen crop that it is most likely to thrive in, the amount of rainfall in the area and the yield that is likely to be produced are just a few of the factors that all farmers are faced with (Adekanmbi and Olugbara 2015). Due to the number of variables a subsistence farmer has to take into account with limited resources at hand, the risk involved is enormous and the emphasis on making good strategic decisions is greater than ever (Baiphethi and Jacobs 2009; Chirwa and Matita 2012). With the current tools available requiring an unrealistic hardware requirement in the form of powerful

yet expensive personal computers to perform simulations or other forms of intensive computation, coupled with the technical knowhow and agricultural knowledge prerequisite that is needed to configure decision support tools; the majority of users that could benefit from such tools are disparately isolated.

The aim of this research is be to provide a frugal agricultural information system that can support subsistence farmers in strategic decision making with minimum costs. The objectives of the research are the following:

(1) To migrate post-simulation information from APSIM to a database that is easily accessible by any communication device.

(2) To develop a frugal web-based agricultural system that allows subsistence farmers to seamlessly connect to the APSIM-based database for relevant information access.

(3) To conduct functional and structural evaluation of the developed frugal web-based agricultural system.

1.3.   Study methodology

The methodology chosen to conduct this research will be the design science methodology with the focus being on the information system. This has been chosen as the dissertation surrounds the construction of a unique software system and in this context, new features that have yet to be demonstrated in other artefacts. This paradigm further addresses two key issues in information system research: The role that information technology artefacts play in information system research and lack of perceived relevance in specialized information system research (Hevner and Chatterjee 2010).

The Unified Modelling Language (UML) will be used to create a blueprint of the system to gain full awareness of the solution. Following the planning, the process of transmuting post-simulation information from the APSIM platform to a relevant filesystem that will enable unrestricted access to such information, will be conducted. The APSIM was developed to simulate biophysical and physical processes in farming systems and has been comprehensively verified and used to study farming systems productivity which makes it an incredibly useful tool for

evaluating cropping system performance under varying conditions (Keating *et al.* 2003; Probert *et al.* 2005; Chen *et al.* 2010; Liu *et al.* 2011; Luo *et al.* 2011).

A frugal information system is one that is developed and deployed with minimal resources to meet the preeminent goal of the client (Watson, Kunene and Islam 2013). In order to create an versatile information system with a minimal footprint in terms of development time, the frugal information system will be created with the Model-View-Controller (MVC) design pattern, due to the responsiveness it brings to web based applications (Pujari, Sayed and Rajput 2015). The front-end of the web solution will take advantage of an open-source mapping platform known as Mapbox GL JS for the reason that it provides a way in which to conceptually visualize large datasets in an efficient manner (Poli *et al.* 2016). The grid mapping data including other agricultural specific information for regions will be extracted from the Agricultural Modern-Era Retrospective Analysis for Research and Applications and will be used to tie in the interactions with users, using JavaScript to provide feedback from the assimilated information output from the APSIM simulations.

Once the implementation phase of the system has been completed and a prototype has been produced, testing and descriptive methods will be used to evaluate the information system. Namely demonstrated through the use of structural testing and a goal-based evaluation to inspect the internal workings of the system to ensure they are sound, and then to see if all goals of the initial proposal for the system have been met.

1.4. Study Scope

The scope of this study concerns crop planning decision making in the area of Sub-Saharan Africa. That being said, the factors encapsulating crop planning decision making are: what to plant, when to plant, where to plant and how to plant in a particular season. There are many factors taken into consideration such as rainfall and soil types in their rough vicinity. In the case of subsistence farmers, there is often either a lack of resources, skill and expertise to deploy agricultural practices that commercial farmers are able to take advantage of to secure large

crop yields. Thus, the emphasis on strategic crop planning is all the more imperative for subsistence farmers.

1.5.   Study Contributions

The research work conducted for this dissertation concerns the development of a web-based frugal crop decision support system which is built on top of an APSIM-based database provides a unique contribution to farmers. The proposed information system satisfies the following requirements:

a) Minimalism - the interface of the system focuses on making only the essential elements aware to the user in an intuitive and interactive way that makes navigation simple.

b) Persistency - due to the focus on flexibility and loose coupling when designing the platform, new post-simulation information can be easily created or changed with little effort from different data sources if need be.

c) Protection - the filesystem and its contents are protected and secured through a content delivery network with no access being given directly to users.

d) Efficiency – the system is able to display, search for and output information in a matter seconds from enormous datasets.

The frugal information system being proposed in this study focuses on the main point of developing an information system with a primary design goal, that being transforming a complex system in such a way that all users can take advantage of it. Expanding more upon that, this study contributes in the following ways:

a) The investigation of an approach to allow a large number of users to seamlessly access simulated agricultural information relating to their specific location with the least amount of input required.

b) The examination of several implementation issues of an online crop-decision support platform, including data structures for storage of simulated information, efficient retrieval of this information and providing a secure environment for this.

c) The experimental evaluation of the proposed frugal information system demonstrates that the direction taken in moving information online and how it's delivered are done in an efficient and safe way.

1.6. Study Outline

This dissertation is divided into five comprehensive chapters. The first chapter outlines the background for the study, problem statement, study aims, objectives, methodology and contributions. More specifically, section 1.1 introduces the problems that will be addressed throughout this thesis, section 1.2 outlines the reasons and motivation for carrying out this study, with section 1.3 and 1.4 explaining the structured process of how those very problems will be solved. section 1.5. addresses the scope of the study, with section 1.6. stating what can be contributed for use, from this study.

Chapter 2 is the backing literature that takes an extensive look at the current state of crop planning, specifically with subsistence farmers in mind. It will examine the existing practices that are currently used, and other theoretical frameworks that have been suggested as a way to assist in achieving the optimal crop yield. The purpose of doing so is to examine the many factors that fall into making strategic decisions surrounding crop planning and how many of the solutions offered, usually fall short in one way or another; noticeably with accessibility and usability. It will look at the many benefits that can be examined from alleviating the stress, funding and hunger that rural areas face.

Chapter 3 outlines the methodology taken for this study. It looks at the technology and tools required to create a frugal web-based agricultural system that is capable of being accessed by a plethora of different devices. It also looks at the planning that was needed to be undertaken in order to make sure components interact in the correct fashion with each other, in particular, the immense datasets that were created and how that information is transposed onto a user-friendly interface that rural farmers or agricultural extension officers can use to assist in making strategic crop planning decisions.

Chapter 4 examines the different forms of output resulting from the simulations run through the APSIM and how these were translated into a more

appropriate output for users. Following, an overview of the prototype will be discussed and where a goal-based and summative evaluation will be conducted based on the requirements that were specified for the frugal information system.

Chapter 5 will conclude the points made in this dissertation and provide recommendations on how this work can be improved upon, with the limitations that were observed in this study.

CHAPTER 2

LITERATURE REVIEW

Agriculture is the term used to portray the growing of crops and raising livestock for human utilization. It has been the main source of subsistence that people consume on a daily basis. Since the development of agriculture, many different implementations of the concept have been and are used by people all over the world with varying levels of success based on a number of factors.

2.1 Classification of Agricultural Systems

There exist many ways in which to classify farming systems in agriculture. Factors can range from the degree of commercialization output from a farm, to the types and intensity of farming rotations that can be in place (AgriInfo 2015). For the purpose of this study, the factors employed in order to classify the agricultural systems are:

- Implements used for cultivation.
- Proportion of land available.
- Amount of labour available.
- Capital investment put into the farm.

Using these constraints, farming can be classified into two broad categories. Namely that of subsistence agriculture and mechanized (industrial) agriculture.

2.1.1 Mechanized farming

Mechanized agriculture can be defined as a type of farming in which large quantities are crops and livestock are produced using specialised machinery and industrialised techniques for the purpose of sale. The primary goal of mechanized agriculture can be viewed as increasing yields (both grain and livestock) to the greatest degree (Cunningham 2016). This ensures that a good financial profit is made and that more people are inevitably fed. Industrialised agriculture relies on utilizing large machinery that can produce faster and work harder, which results in producing large quantities of food without having to rely on manpower or animals in order to cultivate, harvest or process yields.

Farmers that take part in mechanized farming also make use of inorganic nutrients which increase crop sizes and yields, along with pesticides to help defend crops against pests that might harm or consume them. An example of an industrial agricultural technique would be monocultures in which a specific type of crop is planted in a very large volume to ensure a stronger yield when harvesting needs to be conducted. These being just a select few of the techniques that mechanized farmers have available for them to make use of.

2.1.2 Subsistence farming

Subsistence farming is defined as crop production, livestock rearing and other activities that are conducted mainly for personal consumption (Berdegué and Fuentealba 2011). Subsistence farmers can play an imperative role in poverty-stricken areas as they can greatly increase the standard of living by alleviating food insecurity. This can go beyond personal consumption where crops can be either traded or sold, bringing in a steady income for farmers and possibly boosting the gross domestic product. With the pressure of food insecurity lightened, this will increase the spending power of each household and overall, improve the livelihoods of residents. Studies have suggested that commercialisation has the potential to unlock opportunities for better incomes and more sustainable livelihoods for subsistence farmers (Von Braun and Kennedy 1994; Omiti *et al.* 2009).

When looked at specifically with regards to small-scale, subsistence agriculture in Sub-Saharan Africa raises unique difficulties that haven't been addressed correctly by the methodologies applied so far in many studies (Adger *et al.* 2003). Supplying simplified information regarding forecasts, crop suitability and the correct inputs required to achieve a favourable crop yield can result in a number of benefits for small-scale farmers. Some of these benefits are not only limited to but also include risk aversion due to climate variability, marginal and barren lands and a lack of skills as these farmers do not have access to resources to manage or recuperate from issues that may arise. This would allow small-scale farmers to even take advantage of this information in order to gain some success commercially. An example of this being that if farmers were aware that a good season was to come and excess crops would be available, they may choose to plant rarer crops which would be in higher demand in a market (Ziervogel 2001).

By utilizing an information system in this fashion, subsistence farmers who depend entirely on agriculture as a means for survival and sustaining their livelihoods could make use of crops in high demand to secure much needed income. Therefore, food security and livelihoods can be increased if small-scale farmers are able to adjust to climate variability by making use of information systems to decrease harmful impacts that can be suffered and to take advantage of uncertain conditions (Ziervogel 2004).

2.1.3 Challenges confronted by subsistence farmers in adaptation

Subsistence farmers from all over the world have to face numerous difficulties in tending to the effects of climate change, coupled with low income resulting in these farmers not meeting their own family food needs, let alone tackling the forecasted climate changes. This means that farmers are very susceptible and have a low capacity to adapt (Masere 2011). Famer's adaption capacity in this context refers to the capability of small-scale farmers to mitigate negative impacts due to variability and changes in climate in order to reduce any potential harm done and to ensure the maximum possible opportunities (Simoes *et al.* 2010).

Some of these challenges contain:

- Land shortages
- Lack of income
- Lack of climate information in locality
- Unrealistic requirements resulted from agronomy-based research outputs

Land shortages: Commonly due to rural communities being huddled together, there is often a shortage of land and therefore not an inadequate amount of space for mitigating the risk of different farming ventures. This means that rural farmers have a high chance of poor crop yields, especially when just breaking into the agricultural scene and this is particularly dangerous for those farmers as they need a yield in order to survive on.

Lack of income: Whether it be due to personal circumstances or just life one was raised up in, income or the lack thereof is a major contributor to as to why ventures with farming are not explored in rural communities. The capital required to purchase fertilizer and even the basic tools can be a huge risk for a household

as this money could be used to purchase more instant forms of subsistence. This will often lead to farmers adopting a conservative risk management strategy in which will result in substandard productivity due to poor utilization of the little resources that were purchased (Hansen and Sivakumar 2006).

Lack of climate information in locality: Agriculture, in all forms worldwide, is profoundly helpless and sensitive to all degrees of climate variability and change (Howden *et al.* 2007). The severity due to the impact of climate change and variability is noticeably worse in less fortunate areas of Africa, owing to a high dependence on agriculture and the limited capability to adapt. In developing countries where small-scale farming is prevalent and accounts largely for many household's daily subsistence, an important issue that still persists is providing these farmers with climate information appropriate to their locality to enable improved decision making. An example of this being what types of crops would flourish due to the surrounding climate and in what way they should be treated with regards nourishment techniques (Mtambanengwe *et al.* 2012). However, the official information available to small-scale farmers is only limited to elite members of the community that have no intention of disseminating the information to the farmers that require it (Mapfumo, Chikowo and Mtambanengwe 2010). This therefore further constraining the progress that could be made by subsistence farmers and limiting their mindsets by what research could further accomplish for them.

Unrealistic requirements resulted from agronomy-based research outputs: In the majority of cases, research recommendations made to farmers are not suitable or feasibly within reach and so, are unable to meet the technology requirements set out by research output (Walker 2002). This can be resolved by gaining an understanding of what farmers need from personal/3rd party interaction so that resource constraints can be taken into consideration when developing solutions. This ensures a high adoption rate by small-scale farmers due to easily accessible technologies without incurring further risk on users that already suffer from many resource-based constraints.

2.1.4 Dynamics affecting subsistence farmer's decision-making

Without the benefits and tools offered by decision supports systems, subsistence farming is all conducted through experience and knowledge that has been passed down, if any. This knowledge is comprised of tried and tested, indigenous methods that offer varying levels of success, depending on environmental factors and the use of extension officers (Morton 2007; Masere 2011; Masere and Duffy 2014). That being said, a frugal crop decision support tool that addresses factors that are not normally considered when creating a decision support system would be able to address the excess variables to ensure a better crop yield. Studies conducted by Yamano and Jayne (2004) and Cooper *et al.* (2008) have shown that rural communities struggle under pressure to ensure food security. Some of the prominent issues affecting decision making being:

- Lack of information and skills
- Climate
- Risk aversion
- Social and economic factors
- Biophysical conditions

Lack of information/skills: One of the main hurdles that subsistence farmers face in their decision-making processes is a lack of information and skills. Robert (2002) states that out of the many challenges that smallholder farmers face, lack of basic and even misuse of information is one of the prevalent factors that needs to be addressed in small scale farming where resources are already limited as this largely affects the decision making process. Due to the large inequality that is generally witnessed in developing countries in Africa, it can also be deduced that major differences in education and skills can lead rural communities to believe that tackling a venture such as farming to be a very risky task with the resources required for start-up (Reardon *et al.* 2000). These same problems have even been documented in the agricultural extension officers that supply assistance to farmers when needed which leaves for little to no support for rural farmers hoping to start planting crops (Belay and Abebaw 2004). This means that subsistence farmers are left to rely solely on indigenous knowledge that has been passed down or that is shared between neighbouring agriculturalists when having

to make key management decisions. There is also a very wide digital divide that has been documented between rural and commercial based farming which makes it extremely difficult for a smallholder farmer to access and take advantage of technology to aid in the decision making process (Townsend *et al.* 2013). As decision support tools that have been developed for agronomy; they are tailored towards scientists in agriculture which infers that the linguistic, technical and hardware requirements of these systems make it almost impossible for a rural farmer to take advantage of. If new information can be made available to these farmers, it could help them reconsider decisions and agricultural practices they already employ in order to produce the highest possible yield.

Climate: All agrarian practices are without a doubt, susceptible to the climate; notably with rainfall and temperature. Sivakumar, Das and Brunini (2005) found that rainfall is extremely significant to agriculture, as it has shown in past research that the biggest pitfall in crop production being due to draughts caused by erratic precipitation levels, meaning that rainfall plays an imperative role in year-to-year production of crops. This infers that precipitation levels affect the decision making process with regards to choosing what crops to plant and when they ideally need to be planted. It has been viewed that due to climate model predictions often conflicting with one another and furthermore disagreeing with indigenous-based knowledge, small-scale farmers would rather revert to tried and tested methods for dealing with the climate, such as noticing specific wind pattern changes or temperature variances as a sign of climatic change to come (Ziervogel 2004; Change 2007).

Risk aversion: Traditionally, risk associated with individuals can be broken down into two categories. Those that adopt risk for the possibility of a high reward and those that avoid risk, no matter what possible outcome it may achieve. In Sub-Saharan Africa, the large majority of subsistence farmers are risk averse due to their economic situations and as such, subsistence farming activities carry an inherently high risk due to the reliance of rainfall to ensure good crop production (Yesuf and Bluffstone 2009). Yesuf and Bluffstone (2009) also went on to add that agricultural extension officers play a vital role in 'selling' the idea that technology can offer substantial benefits to farmers in low-income, high-risk environments as they have found that even if risk is present in the smallest form,

there is resistance in adapting. Farmers place more importance on maintaining their current crop yields, than on using new and proven methods to increase crop yields, because of the risk involved. Concluding, it can be said that because of risk and uncertainty that farmers face; crop selection, crop rotation strategies, adoption rate of technology and environmental degradation are all seemingly affected (El-Nazer and McCarl 1986; Purvis *et al.* 1995; Menapace, Colson and Raffaelli 2012).

Social and economic factors: The decision making process is affected by a host of economic and social pressures that small-holder farmers have had to conform to. Some of the economic specific factors involved being not having sufficient capital to pursue management decisions at a farm-level when climate change signals are observed, limited labour on hand and constrained diversification in crops due to the limited amount of land owned (Bradshaw, Dolan and Smit 2004). The social milieu of this comes into play as being in a more closely bounded community, members tend to depend on social norms and not deviate from paths, more specifically with the propensity to follow the opinions of others and thus directly affecting decisions made (Ziervogel *et al.* 2005).

Biophysical conditions: Taking into account factors mentioned above; decisions made by farmers are, and always will be affected at the fundamental level by biophysical conditions which need to be taken into consideration when practicing agriculture (Arbuckle Jr 2013). This means that even the best decisions made at times can be susceptible to poor yield results due to uncertainties which can range from climatic variability to environmental conditions which in most part, are beyond the control of the farmers involved.

2.2 Crop decision support tools

Crop modelling has been a defining point of agriculture research for over the last 40 years since its inception (Sinclair and Seligman 1996). It has long been suggested that crop modelling has the potential to be a powerful tool to understand crop yield formations and to assist in crop improvement programmes (Yin and Struik 2015). Crop reproduction models are numerical representations of plant growth processes as influenced by interactions following genotype, crop management and environmental conditions. They have become an imperative

part of supporting agronomy-based research, crop management and policy analysis (Fischer *et al.* 2001; Hansen 2002). These modelling platforms are generally utilized to assist agricultural scientists, farmers that well versed in agronomy-based science or that have the resources to employ someone who does (Abayomi 2015). Crop modelling can be a powerful asset if made easily accessible and usable to a wider range of people, removing the limiting factors that have already been discussed thus far. Matthews *et al.* (2013) states that the decision support systems that stem from crop modelling can also play an active role in educating and training both new and existing farmers which is crucial for all future prospectors as this provides a way to dive into agriculture without having to specifically have past experience or knowledge.

Decision support tools are developed to make agricultural science more accessible to farmers and agricultural extension officers, to bridge the gap created by the required knowledge and skills. Yield predications based on a number of factors that affect it, can prove to be of great importance to farm management (Papageorgiou, Markinos and Gemtos 2011). This is especially true for rural farmers that have limited resources and the high risk involved in subsistence farming. Decision support tools can succeed in empowering a wide range of users by providing them with large, sophisticated systems but simplifying how they're operated and the linguistics used. Thus, the user does not need to understand how the system functions or the intricacies of how the variables correlate with each other, and is still able to operate the platform with ease.

2.2.1   Limitations associated with crop decision support tools

The purpose of agricultural decision support tools are to secure and continue to help grow crop yields for the human population (Adekanmbi and Olugbara 2015). Considering the difficulties that small scale farmers face, computer crop modelling can be used to assist farmers in making informed crop management decisions that will benefit them by way of good crop yields (Hammer *et al.* 2002). Crop modelling also affords the ability of assessing and quantifying risks to assist the farmer in the decision making process under varying climate conditions (Bontkes and Wopereis 2003). Currently such decision support tools are catered and designed around a user base that is assumed to have an agriculture expertise in some form or manner and the majority of cases, require a fairly

powerful computer in order to run these platforms. Walker (2002) suggests that decision support tools originally aimed at rural farmers fail due to a number of reasons. Some of these being:

- Non-acceptance
- Inaccessibility
- Inflexibility
- Irrelevance

Non-acceptance: The lack of adoption of a support tool can be linked to design failures of not meeting the requirements that were initially set out. This can lead to the tool being inaccessible, inflexible or irrelevant to farmers. The low adoption rates of some decision support systems are most likely due to technical constraints and the end-user's attitude that have not been sufficiently addressed during the development and execution stages of the decision support tool (Gent, De Wolf and Pethybridge 2011).

Inaccessibility: The ability to access and use a decision support tool with ease is a key deciding factor as to whether a support tool will be accepted (Davis 1989). These tools are often either physically inaccessible due to locality, are technically inaccessible where the skills and technical resources required are just are unrealistic, or are conceptually inaccessible. Technical inaccessibility is often witnessed as the decision support systems created to aid farmers require semi-powerful processors found in desktop computers and laptops in order to run simulations or pool data, which in turn requires the skills to operate these personal computers. Conceptual inaccessibility is arguably one of the biggest factors and is viewed across all levels of decision support systems. Conceptual accessibility in this context refers to developing a tool for a specific field such as agriculture but allowing users without any agricultural experience or knowledge to be able to use such a system without being locked behind a knowledge barrier.

Inflexibility: Even with decision support tools satisfying all forms accessibility, with having a sound design choice, and being relevant for farmers – they can still fail by way of not satisfying the amount of depth that farmers would need in such an application. In a study conducted by Walker and Johnson (1996), it was observed that decision support platforms that addressed only very specific issues

were much less likely to be adopted by users as the platform focused on too small a factor in the management undertaking. Thus, decision support tools need to be designed and applied in such a way that if fulfils a much wider range of tasks to make it more applicable to users.

Irrelevance: One of the most prevalent challenges faced by researchers and developers of decision support systems is producing a system that is relevant to user's needs and can assist in making strategic decisions. In a study conducted by Arnott and Pervan (2005), where 756 publications were reviewed; it was found that only 9.6% of the research was regarded as having high or highly practical relevance. Over 50% of the articles that were reviewed showed the output produced had no or a low practical relevance. This shows that there is a clearly a fragmented understanding between what users need and what their perceived needs are by researchers. It is also to be noted that Fodor and Roubens (2013) mention that the European school of decision analysis has always been sceptical about the relevance of platforms that have tried to assist users in the decision making process due to there not being a clear understanding between the two parties involved.

Table 2.1: Summary of related research focused on tools and practices for securing and increasing crop yields.

Category	Results	Author(s)
Modelling	Gichamba and Lukandu (2012) developed a model to address the lack of innovative technological solutions in farming in developing countries. The proposed mobile information system sought to give farmers access to e-commerce services to allow them to buy and sell agricultural related products. The proposed system suffers in that it assumes rural farmers have access to produced goods or funding to be able to take advantage of this application.	Gichamba and Lukandu (2012)
	Adekanmbi and Olugbara (2015) formulated a crop-mix optimization model to tackle inadequate information necessary for making crop management decisions that subsistence farmers face. The information system developed using the proposed model lacked in terms of responsiveness in design, such that smaller devices would not be able to make use of this solution.	Adekanmbi and Olugbara (2013)
Simulation	Masere (2011) conducted a case study in which he made use the APSIM platform by applying it to rural farms in Zimbabwe as a way of evaluating the system in the real environment. He found that the APSIM platform was accurate in the simulations that were run and was able to assist farmers in what, how and where to plant with good results but found that the platform was not practical at all. It posed a huge technology and language barrier to subsistence farmers.	Masere (2011)

Observation/Study	Vignola *et al.* (2015) looked at trying to solve the problem of crop vulnerability in the face of climate extreme events. A framework was created to analyse ecosystem-based agricultural practices that could help smallholder farmers increase yield stability. However, with ecosystem-based adaption, comes the information and resource requirement that rural communities don't have access to.	Vignola *et al.* (2015)
	Wegner and Zwart (2011) conducted a study and subsequently proposed a model to bridge the gap between large and small scale farming. The study looked at the benefits held by each side in the equation and adopting them into a model. In the current state of our economy, this model seemingly is not feasible as the input required is much too vast at this current time.	(Wegner and Zwart (2011))
Study	Crane, Roncoli and Hoogenboom (2011) looked at the popularity of implementing modelling as a way predicating the effect of climate change and climate variability in relation to agricultural production. They criticized the use of modelling due to the systemic overview and interactions it exhibits and in a large number of cases, farmers are never even looked at in the system analysis.	Crane, Roncoli and Hoogenboom (2011)
Variety mixtures	Okonya and Maass (2014) proposed using crop variety mixtures to increase yield stability in crops. The study focused on Cowpea variety mixtures as it is an integral part of cropping systems in subsistence agriculture. Improvements in yields were observed in some variety mixtures, but lack of consistency was evident in the end result.	Okonya and Maass (2014)

Agroforestry	Thorlakson, Neufeldt and Dutilleul (2012) looked at using agroforestry as a means to help subsistence farmers mitigate vulnerability to climate change. Whilst it does offer many benefits ranging from alleviating poverty to stabilizing depleted soil from erosion, it does not address yield stability by a margin that makes the implementation stand out.	Thorlakson, Neufeldt and Dutilleul (2012)

2.3 Agricultural Production Systems Simulator (APSIM)

Agrarian system models worldwide are progressively being utilized more to investigate options and solutions for food security, climate change adaptation and ways in which to mitigate these changes. The APSIM is one such framework that continues to be applied and adapted and is at the forefront of this agenda (Holzworth *et al.* 2014). The APSIM is a modular modelling framework that is designed to incorporate accurate predictions of economic output (e.g. Yields and biomass) with regards to a plethora of crop types in reaction to climatic, soil and management conditions (Keating *et al.* 2003; Hammer *et al.* 2010). Keating *et al.* (2003) noted that traditional, stand-alone crop models suffered in simulation accuracy as they were unable to simulate a substantial number of essential cropping systems. APSIM uses a model that concurrently incorporates all the necessary factors that take place during crop production which makes it a more reliable tool.

The APSIM operates by dynamically linking configured variables from chosen modules (e.g. A controlled simulation could be run with just crop and soil modules to see how a specific cultivar would react in a certain type of soil), at which point the APSIM's engine then interprets the project set up by the end-user, and coordinates the communication between the different modules – creating a simulation (Zhao, Bryan and Song 2014). This makes the APSIM a very useful tool for evaluating cropping system performance under varying conditions. It has been used to study farming system's productivity for over 20 years and has been comprehensively verified as a well-developed, accurate framework (Keating *et al.* 2003; Probert *et al.* 2005; Chen *et al.* 2010; Luo *et al.* 2011)

2.3.1 Limitations of the APSIM as a stand-alone tool for subsistence farmers

While the APSIM model is an exceptional tool for quantifying risks due to variable climate patterns and having the ability to simulate a large number of variables in cropping systems, its use in subsistence farming as a stand-alone tool is restricted owing to a lack of capable modellers and sufficient reliable input data (Bontkes and Wopereis 2003; Masere 2011). The APSIM is also a very complex system to operate, even though it is targeted at farmers in general. It requires a knowledgeable understanding of agricultural based science in order to build

simulations and understand outputs; on par with that of agronomists. It also has a technology requirement that small-scale farmers cannot match, needing at least a quad-core based personal computer in order to build and run simulations. This makes the framework practically inaccessible to subsistence farmers that don't have the resources or the required knowledge to be able to reap the benefits from this tool.

2.4 Frugal information systems

The quality of being economical or sparring with regards to resources is an appropriate attitude to adopt in a world where resources are scarce, severe weather events become more frequent and where many people in developing economies are financially constrained. Watson, Kunene and Islam (2013) defined a frugal information system as one that is developed and deployed, with minimal resources to meet the pre-eminent objective set out by the client. There are two key points that are focused on in frugal information systems. Those being that the project must use minimal resources; projects are managed between the constraints of a scope, resources required and time needed. The second point that is emphasized as the most significant is that the primary goal of the client must be achieved. One noticeable variance that sets frugal information systems apart from their regular counterpart is that they tend to have one primary design goal, in conjunction with the constrained scope will ensure that secondary goals are not considered as they not only raise the cost of development, but also increase the complexity of the information system.

The foundations that the concept of frugality in information systems was built on, are the four constructs that Junglas and Watson (2006) termed as fundamentals to what consumers expect from an information system. The success of any information system is dependent on how well it satisfies the aforementioned fundamentals (Junglas and Watson 2006; Watson 2013; Watson, Kunene and Islam 2013; Olugbara and Ndhlovu 2014).

Table 1.2: The four information drives (Junglas and Watson 2006).

Drive	Definition
Ubiquity	The drive to access information unimpeded by time and space
Uniqueness	The drive to know accurately the attributes and location of a person or entity
Unison	The drive for information consistency
Universality	The drive to overcome the friction of information system incompatibilities

Achieving frugality in an information system does not imply that it lacks in complexity either. An example of this being the use of the internet, in which it might appear simple to navigate pages and find information, but there is an extremely complex network that facilitates data transfer across both the hardware and software boundaries. A frugal information system can operate on top of an intricate infrastructure, as long as the complexity is hidden as that is what will contribute to a frugal solution. Designers that work on frugal information systems find ways to build simplicity on top of complexity (Watson 2013). Harnessing and developing information systems in such a fashion effectively means extending the user base that can access and use the system by a huge margin.

2.4.1 Applicability of frugal information systems in decision making

Frugal information systems can be used to convert complex system plans or ideas onto an interface that anyone can use by simplifying the complexity superficially and displaying that to the user. This means that agricultural systems that have high requirements that in most cases isolate target audiences, can now be broken down into 'simpler' applications by focusing on certain constraints which in turn will mean that frugal information systems also have a faster turnaround time in terms of development time at a fraction of the cost and resources required. Goldstein and Gigerenzer (2009) have found that simplicity not only creates robustness in an information system, but also creates transparency which can further add longevity to a system as maintenance or additional improvement can be done in a more steadfast fashion.

This can aid subsistence farming in a significant way by assisting in management decisions, as the proposed system is one such example of that. It proposes to take a complex idea that would inherently involve multiple forms of knowledge-based input that would be required to meet an end result, and strip it of all but the essential input requirements, with using frugal innovation to acquire other forms of inputs. One such example is using geo-location data from a user's mobile device to pinpoint a location which can then be cross-referenced with a database for necessary information. This will result in a frugal information system with an extensive database comprised of climatic and soil information over the years for the southern region of Africa that would have been processed according to location to produce an easily understood output detailing the success rate of a chosen crop for the region that farmers can take advantage of in order to make crop management decisions. All of this completely automated all from a few forms of input.

What this translates to for small-scale farmers is that they can potentially access vast amounts of information without needing any form of agrarian knowledge, off of any device that has a web browser that can connect to the internet to provide simple feedback that can be beneficial in the crop decision phases.

2.5 Adaptation to climate change

By the year 2050, the world will need to produce enough crop yield to feed a projected nine billion people, with having to contend with the impacts of climate change (Beddington 2010). Climatic change is a serious issue that poses a major threat to food security, even more so in areas that experience food insecurity. Small-scale farmers are inexplicably more vulnerable to the impacts of climate change as a consequence of marginalisation, poverty and the reliance placed mostly on natural resources (Frank and Penrose Buckley 2012). Furthermore, due to relatively primitive cultivating procedures and the fact that most of the African continent is arid with rural farming dominating the landscape, it leaves little room for subsistence farmers in which to adapt (Müller *et al.* 2011; Knox *et al.* 2012). It could have grim consequences for subsistence farmers as it could potentially ruin crop yields due to weather patterns not previously seen before,

thus adversely affecting food security and increasing malnutrition (Müller *et al.* 2011).

Schipper and Burton (2009) suggested dividing the approaches of adaptation into two categories: that of autonomous and planned adaptation, with the former being more suitable for resource-constrained, subsistence farmers. Autonomous adaptation is adaptation that is not externally planned in response to a situation, meaning that it makes use of farmers' tried and tested methods mentioned in the above, combined with the knowledge that they encounter in order to mitigate the effects of climate change in their areas. This type of adaptation can be particularly relevant to resource-constrained farmers as it does not necessitate an excessive amount of spending, nor does it require a high level of agronomy-based knowledge. In a study conducted by Harvey *et al.* (2014), a number of autonomous adaptations were listed for farmers. Some of these being:

- Use of new crop varieties that are drought tolerant or can handle environmental stresses.
- Adjustments in irrigation practices and systems.
- Adjustments to cropping structure and application of fertilizers and pesticides.
- Mitigating risk by way of different crop specifies or by integrating livestock rearing.
- Altering sowing times to reduce risk (Masere 2011).
- Using seasonal or multiyear forecasting as a way of making crop management decisions.

Whilst the above cases of autonomous adaptation provide a way to compensate for the impacts of climate change, many of them are not sustainable in practice. This means that small-scale, resource constrained farmers defer to more planned methods of adaptation in order to ensure their livelihoods. Planned adaptation refers to a result obtained due to deliberate decisions being made, taking into account conditions that may occur, or have already changed and that some activity is required in order to maintain, accomplish or return to a pervious state (Walker, Haasnoot and Kwakkel 2013). This procedure can therefore be supplemented by the integration of technology and relevant information outputs

in order to assist in the decision making process, which can be realised through the use of decision support tools. Small-scale farmers and other less fortunate users that have access to a minimal subset of technologies are more likely to adjust their perceptions of modern technologies and make use of the information in adaptation if the technology satisfied both the user's perceived usefulness, and the perceived ease of use. Thus, by satisfying these two criteria, a perceived value can be created for users by them understanding what the system does, what it can offer them, and that it is easy to use and obtain.

2.5.1 Applicability of the APSIM through frugal innovation in adaptation

The APSIM can be used to assist farmers in mitigating the impacts of climate change by modifying existing climate data based on current climatic information in order to create scenarios that will show what the climate will possibly be like in the future. These modified scenarios can then be simulated using crop types that are typically grown by subsistence farmers. An example of this was conducted by Wang *et al.* (2012) where the APSIM was used to create climatic change scenarios in order to find ways in which to boost a specific crop type yield. This will aid farmers in their management options that might be viable under climate variations.

2.6 Conclusion

Subsistence farmers face extremely high barriers to entering the agricultural industry, and face a number of difficulties in maintaining their place in it. Whether it be resources, skills and knowledge, there is a very clear divide between commercial based farming and subsistence farming, on a global scale. As subsistence farmers rely on their crop yield to feed their families, it is imperative that they have the necessary tools to combat the climate and have an understanding of the success rates that they have when deciding what crops to plant as it has been noted that resource-constrained farmers are generally risk averse which makes it incredibly difficult for them to experiment when they have so little to begin with.

This issue has previously been faced in various other studies with potential solutions being developed. However, the majority of these cases are never adopted due to factors that were not taken into account when developing these

decision-support tools. A complete solution taking into account small-scale farmer's backgrounds meaning their current technology available to them, their knowledge of agriculture and their different locations needs to be viewed beforehand. These tools need to be relevant, flexible and accessible to the user-base that is being targeted in order to ensure the highest adoption rate.

To assist small-scale farmers, a bridging of the gaps needs to be erected to either bypass or solve the factors mentioned in order to assist farmers correctly and efficiently. This can be achieved by developing and implementing a frugal information system that would provide the necessary functionality from an extremely complex system such as the APSIM, but by simplifying the perceived intricacy and allowing farmers to access unconstrained and linguistic friendly information in order to make informed decisions regarding crop management. By leveraging frugal innovation in this fashion, it is possible to essentially make a portion of the APSIM platform available to a potentially much wider user-base by eliminating the requirements needed to access and use it.

CHAPTER 3

METHODOLOGY OF STUDY

The methodology utilized in this study is a design science approach. Design science research in information technology (IT) is defined by Von Alan *et al.* (2004) as the creation and evaluation of IT artefacts in order to solve identifiable organizational problems. In order to accomplish this, the approach contains rigorous processes that are needed when designing artefacts to solve observed problems, to contribute to research, to perform evaluations on the designs, and communicate the findings to the appropriate audiences. This was chosen as it involves the creation of new knowledge, by way of designing novel and innovative artefacts and then analysing the performance or use of these processes. On top of this, abstraction and reflection are utilized to further improve and understand the behaviour of aspects of information systems (Vaishnavi and Kuechler 2004).

The guidelines regarding design science research that were laid out by Hevner *et al.* (2004) were used to conduct this research and develop the artefact. These guidelines are represented in the following text and how they were carried out in this specific context:

Problem relevance: The primary objective of design science research in information systems is developing solution to an important and relevant problem. The topic chosen was one based on assisting subsistence farmers in making the correct choices when choosing what to grow and how to grow it. This is highly relevant at the time of writing as access to food for a portion of the populace in Southern Africa is still an issue that has yet to be addressed due to many factors.

Research Rigor: Design science requires the use of rigorous methods in both the construction and evaluation of an information system to ensure its quality and structure. As the main focus of this dissertation was to produce a frugal information system which in itself is supposed to be produced efficiently, planning was implemented in the form of class diagrams and use-case narration for conceptualisation and then further descriptive evaluation, post prototype.

Design as an artefact: This guideline focuses on effectively representing the design artefact, confirming that the implementation and application of the system are done appropriately. A fully working prototype was produced demonstrating the functionality that was initially stated to be included in the implementation. It confirms that crop decision support tools can be transformed in such a way that opens them up to their specified target audience and yet still maintain their complexity.

Design Evaluation: Venable (2010) describes this process as one that is used to evaluate the efficacy and quality of the design research artefact. As noted in *Research Rigor*, a descriptive evaluation was conducted using an illustrative scenario and further using the four u-constructs to validate the system against.

3.1. APSIM Setup

The APSIM is a crop simulation framework designed to assess complex interactions that occur in soil, during crop production, under various climate conditions and management options (Keating *et al.* 2003; Holzworth *et al.* 2014). In order to use the model efficiently, long-term daily climatic data is needed in the form of rainfall, solar radiation, minimum and maximum temperatures (Kelpie 2016).

The model specification in this case, was setup using the following input data:

- Soil description.
- Daily climatic data.
- Crop management data.

The platform implemented the soil descriptions defined by Koo and Dimes (2015) who defined the 27 generic soil profiles based on their texture (clay, loam, sand), fertility (low, medium, high) and soil depth (shallow, medium, deep). These 27 soil profiles are universal and thus, are compatible with most modelling platforms including the APSIM. Historical daily climatic data was extracted from the Agricultural Modern-Era Retrospective Analysis for Research and Applications (AgMERRA). The AgMERRA are gridded, global, daily climate forecast datasets that contain climate variables useful to agricultural models, with historical daily climate data ranging from as far back as 1980 (Ruane, Goldberg and Chryssanthacopoulos 2015). These datasets were used to create Met

(APSIM output) files for each simulated grid (10km x 10km). Each Met file consists of 30 seasons of daily radiation, rainfall, minimum and maximum temperature. The 30 seasons are categorised into three classes of 10 seasons, each based on total seasonal rainfall (rain received from October to March) and these being; Below Normal (BN), Normal (N) and Above Normal (AN). The BN category comprise of the 10 seasons with the lowest rainfall totals, N comprise the middle 10 seasons while the 10 highest rainfall seasons are categorised as AN. Crop management data for the various crops like maize, sorghum, beans and potato (See Tables 1-4) were based on literature, farming handbooks (Smith, 2006; NDA) and researchers' past work and experiences in small-scale farming systems (Masere 2011; Masere and Duffy 2014; Duffy and Masere 2015). This information includes sowing dates, sowing density, soil depth, weed control and fertiliser management (times and amount of application, type of fertiliser). Only low to medium fertiliser amounts are simulated as the project is targeting small-scale farmers who generally uses low fertiliser and may only be able to afford and willing to invest in these low to medium fertiliser amounts.

3.2. Criteria for selecting Grids to simulate crop production

Most crops including maize, sorghum beans and potato require rainfall between 500mm to 900mm to grow optimally (Smith 2006; Paul and Oluwasina 2011). However most small-scale farmers of sub Saharan Africa reside and farm in semi-arid areas receiving low rainfall. These farmers grow their staple crops regardless of the low rainfall. According to the National Department of Agriculture (2010) of South Africa, the minimum rainfall requirement for production of main staples like maize and sorghum is 350mm per season. Based on this guideline only grids with an average of 300mm per season (October to March) were selected and simulated. In South Africa there are 237 such grids. Thus maize, sorghum, bean and potato production are simulated in the 237 grids, for 30 seasons, with various cultivars and fertiliser management options under all 27 soil profiles.

The Maize and Weeds Simulation template was chosen in running APSIM as it mimics the reality in small-scale farmers' fields where weeds compete with the maize for nutrients, water and radiation on a daily basis. This simulation template was also modified to simulate sorghum, beans and potato production. Maize and sorghum sowing was set to occur at the first opportunity when a

cumulative rainfall amount of 20mm is received over five consecutive days, and a soil water of 30mm is achieved within a sowing window from 20-October to 15-December. If this criterion is not met, the model was set to force sowing on the last day of the sowing window (15-December). Similarly, weed is set to be sown throughout the course of the season (1-October to 30-March) at the first opportunity a cumulative rainfall amount of 10mm is received over 5 consecutive days. The longer sowing window for weeds meant that there will be multiple sowing of weeds throughout the season.

The model was set to reset the soil, nitrogen and surface organic matter at sowing so as to eliminate carryover effects as the study is aimed at exploring a management option/strategy over the 30 seasons as opposed to a continuous long-term simulation which incorporates the carry over effects of a management strategy to the next seasons. Below are the following input parameters for each crop type that were passed in the APSIM platform.

Table 3.1: Input data for maize simulation

Item	Description
Soil description	All the 27 generic soil profiles developed by Koo and Dimes (2015) are simulated in all the grids.
Met files	Each grid had a Met file consisting of historical daily minimum and maximum temperatures, radiation and rainfall over 30 seasons.
Maize cultivars	Three cultivars are simulated: Early, Medium, Late maturing
Sowing density (plants/m2)	4.75 plants/square metre (47 500plants/ha)
Sowing window	20-October to 15-December
Sowing depth (mm)	100
Row spacing (m)	0.7
Weed sowing density (plants/m2)	12
Weed sowing depth	15mm

Weeding	Maximum of three in-crop weeding times were set. The maximum days to weed after emergence was set to 35 days. This is provided a weed biomass threshold of 1000kg/ha has not been reached before the 35 days after weeds emerge.
Fertiliser	40% applied at sowing and 60% applied as top dressing at 35days after emergence. Five fertiliser options: 5kgN, 20kgN, 30kgN, 40kgN and 50kgN/ha.

Sources: Smith (2006); Masere and Duffy (2014)

Table 3.2: Input data for sorghum simulation

Item	Description
Soil description	All the 27 generic soil profiles developed by Koo and Dimes (2015) are simulated in all the grids.
Met files	Each grid had a Met file consisting of historical daily minimum and maximum temperatures, radiation and rainfall over 30 seasons.
Sorghum cultivars	Three cultivars are simulated: Early, Medium, Late maturing
Sowing density (plants/m2)	7. 5 plants/m2 (75 000plants/ha)
Sowing window	20-October to 15-December
Sowing depth (mm)	30
Row spacing (m)	0.9
Weed sowing density (plants/m2)	12
Weed sowing depth	15mm
Weeding	Maximum of three in-crop weeding times were set. The maximum days to weed after emergence was set to 35 days. This is provided a weed biomass threshold of 500kg/ha has not

	been reached before the 35 days after weeds emerge.
Fertiliser	30% applied at sowing and 70% applied as top dressing within 35 days after sowing. Five fertiliser levels: 10kgN, 20kgN, 30kgN, 40kgN and 50kgN/ha.

Sources: Smith (2006); Department of Agriculture (2008); Department of Agriculture (2010)

Table 3.3: Input data for bean simulation

Item	Description
Soil description	All the 27 generic soil profiles developed by Koo and Dimes (2015) were simulated in all the grids.
Met files	Each grid had a Met file consisting of historical daily minimum and maximum temperatures, radiation and rainfall over 30 seasons.
Bean cultivars	Three cultivars are simulated: Early, Medium, Late maturing
Sowing density (plants/m2)	26 plants/m2 (260 000plants/ha)
Sowing depth (mm)	30
Sowing window	15-November to 10-January
Row spacing (m)	0.5
Weed sowing density (plants/m2)	12
Weed sowing depth	15mm
Weeding	Maximum of four in-crop weeding times were set. The maximum days to weed after emergence was set to 35 days. This is provided a weed biomass threshold of 300kg/ha has not been reached before the 35 days after weeds emerge.

| Fertiliser | 70% applied at sowing and 30% applied as top dressing within 28 days after sowing. Five treatments levels, 10kgN, 20kgN, 30kgN, 40kgN and 50kgN/ha. |

Sources: Smith (2006)

Sowing for both bean and potato crops were set to occur at the first opportunity when a cumulative rainfall amount of 20mm is received over five consecutive days, and a soil water of 30mm is achieved within a sowing window from 15-November to 10-January. If this criterion is not met, the model was set to force sowing on the last day of the sowing window (10-January).

Table 3.4: Input data for potato simulation

Item	Description
Soil description	All the 27 generic soil profiles developed by Koo and Dimes (2015) are simulated in all the grids.
Met files	Each grid had a Met file consisting of historical daily minimum and maximum temperatures, radiation and rainfall over 30 seasons.
Potato	APSIM has only one cultivar, Russet.
Sowing density (plants/m2)	15 plants/m2 (150 000plants/ha)
Sowing window	15-November to 10-January
Sowing depth (mm)	100
Row spacing (m)	0.75
Weed sowing density (plants/m2)	12
Weed sowing depth	15mm
Weeding	Maximum of four in-crop weeding times were set. The maximum days to weed after emergence was set to 28 days. This is provided a weed biomass threshold of 500kg/ha has not been reached before the 28 days after weeds emerge.

| Fertiliser | 70% applied at sowing and 30% applied as top dressing within 35 days after sowing. Five treatments levels, 10kgN, 20kgN, 30kgN, 40kgN and 50kgN/ha. |

Sources: Smith (2006); Food and Agriculture Organization (2009); Department of Agriculture (2013)

3.3. ASP.Net

Watson (2013) defines a frugal information system as one that is developed and deployed with minimum resources to meet the pre-eminent goal of the client/users. These information systems are developed with very little resources being required and with an emphasis being on the scope and time of the project. In order to accomplish this, a powerful, patterns-based framework was chosen to construct the web implementation. ASP.Net is a web development model that is part of the .NET framework which includes the necessary services to develop web applications at enterprise level but only requiring minimum coding (Microsoft 2016a). This allows web sites and pages to be setup in a timeously fashion. The web model offers flexibility and extendibility with many asp.net features allowing easy incorporation of custom structures into applications. It was also built with performance whilst being secure in mind offering features like precompilation, configurable caching to optimize the performance of web applications and relatively easy authentication and authorisation features (Microsoft 2016c). ASP.Net essentially offers all of the necessary services available to create a frugal solution that is still at the same time powerful, efficient, secure and versatile.

3.4. ASP.Net Model-View-Controller (MVC)

Of the three paradigms offered by ASP.Net, the MVC design pattern was chosen for the web implementation. The ASP.Net MVC framework offers a high-in-productivity web programming model that promotes clean code architecture, test-driven development and powerful extensibility (Gao *et al.* 2016). This allows developers to create dynamic websites that enable a clean separation of concerns and gives full control over markup for agile development (Microsoft 2016b). The advantage of this is that it makes it easier to manage complexity by

dividing an application into the model, the view and the controller. It gives developers the power to alter anything in a web application through the use of languages like C#, CSHTML, CSS and JavaScript.

One of the most appealing features available to ASP.Net MVC developers is the responsive design it offers, allowing a broad range of clients, including browsers and mobile devices, to access the implementation without encountering compatibility issues. It also is compatible with many client-side technologies such as jQuery and Ajax to provide a rich end-user experience and quick response time. The ASP.Net MVC framework is open-source software which makes it accessible to all developers wishing to take advantage of this powerful model. It also offers very useful database tooling features, one of which is Code First Migrations. This feature enables developers to alter data models and deploy the changes made to them by only updating the database schema, without having to waste time re-creating databases (Dykstra 2014).

3.5. Client-side rendering with Mapbox GL JS

Traditionally, the way maps are displayed on a web browser is by downloading raster images (a set of grid dots called pixels) from a server and then have these images placed parallel to each other to make up a full screened map. If however, any information on the map is altered, the browser has to send further requests to the server for new images to be downloaded, it cannot be completed client side (Eriksson and Rydkvist 2015).

Mapbox GL JS is a vector tile-based, JavaScript library that takes advantage of WebGL to visualise interactive maps. With the introduction of WebGL, new frontiers have opened up in terms of delivering advanced graphics content to end-user browsers. By leveraging this technology in the displaying of maps means that only source data is sent to the web browser, where the device's GPU then renders the map. This is quite beneficial as it allows the changing of appearance, the addition of new features and less data transfer. The Mapbox GL JS library is based on vector tiles which are structures that contain geometries and metadata such as places, roads or rivers that are stored in a special, compact format. This holds a considerable advantage over other mapping libraries such as Google Maps that make use of raster-based imaging, as vector tiles render faster, are more efficient and offer real-time styling (Belousko 2016).

One of the features that distinguish Mapbox GL JS apart from competitors and the primary reason of why this JavaScript library was chosen is how it stores its web maps, which may contain millions of tiles. This remains a huge problem for other mapping libraries as they are unable to handle large amounts of custom data. To overcome this problem, the Mapbox team has developed an open-source data format called MBTiles for storing tiles in a single SQLite database. The reason why this was used is that it is available on all platforms, including mobile devices and doesn't require any kind of setup, which makes it highly portable. MBTiles also offers a very efficient way for storing duplicate tiles where it is able to reference multiple tiles of the same image without the need to reload the image (Belousko 2016).

In order for users to find their precise location easily in the case where they might not be as literate with technology or have an understanding of navigating geographical maps, the geolocation function will be used. This will allow users to, at the click of a single button, find their precise location by accessing the browser's geolocation API to locate the user on the map. This allows users that only want specific information to their vicinity, to be accessed within a matter of seconds with the least amount of user interaction required. It helps keep the proposed web solution a viable option to as many potential users as possible without altering the design or other features to accommodate for it.

The Mapbox GL JS library suffers only to the fact that web sites that take advantage of this library require graphics processing units (GPUs) by the devices that access them, this due to the client-side rendering. This will only be seen as an issue to users that are on mobile phones that are roughly five years or older.

3.6. Modelling a Frugal Decision Support Tool

As this is a frugal information system, there existed a single focus when development was taking place. That was to allow subsistence farmers to seamlessly connect to the APSIM-based database for relevant information access. That meant creating a web site that was user-friendly and simple to understand. In order to realize the system design, it's esential that modelling take place first to provide a blueprint of the system. In order to accomplish this, use case narritive (UCN) was selected in order to model out the functional requirements and scenarios the system will exhibit. UCN was selected as it

provides a textual representation of the events that occur between the actor and a system (Popel 2003). They are applied by describing each use case in detail, following the traversal across the system in order to meet a requirement. This helps to create a visualisation of the system and how it operates and provides an understanding medium for both developers and clients about the functions the system should demonstrate. Use case narrations provide detailed context about all possible scenarios that exist in a system and their relationships. This helps to identify and eliminate, both misunderstandings and possible problems before any further progress is made on the information system (U.S. Deptartment of Health and Human Services 2009).

The proposed decision support tool was modelled using UCN in order to provide a clear and concise understanding of the processes involved and how they would be triggered by users. Table 3.5 presents the overview of the use case narrative for the decision support tool.

Table 3.5: Summary of use case narration for the decision support tool.

USER CASE ID:	USER CASE NAME:
USC-1	View current location
USC-2	View how web elements function
USC-3	View different layers on map
USC-4	Search for specific location
USC-5	Perform optimization
USC-6	Perform compatibility test

A typical use case narrative involves an actor (primary stakeholder who benefits from the execution of the use case), interested stakeholders, use case desciption, pre-condition, trigger, typical course of events, alternative paths, conclusion, business rules and assumption. The actor is the primary stakeholder

that achieves a result and benefits from it by utilizing the system. Interested stakeholders are those that have vested interests in the system and how it behaves. Pre-conditions are what criteria must be true before a use case can initiate. Triggers are the catalysts that cause events to be initiated. The typical course of events are the steps in which the use case is realized, with alternative paths being what the system defaults to if there is a condition that is not met or a problem arises. The conclucsion specifies the criteria in which the use case must exhibit in order for it to be completed. The business rules involve the unique rules and methods of the business that the system should follow and assumptions are what the developers expect users to have when using the system.

In order to build upon and supplement the UCN that was described, a more technical model was created to describe the overall frugal information system, during which other technical elemets were also decided, in the form of data structures and programming languages used to construct the system. In order to perform this, a class diagram is designed. A class diagram in this context is part of what makes up the Unified Modeling Language (UML). UML is a modeling language in the field of software engineering and provides ways in which to visualise a system's artectural blueprint in the form of a diagram. A class diagram describes the static structure of object-oriented systems by showing the system's classes, their attributes, operations and the relationship between these objects (Soler *et al.* 2010). Class diagrams also serve as the basis for generating artefacts for systems, such as base code.

Figure 3.1 presents the class diagram of the frugal information system. As described in detail in the previous chapter, there was no need for a specific database apart from the storage of soil definitions and due to the implementation of code first migrations thanks to MVC, an overall class diagram is shown with the database schema as part of the class diagram. The overall class diagram is used to show the static structure of the system and relationships between objects, along with their methods and operatations .

Figure 3.1: The frugal information system class diagram

3.7. Single Page Application (SPA)

In traditional modelling of a system, there would be thorough modelling that would need to be conducted in order to plan out the user interface and how different pages might interact with each other. Despite web applications being extremely popular now, they still suffer from poor interactivity and responsiveness towards end-users (Mesbah and van Deursen 2007). As explained in chapter 2, a frugal information system is designed to meet the preeminent goal of the client. As such, there is one primary design goal that is focused on, in this case being able to provide sufficient feedback to assist farmers in making strategic crop planning decisions. For this reason, the web solution was designed as an SPA.

This technique is used for creating interactive web applications made up of only a single web-page interface. The page consists of individual components that independently change without having to refresh the page. SPAs use Asynchronous JavaScript and XML (AJAX) and HyperText Markup Language 5 (HTML5) to create fluid and responsive experiences when using a website. Mikowski and Powell (2013) state that an SPA can deliver the best of both worlds to users – the response time of a desktop application and the portability and accessibility that a website offer. Some further benefits include:

- SPAs render in a similar fashion to desktop applications. Portions of the interface are only rendered when needed to. In contrast to traditional web pages that need to reload an entire page for every user action that is processed. This can especially be detrimental when dealing with large information or the server being under load, as this reload can take long and effectively disrupts the user's experience.

- SPAs minimise response time by feasibly moving as much working data and processing possible from the server, to the browser. This cuts down on requests that are needed to be exchanged between server and browser by a very large margin which in turn improves the response time of the website.

By utilizing the SPA technique, the need for modelling of the user interface is eliminated as the web page is dynamically created as the user interacts with the information system.

3.8. Security

As the location of users is regarded as sensitive information, web browsers have started to deprecate such features on non-secure origins to ensure that these functions are not only secure when being sent to the server, but also so the websites that take advantage of such features are able to be to verified and this verified status be visible to end-users. This helps safeguard the privacy of users that wish to take advantage of such functions. If the user's location is available during a non-secure connection to a website, an attacker would be able to siphon this data and determine where the user is, which compromises the user's privacy severely (Kinlan 2016).

To ensure a strong and safe connection, the use of Cloudflare and the secure socket layer (SSL) encryption standard was selected to sit on top of the implementation. Cloudflare is a next generation content delivery network (CDN) that sits acts as an intermediary between the host's server where the site is hosted from, and the entire web where all users or software processes can access it. It handles all requests to and from a website. As all requests are then monitored by Cloudfare, a number of benefits can be viewed. Prince (2012) defines some of these as:

- Intercepting and stopping attacks directed to a site.
- Provides rich analytics e.g. developers can view if their site is reaching their target audience.
- Is able to determine what objects are static and therefore cacheable on a site to thus save on bandwidth consumption for the host and quicker response times for end-users. It must be noted that Cloudflare has a data centre located in Johannesburg where cached data is stored.
- Provides a gateway for network protocol translation between internet protocol version 4 (IPv4) and internet protocol version 6 (IPv6).

As the proposed implementation will be available to use by all without needing to authenticate the person browsing the web site, it was important to implement a gateway between the site, and the users that access it. Why this is needed is that as many potential unauthenticated users might use the site, the web traffic generated will increase too. While this is good in theory, it means that the site can be also easily be bombarded by a series of nefarious procedures such as a distributed denial of service (DDoS) attack. With Cloudflare, it helps prevent

attacks such as that by screening all requests coming in to the server so that they can be filtered out and never are performed.

In the same way that Cloudflare is used to protect the host's web implementation from threats by using a gateway, SSL is a security technology aimed at protecting end-users by ensuring that the communication channel between the server and user is encrypted. Arai (2015) defines the SSL encryption protocol as a fundamental technology that's used to secure personal data that is processed browser-side and is sent to the server. This is done by initiating an SSL handshake between the server and browser where a series of steps take place to ensure that all parties are valid, including keys being sent and created in order to encrypt and decrypt data from both points and for that session alone. This ensures that communication between a site's visitor and the web server is confidential. Additionally, SSL offers visitors a way to verify that they're on the host's website and not that of an imposter through the use of a visual indicator, and that the website's content has not been in any way modified during transit. This is not only important when dealing with sensitive information, but also provides potential users with a sense of safety knowing that their personal information is secure. In the case of the proposed web solution, the sensitive information being transferred to the web server is the user's location. As this is deals with the user's privacy, it is imperative that the transfer of such data is kept as secure as possible during transit.

3.9. File System

Due to this study taking advantage of post-simulation output from the APSIM, the resulting files produced are relatively small in size but due to the sheer number, make up a very large file system that needs to be accessed in a quick fashion. They can be theoretically calculated per grid block in such a way: (4 (crop types) X 3 (soil textures) X 3 (cultivars) X 27 (soil type)) X 237 (grid blocks making up Southern Africa) = 230 364 simulation results. Because of this, the post-simulation images were chosen to be accessed from the filesystem as opposed to storing them in a database. According to Razeghi (2014), storing images in a database has several disadvantages:

- Queries can become very slow and this creates wasted overhead that the system needs to manage the locations of.

- Doesn't offer interoperability with other applications due to the images being on a database if other applications try to access from different databases and therefore reduces flexibility in the system.
- Migrating data can become a time consuming exercise, if for example you to switch to Oracle from SQLServer.
- Temporary files are created when retrieving images from a database. This is wasteful and unnecessary.
- If the database grows past an expected size, it might cause an issue with space as databases have a file size limit.
- Typically, more expensive in price than filesystem storage.
- Suffers from worse performance in general.

As performance has the highest priority with the images not containing private information that needs to be secured and this particular image procurement offering a very flexible solution, a filesystem approach was adopted with the pointer to each image being dynamically generated according to how the user's questionnaire was answered. This provides crop type, soil texture and cultivar. The soil type, being one of the twenty-seven defined by Koo and Dimes (2015) is not asked for directly as it relates to more of a scientific audience, but instead is derived from the answers chosen from the aforementioned variables. .

CHAPTER 4

EXPERIMENTAL RESULTS

This chapter delves into the results produced either through development or as a final result of the frugal crop decision support tool to assist farmers in making strategic decisions in regards to crop management. The main resolution undertaken in building the proposed information system was to support and validate the idea behind providing a quick and effectual solution to crop planning problems that have been observed in chapter two. Coinciding with that goal, it was also to ensure that the tool could be used by the largest possible audience. It will also examine all forms of output produced and expand upon those. As having reliable data was a necessity in this research; temperature and rainfall had to be secured from the AgMERRA (Agriculture modern-era Retrospective Analysis for Research and Applications) Climate Forcing Dataset for Agricultural Modelling. This was then processed as input into the APSIM platform to derive a baseline from which the web implementation could be built upon.

4.1. APSIM output

The simulated crop yields for a variety of fertilizer options, crop cultivars and soil types under a forecasted season type (Below Normal, Normal or Above Normal) are presented as boxplots for each grid. Table 4.1 shows an example of one such output. The APSIM report module creates a column based document in which record data is stored from the APSIM simulations that are run (APSIM 2016). This partial output in table 4.1 shows a simulation run over a number of years using the maize crop type and the soil type in the targeted region which is then run against climatic information from the Agricultural Modern-Era Retrospective Analysis for Research and Applications database. As informative as this form of output is with showing simulated outputs over the specified time frames, to farmers that have no experience or understanding of agricultural science, there is a slim chance that anything can be gleaned from the current format the result is in. As the result of this study was to be understood by subsistence farmers, each output file was run through a script to produce a more user-friendly graph that can appeal to a much wider range of audience as can be seen in Figure 4.1.

Date	esw	day	year	weed.yield	maize.yield	stover	weed.biomass	maize.biomass	rain
(dd/mm/yyyy)	(mm)	(day)	(year)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(mm)
13/03/1981	88.461	72	1981	0.0	0.0	1344.5	304.0	1344.5	0.000
09/03/1982	30.661	68	1982	0.0	0.0	756.2	50.3	756.2	0.000
03/03/1983	0.067	62	1983	0.0	0.0	636.0	0.0	636.0	0.000
18/05/1984	3.612	139	1984	0.0	0.0	1373.5	0.0	1373.5	0.000
14/04/1985	3.817	104	1985	0.0	0.0	1723.1	89.7	1723.1	0.000
30/04/1986	3.441	120	1986	0.0	0.0	959.4	68.1	959.4	0.000
01/05/1987	0.000	121	1987	0.0	0.0	300.1	0.0	300.1	0.000
27/03/1988	110.415	87	1988	0.0	0.0	2336.9	0.0	2336.9	3.400
23/02/1989	78.720	54	1989	0.0	0.0	421.1	83.9	421.1	32.500
05/03/1990	12.559	64	1990	0.0	0.0	1478.6	121.8	1478.6	4.900
21/04/1991	77.523	111	1991	0.0	677.3	2238.1	59.4	2915.4	0.000
07/04/1992	11.914	98	1992	0.0	0.0	429.4	13.5	429.4	0.000
26/05/1993	0.000	146	1993	0.0	0.0	660.4	0.0	660.4	0.000
16/04/1994	4.192	106	1994	0.0	463.7	1901.2	19.4	2364.9	0.000
19/04/1995	29.506	109	1995	0.0	42.4	1811.0	45.8	1853.3	0.000
08/03/1996	152.360	68	1996	0.0	655.5	2484.4	155.7	3139.9	0.000
02/03/1997	33.973	61	1997	0.0	0.0	1188.4	115.2	1188.4	0.000

Table 4.1: A partial of an APSIM output file showing the defined input fields that were specified in configuring the simulation.

The graph in figure 4.1 shows an example of the processed output from table 4.1 into something a lot more user friendly and readable. It looks at the same crop type and shows the end-user what the yield is expected to be according to the amount of fertilizer used when growing a specific cultivar.
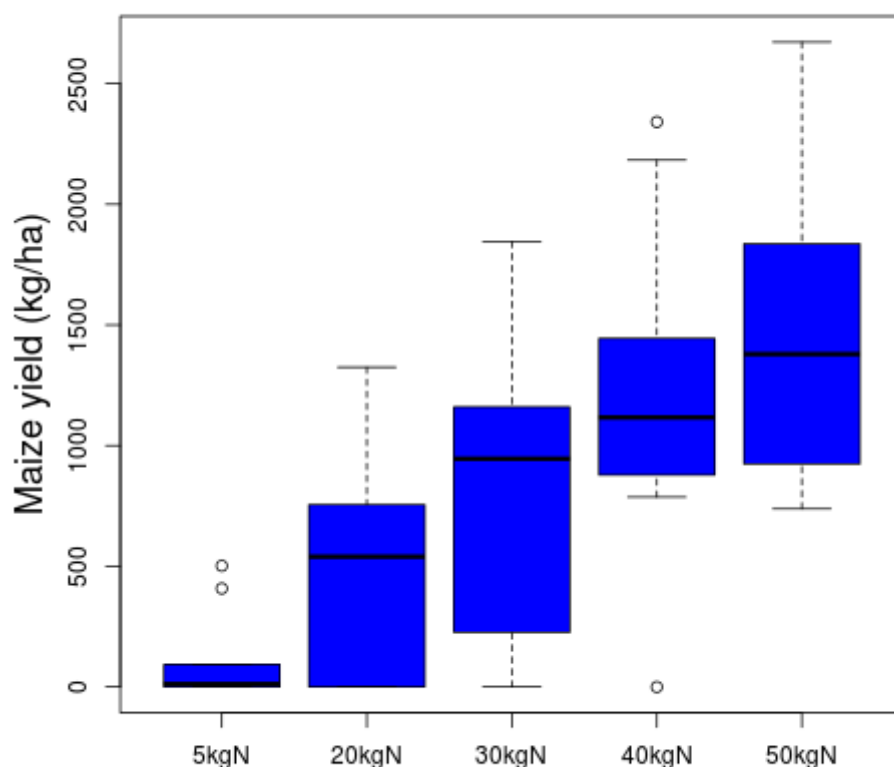
Figure 4.1: The graph shows crop yields possible under the chosen conditions of soil and predicted rain for different fertiliser levels, indicating the variations a farmer might encounter when using the different volumes of fertilizer.

4.2. Implementation of the frugal crop planning decision tool

This section reviews the implementation of the crop decision support tool that was built from the architectural blueprint described in the above. The single and prime objective of this research was developing a decision support tool to aid

subsistence farmers in making crop management decisions. The proposed system should therefore assist subsistence farmers in making optimal strategic decisions in crop planning. The prototype implementation provides the basic functions that were defined in the UCN. The overall post-simulation information is stored in the filesystem, with soil descriptions making up a small database which provides for easy access for future use if the system is to be expanded. The prototype is relatively simple to use and has been designed to accommodate users with poor computer literacy skills.

4.3.   Functional description of the crop planning decision tool

The frugal crop decision support tool is an instrument designed as a service that all members of the public wishing to get assistance in crop management decisions can make use of. As such, it was decided that user authentication was not necessarily required as it only proves to be an unnecessary hurdle to users that don't have good computer literacy skills. Thus, any unauthenticated user can visit the site from https://www.frugalcropdst.com, to which a loading screen was designed to show until all elements of the SPA are loaded in the background. This can be seen in figure 4.2. Once all elements have loaded in the web browser, the user is transitioned into the main interface which houses all of features required to provide crop decision support. This can be seen in figure 4.3. The lock next to the URL verifies and shows the user that the website has been verified and that all information incoming and outgoing is encrypted.
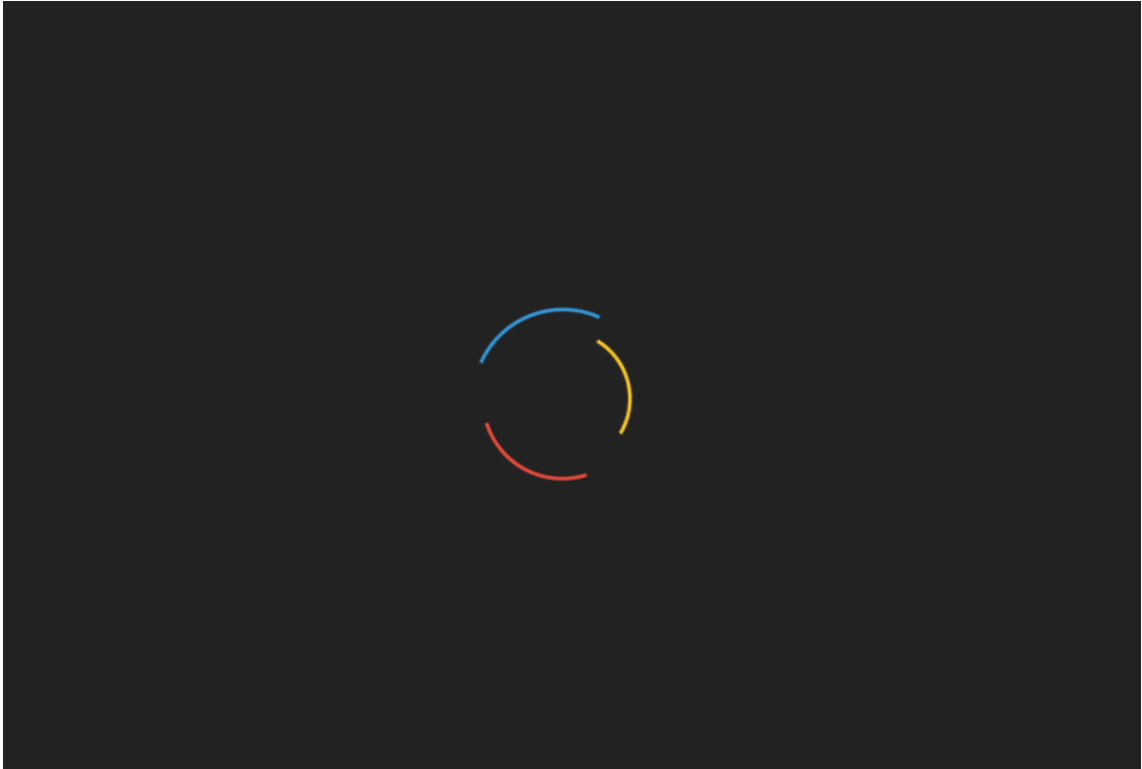
Figure 4.2: **Loading screen shown to users whilst all elements, data and evaluation checks are run on the back-end of the web application.**
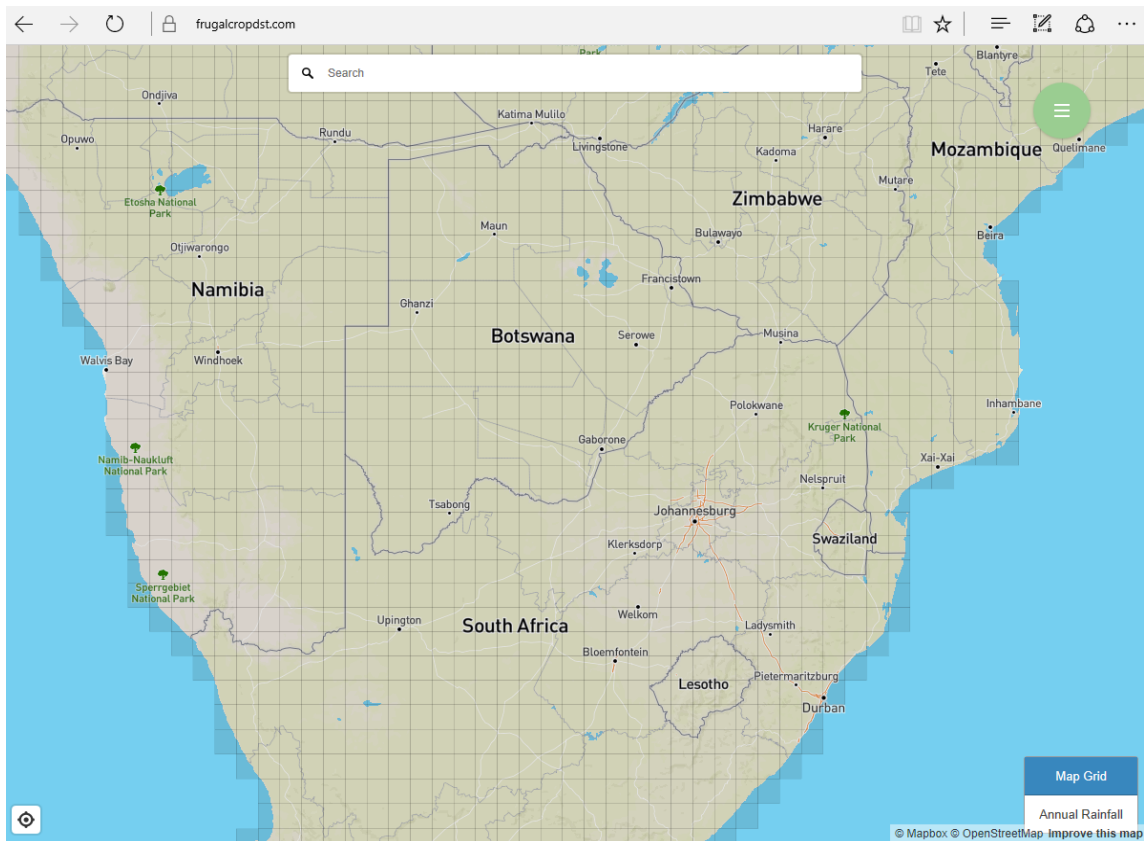
Figure 4.3: The SPA is loaded with all elements ready to be used by the user. The ability to see this stage of the application means that all elements have loaded successfully.

4.3.1. Geolocation tracking of users

Tracking the user through geolocation is performed when the user clicks on a button located in the bottom left hand corner of the user's screen. A prompt is displayed about what the system is about to perform as verification to the user, as this is a highly private function. When the user agrees to this, they are then pinpointed immediately to their location with an interactive transition showing the user where they are traveling to from their current location. This can be viewed in figure 4.4.
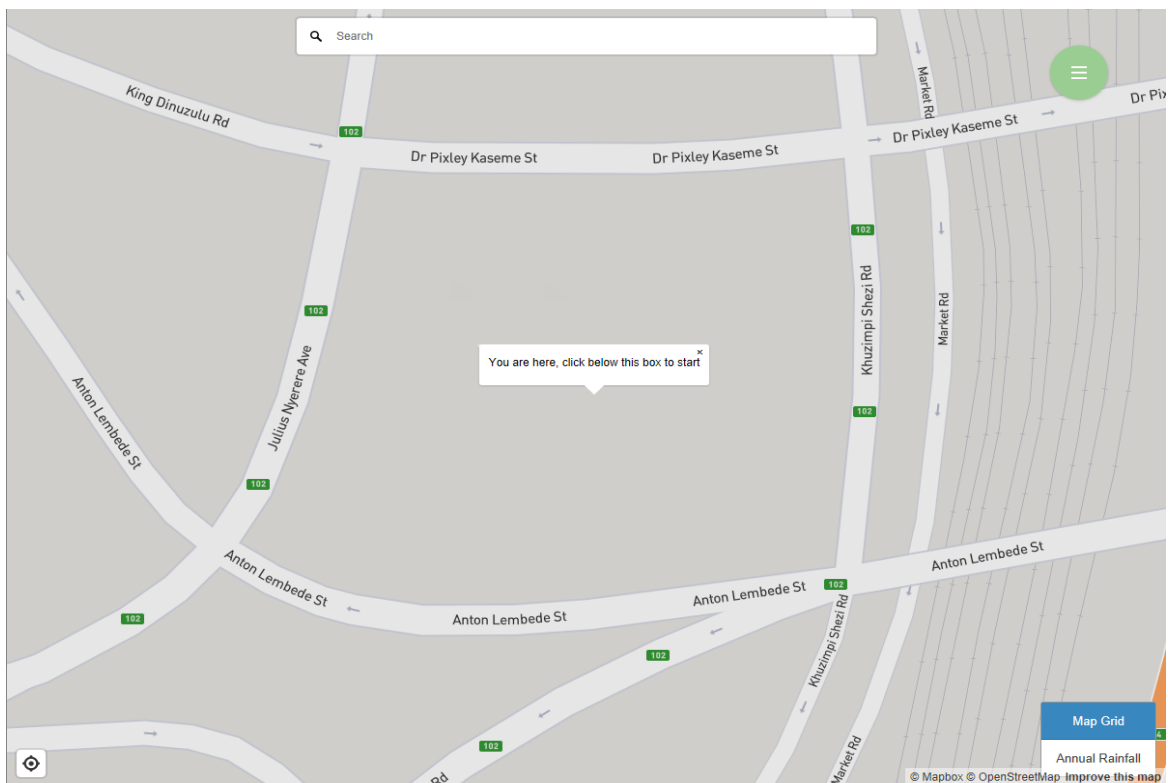
Figure 4.4: Shows current location after geolocation tracking has taken place.

4.3.2. Web element functions

This helper feature enables new users to view what each element's function is on the webpage so that users aren't left feeling confused about how to make use of the website. This can be viewed in figure 4.5.
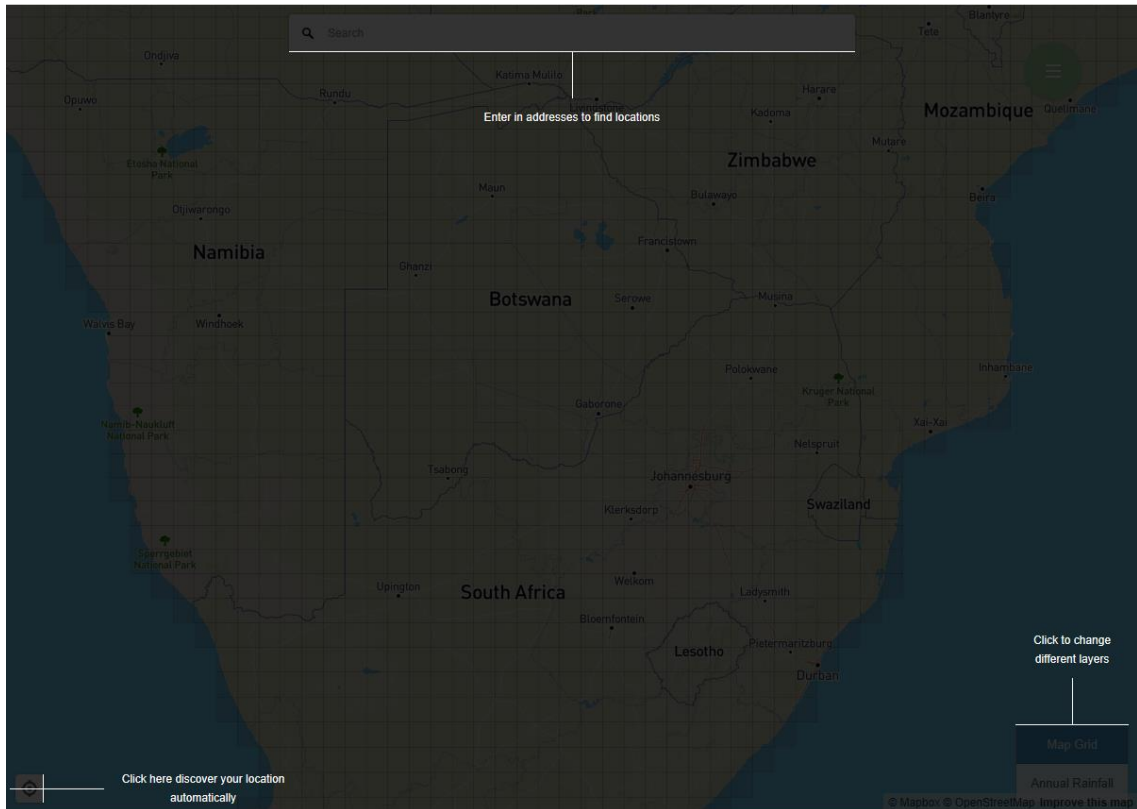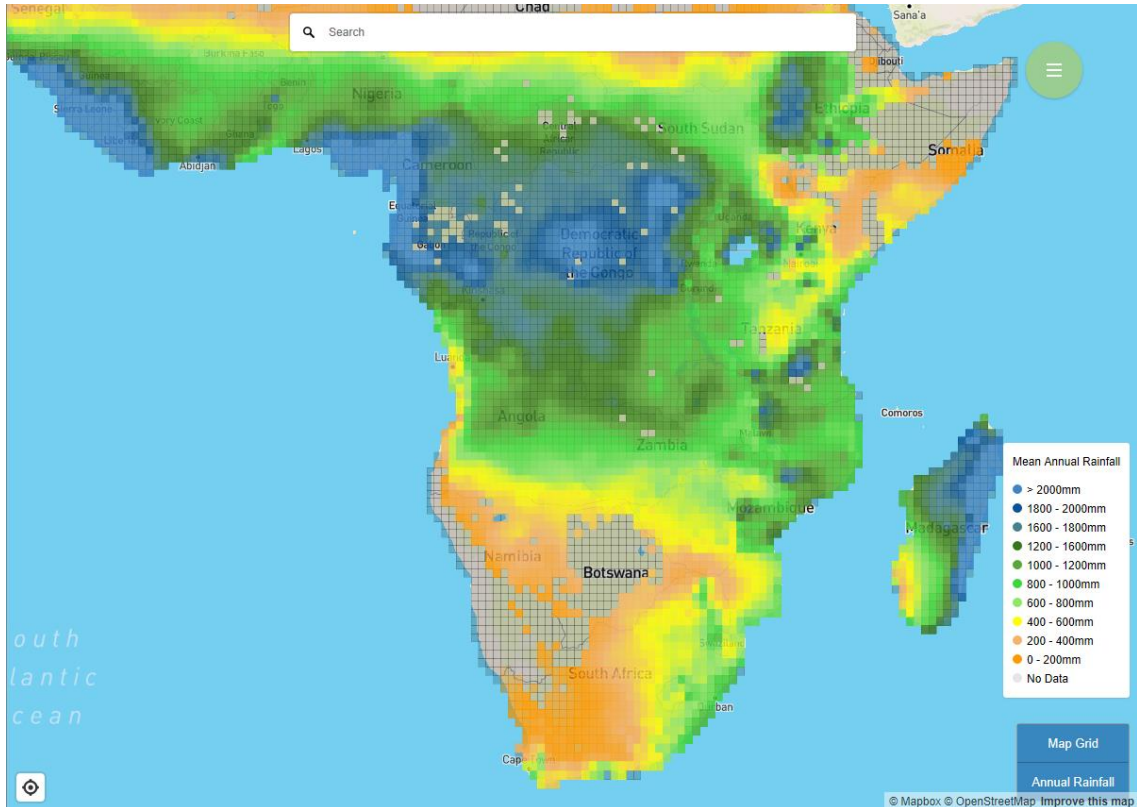

Figure 4.5: Shows the user what each feature is used for as a silhouette over the main interface.

4.3.3. Overlays – Mean Annual Rainfall

This feature is available to users if they wish to view different overlays on the geographical map to show useful information. In this case, the mean annual rainfall in Sub-Saharan Africa is displayed. This can be seen in figure 4.6.

Figure 4.6: Showing an overlay turned on to provide other information. This can be enabled and disabled easily from the toggle buttons located in the bottom right hand corner of the site.

4.3.4. Location search

This feature allows users to search for specific locations using unique identifiers of that location. This can range from addresses to specific landmarks in the region. A number of results are produced according to what is entered by the user and then the map is transitioned to the specific location selected. This can be seen in figure 4.7.
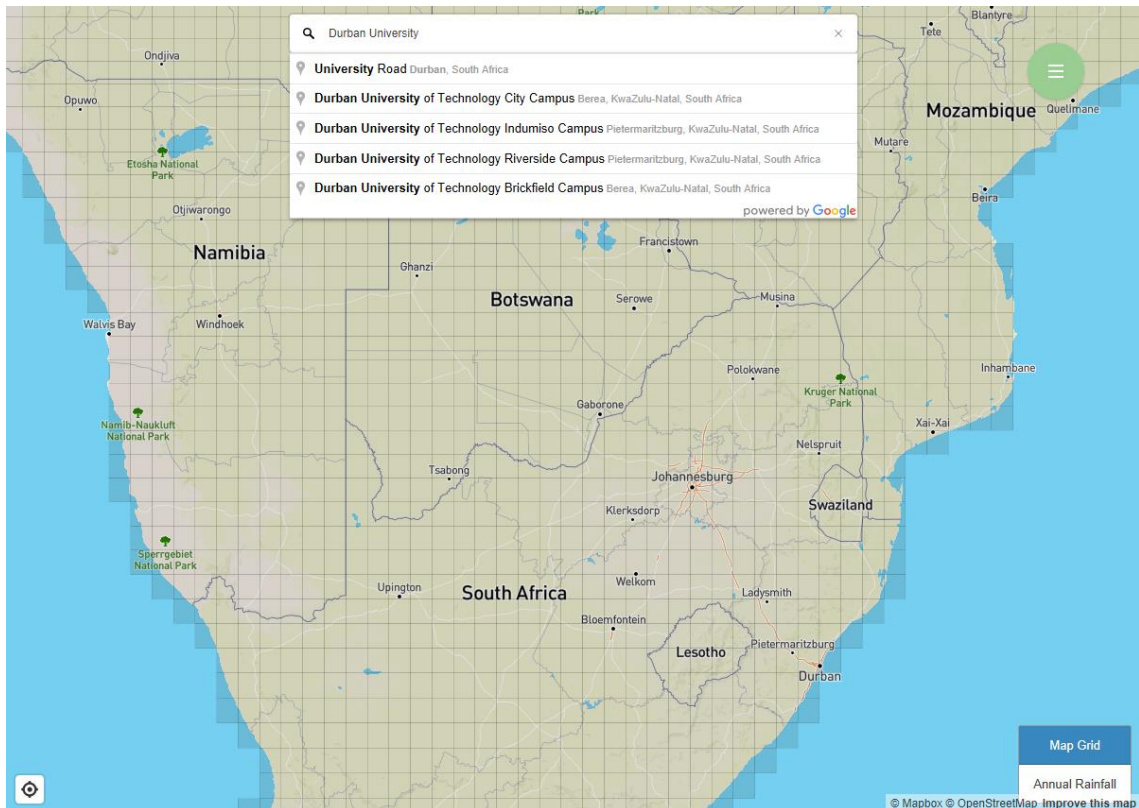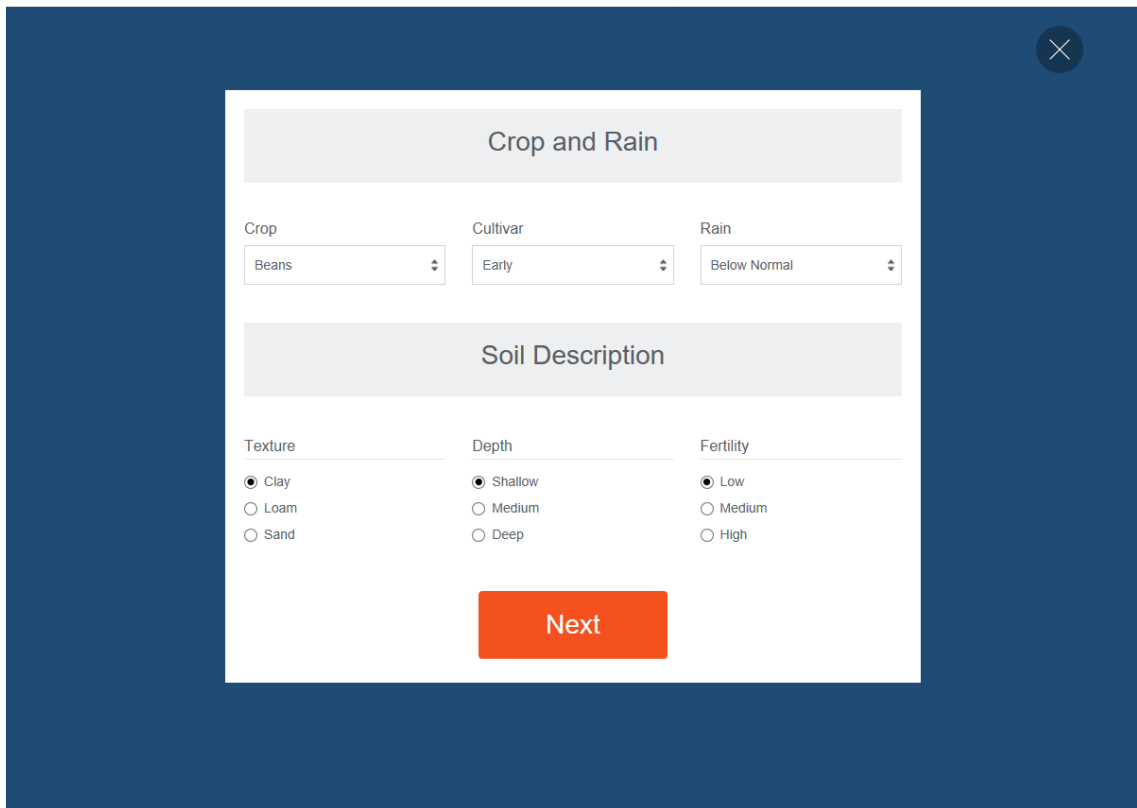
Figure 4.7: **Shows multiple search results according to user input.**

4.4. Crop planning optimization

The main function and goal of the system, to provide feedback to users regarding crop management decisions. This feature is accessed when users have located the area they wish to receive feedback on. Once the region has been clicked on, a small and simple questionnaire is transitioned into. This can be seen in figure 4.8.

Figure 4.8: Shows the questionnaire that users have to answer.

From there, users have to select a number of answers about the crops, rainfall and soil properties in the region. Once that has been completed, a search is made to find the post-simulation information for that region and properties selected and is displayed back to the user. This can be seen in figure 4.9.
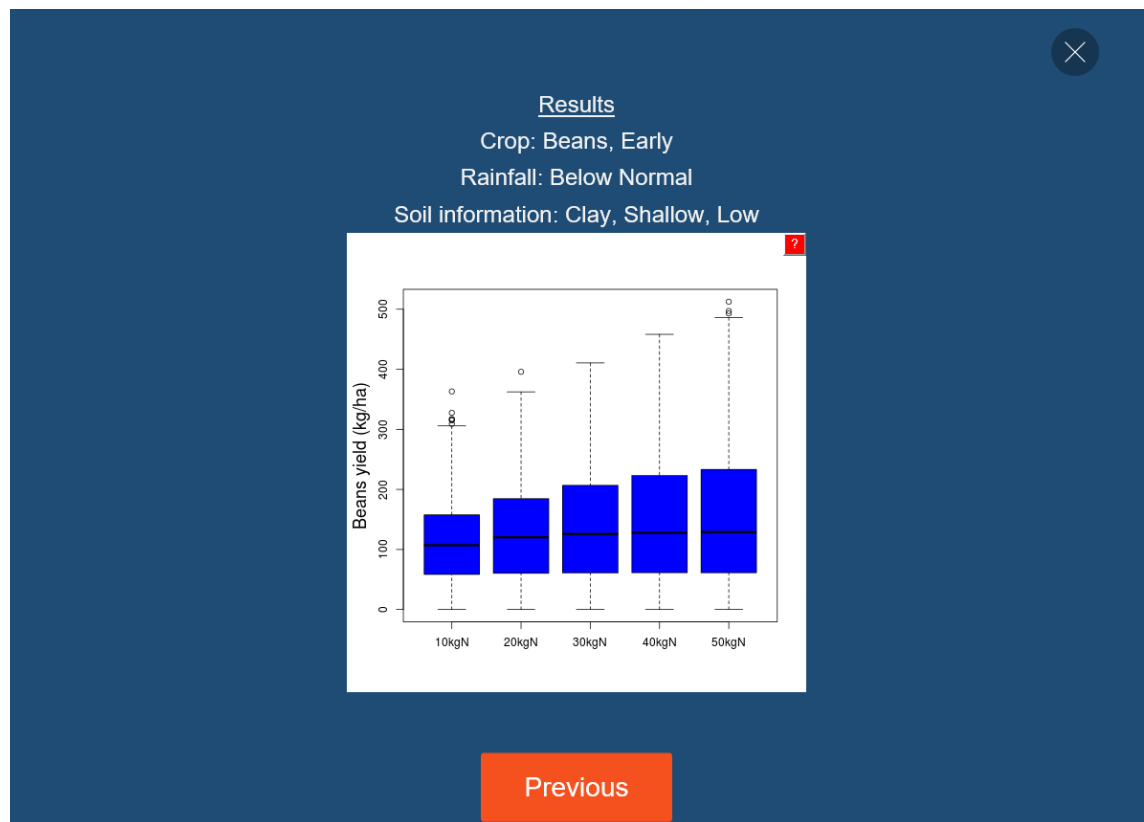

Figure 4.9: Output produced to users. This informs users on their selection they made on the previous page and has displays a graph corresponding to their location and input parameters. This informs users on how much fertilizer needs to be introduced when planting and shows the corresponding crop yield for that.

4.5.   System performance evaluation

In order to validate the information system, evaluation needed to take place. As stated by Hevner and Chatterjee (2010) regarding design evaluation methods, experimental and testing evaluation methods were selected for this research. As a prototype was developed as a goal of this research, a simulation was conducted. This involved executing the artefact with artificial data and formed part of the functional testing. An illustrative scenario was drawn up to show the artefact performing in a real world scenario to demonstrate its utility. It was then

supplemented using the u-constructs that were touched upon in chapter 2 as a type of informed argument to determine if the system satisfied the four information drives that were extended upon from Watson (2000). Structural testing was then conducted on the information system. This dealt with executing the artefact's interfaces to discover if there were any failures or defects and to perform unit tests to test quality, functionality, and achieve a comprehensive code coverage showing all execution paths of the artefact (Peffers *et al.* 2007; Hevner and Chatterjee 2010).

4.5.1. Illustrative scenario

The system is tested with a scenario in which a subsistence famer has just enough money to purchase one type of crop in with the intent of feeding his family. In order to view what crop would perform the best or even if it would be suitable at all to grow crops in his region, he visits the system, as shown in figure 4.3. The farmer does not possess a strong understanding of the controls that are available to him so he clicks on the tutorial which shows him what each element on-screen does. This can be seen in figure 4.5. The farmer wants the easiest possible option so he clicks on the geolocation button where he is prompted, accepts and is taken to his current location. This can be viewed in figure 4.4. He clicks on his grid as prompted to do so and a questionnaire is opened up. The farmer then goes through the process of selecting the crop, rain and soil description options which can be viewed in figure 4.8 and once he's satisfied, clicks next. The search result then returns post-simulation information which can be viewed in figure 4.9 about how well a crop will perform under the specified conditions selected before and how much fertilizer is required to produce the appropriate crop yields displayed in each column. If the farmer does not understand this visual representation, there is an option to view a help page describing how the images are meant to be interpreted. This can be viewed in figure 4.10.

How to use this site

This site is primarily aimed at improving certain African crop staples through assistance with decisions on how much fertiliser to use based on the predicted rainfall. Other useful information on improving crop yields can be found on the improving crop yields page. To use the site:

1. Locate the region close to your farm by zooming in on the map. Zooming is done using the +- tab on the upper left hand side of the map. Otherwise use your mouse.
2. Choose your crop from the drop down tab on the left.
3. Choose the cultivar from the tab below this. Early, normal and late cultivars are those that best suit the climatic conditions and expected aims. Generally ...
4. Choose your soil type by marking the tab choices under <u>texture</u>, <u>fertility</u> and <u>depth</u>: Texture: Clay, Loam, Sand. If you are not sure a simple test is to take some soil and place it into a pyramid on a flat surface. Clay will remain in place, sand will collapse and loam will have sides that run. (I can not find a reference but this is what I remember !!!) Fertility -soil organic carbon content Low: less than 0.7 % Medium: between 0.7 and 1.2 % High: greater than 1.2 % (How do they know how to judge this????) Rooting Depth Shallow: less than 90 cm Medium: between 90 and 150 cm Deep: deeper than 150 cm
5. Choose the rainfall that is predicted for the coming season. This prediction is found by turning on the predicted rainfall toggle at right hand side. When you locate your farm position on a rainfall map the predicted rainfall will be one of:

   1. Above normal – in the highest 33% of historic rainfall for that location
   2. Normal – in the middle 33% of historic rainfall for that location
   3. Below normal – in the lowest 33% of historic rainfall for that location

   You then fill the rainfall tab on the left with one of these options. Use the predicted rain from the map or your own predictions. You can also compare results using different predictions.
6. Now return to the map and place your cursor on your location. Click the mouse and a graph will appear. If no graph appears either that location has not been covered by our project or it is a region not entirely suitable for that crop.
   The graphs show crop yields possible under the chosen conditions of soil and predicted rain for different fertiliser applications. To read these graph, first understand that they are box plots. Thus, the dark horizontal line is the median (the middle value of the data). The blue boxes are where 50% of the data is found and the other horizontal lines bound most of the data results.
   To read the graphs compare the medians (dark horizontal lines) and the overlap of the boxes. If the medians and boxes do not overlap then the highest yields are more likely for a particular fertiliser application. The boxes represent the risk because there is a chance that conditions will give as little (or more) yield in the range provided. THE LARGER THE SPREAD THE MORE THE RISK. You need to weigh up the possibility of a better yield against the cost of the added fertiliser. Keep in mind that other less costly methods can improve yields (see our pages on improving crop yields).

Two examples are given here:

1. For maize, using an early maturing cultivar with a clay, medium texture and medium depth soil and an above normal expected rainy season in the Ladysmith region of South Africa, the following graph is predicted:

Figure 4.10: Screenshot of the help page describing how to use the site and read the corresponding output.

4.5.2. Information Drives

The four information drives, or 'u-constructs' that serve as the foundations for frugal information systems were built upon the four u-commerce elements that were first theorised by Watson *et al.* (2002). These aimed at overcoming the spatial and temporal boundaries faced by e- and m-commerce and represents the next generation of commerce. Junglas and Watson (2006) saw the potential of these concepts and how they could be applied to innovation in information technology. The u-constructs we derived by observing recent trends in information technology innovation and the way in which it's currently evolving.

These four information drives are used to see if proposed frugal information system satisfies the u-constructs:

Ubiquity: This is the culmination of both portability, accessibility and reachability. Portability in this case being if the implementation can be accessed from any place and accessibility being if it can be accessed at any time. The

proposed web site meets this u-construct partially as the implementation is able to be accessed from any device that has a graphics processing unit which even in the event that potential farmers do not, can access the implementation from the nearest agricultural extension office. The site fully meets the accessibility clause as it is online and therefor, is available at any time for the user to take advantage of. As the proposed system does not require user-specific access, reachability does not apply in this context.
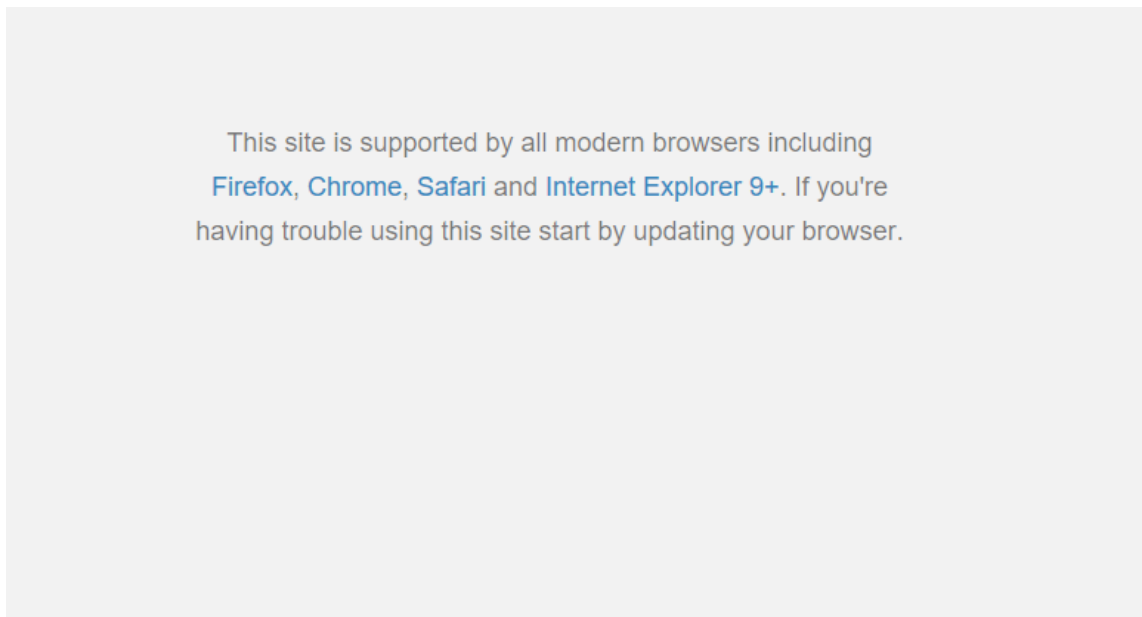
Uniqueness: The following u-construct is composed of how well a system is able to identify a user. Not only in terms of identity and the associated preferences of that identity, but also their geographical location. What this does is localise the implementation to specific parties. Whilst the system does not require identities as it strictly provides one-way feedback, it does cater for geographical positioning that adds to the user experience using the Mapbox application programming interface (API). This allows the system to locate a user by the click of a button and then references all data relevant to their location.

Universality: This concept follows the incorporation of interoperability, universal usability and multi-functional entities. It is the drive to overcome the incompatibilities that information systems suffer from. The way in which the proposed information system complies with this standard is through the use of ASP.Net MVC. This framework offers responsive design which was created in order to bridge the gap that was created by incompatibilities in information systems. It functions by detecting the resolution available on the device accessing the web implementation and then resizing all visible elements on the webpage, making it usable for the device. This ensures that no devices are isolated by the web element of this system and it can be used by the largest possible target audience.

Unison: This idea focuses on having integrated data accessible across multiple applications and devices so that users are able to access consistent information, regardless of the device being used. The proposed implementation does this by being online. By the system being online, it means that all devices essentially access the same data repository through the use of the devices browser, which has been a device standard for around 15 years.

4.5.3. Performing compatibility test

Whilst the site initially loads, a compatibility test is performed in the background to assess whether the browser and the device's hardware meets the necessary requirements in order to run the implementation. Figure 4.11 shows the result if the compatibility test fails and displays how it can be remedied to users.

This site is supported by all modern browsers including
Firefox, Chrome, Safari and Internet Explorer 9+. If you're
having trouble using this site start by updating your browser.

Figure 4.11: Incompatibility page shown to users that don't meet requirements. This informs users that they do not meet the required browser version.

4.5.4. Structural testing

The unit testing evaluation of the crop decision support tool was carried out using the xUnit testing framework. (Tillmann, de Halleux and Xie 2010); Andrews, Menzies and Li (2011) define the goals of testing software to be thorough and eliminating failures during runtime. Unit testing has been widely recognized as a way of improving reliability in information systems as it not only removes bugs during development, but also gives developers confidence to make changes to a complicated system knowing that unit tests cover the behaviour of what the system expects. Unit testing also promotes loose coupling when coding, ensuring a separation of concerns is maintained so that the system remains robust and scalable. However, it has been noted that configuring test code for individual classes can be a time and resource consuming practice, especially when dealing

with larger systems that can have many possible test cases (Wiederseiner *et al.* 2010).

The researcher has chosen to apply the xUnit testing framework which is a free, open-source and community focused unit testing framework created for the purpose of testing within the .Net framework. It is a mature framework and integrates well with other languages and tools such as ReSharper which make it an ideal choice for creating solid test cases. Comprehensive unit tests were created to run through all core logic in the system, to detect if any bugs were present that might've been missed. The runtime of the unit tests is also shown in figure 4.12. The average time for each individual test was 51 milliseconds, showing that the system delivers outputs at an optimum level.
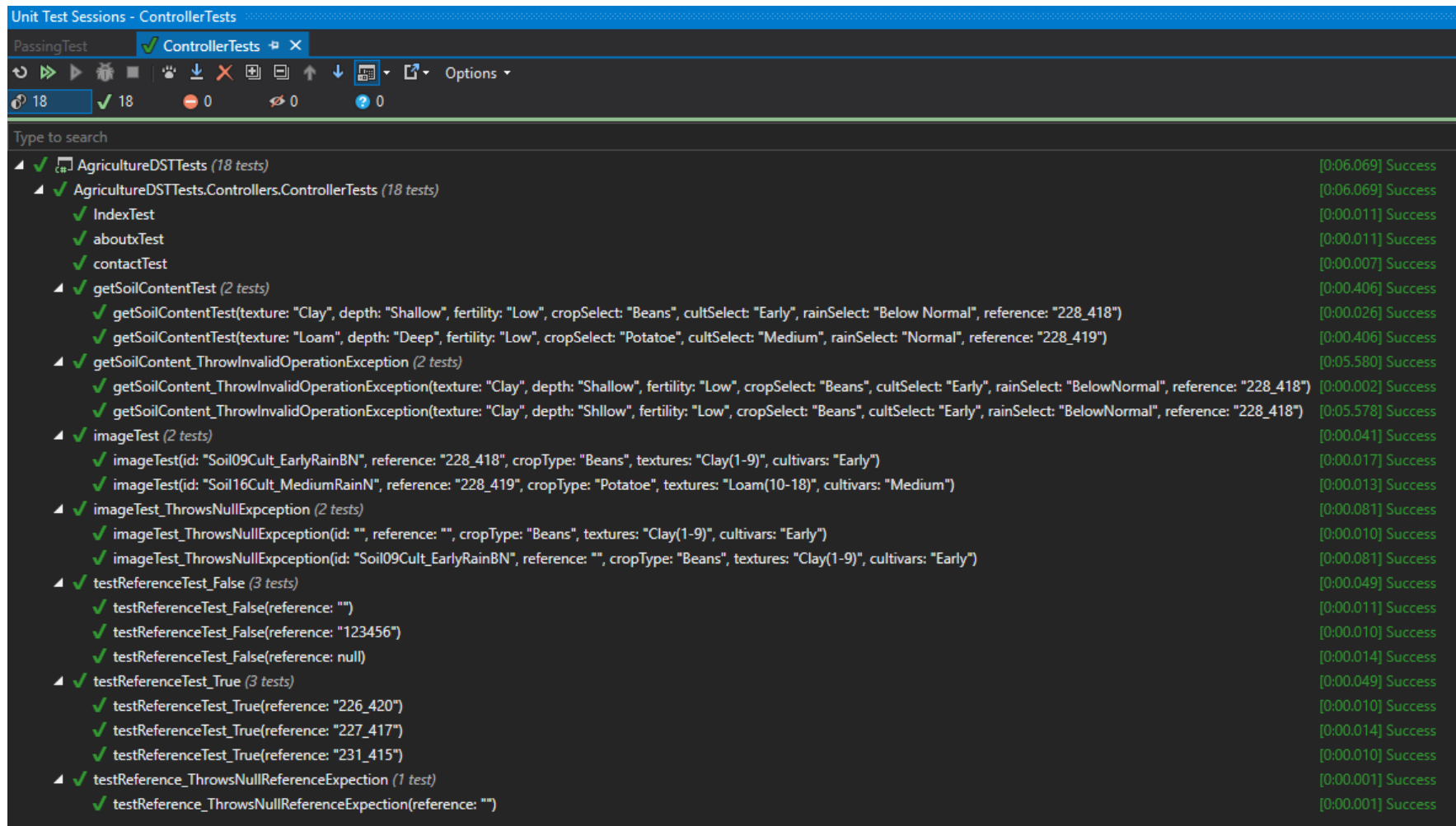
Figure 4.12: Application evaluation using unit tests

4.6. Conclusion

The output produced in the form of the prototype suggests that decision support tool provides a useful means for optimal crop planning. The suggested system can help subsistence farmers to effectively and efficiently utilize the amount of funding available to them, along with time and money. The approach taken using transmuted, post-simulation information from the APSIM combined carefully with the correct technology can help subsistence farmers determine what crops can perform the most effectively in their region. It also allows for a wide range of users as the system was designed to not alienate any users that might wish to take advantage of this implementation. The prototype was also tested in a variety of ways to ensure that it met not only its required functions, but also that the coding process involved in achieving those functions was evaluated thoroughly in the form of unit testing.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

This chapter discusses the summary of findings of this study with respect to the development of a frugal crop planning decision support tool to assist subsistence farmers. The discussion to follow will also cover reflections on the lessons and limitations experienced during the research work. The suggested recommendations are based on the overall outcome and experiences during the implementation of the crop decision support tool.

5.1 Summary of Study

This study explored the problems subsistence farmers face in terms of getting adequate assistance when making crop planning decisions and consequently the current tools aimed at helping those farmers. Recent studies have seen shown through technology and innovation, farmers can be assisted in crop management in a number of ways (Zhang *et al.* 2010). The overarching goal of this study was to develop a web-based, frugal information system based on the APSIM platform to assist farmers in making strategic crop planning decisions. The research objectives have been met in order to achieve the goal of this study:

a) To migrate post-simulation information from APSIM to a database that is easily accessible by any communication device.

   This objective was met through the transposing of the APSIM post-simulation data which took into account over ten years of climatic information, along with soil types that have been recorded in regions across Africa. The output produced by the simulation was transformed into a user-friendly format and type in which farmers are able to quickly understand what changes need to be made in order to have the best chance at increasing crop yield margins.

b) To develop a frugal web-based agricultural system that allows subsistence farmers to seamlessly connect to the APSIM-based database for relevant information access.

This objective was met through the development of a web-based crop decision support system that integrates post-simulation data for the entirety of sub-Saharan Africa. The post-simulation information ties in with a powerful mapping platform that allows users to easily traverse the entire continent showing the likelihood of crop sustainability in user-selected regions. With a strong focus on wanting as many users as possible to use this application, responsive design was implemented. This means that the system can be accessed by any device, as long as it contains a dedicated graphics-processing unit which most devices demonstrate now. Farmers are able to access relevant agricultural information relating to their specific region in a matter of seconds.

c) To conduct functional and structural evaluation of the developed frugal web-based agricultural system.

This objective was achieved by performing functional testing in the form of an illustrative scenario where functions of the system are demonstrated by feeding in data to the system and examining the output. This was further supplemented by examining the four information drives theorized by Junglas and Watson (2006). Structural testing was conducted by building unit tests for the web application. These covered the entirety of the logic core, feeding in test information to ensure a bug-free solution. Tests were also created to intentionally break the current build, to make sure exceptions are catered for.

The frugal web-based decision support system can be viewed as a tool that could contribute to effective crop management and help increase food security levels. Previous authors have suggested that through the use of technology and innovation, farmers can be assisted in the decision making process (Gent, De Wolf and Pethybridge 2011). Efficiency is also achieved through the use of many technologies, an example being the implementation of a content delivery network to ensure not only safety, but also the caching of browser-end files to increase load and response times.

5.2 Benefits of a Frugal Crop Decision Support Tool

The frugal crop decision support tool is a web-based system that enables subsistence farmers to seamlessly connect to the APSIM-based database for

relevant information access. The information system is highly robust as it makes use of a file system that can be easily updated with new simulation information without ever having to turn off or change anything programmatically. This ensures that the system is constantly up for users wishing to take advantage of it, and that it can be updated with new data relatively easily without ever having need of a programmer post-launch. Even though any user can take advantage of the website without ever having to create an account or relinquish any details, the web-application remains secure through the use of a content delivery network and encryption in the form of encoding data between the server and the CDN. This also ensures that no distributed denial-of-service attacks can ever affect the main server and that attacks can be subverted, allowing the site to still operate as per normal. The application also displays independence of other services or databases, meaning that no changes to the system need to be made wherever it is implemented, making it a low cost system to install and maintain.

The frugal information system addresses issues that current decision support tools still exhibit which make them either unusable to subsistence farmers, or have very low adoptability rates. Some of these ranging from offline solutions with high technology requirements, to linguistic and expertise barriers that make it difficult for farmers to use. During the design of the frugal crop planning decision support tool, these issues were looked at and addressed with technology and innovation, allowing anyone with a device that has internet capability and a dedicated GPU to access the implementation. It uses visual cues to guide users rather than rely on language which makes it easier to operate by users that might not be very technology literate.

The development of the crop management tool was based on the design science research aphorism, which is to contribute innovative and useful information systems that are relevant and are purposeful (Hevner *et al.* 2004). The frugal information system developed and reported in this dissertation contributes to design science and well as the ICT knowledge domain and satisfied the following requirements:

a) Minimalism - the interface of the system focuses on making only the essential elements aware to the user in an intuitive and interactive way that makes navigation simple.

b) Persistency - due to the focus on flexibility and loose coupling when designing the platform, new post-simulation information can be easily created or changed with little effort from different data sources if need be.

c) Protection - the filesystem and its contents are protected and secured through a content delivery network with no access being given directly to users.

d) Efficiency - the system is able to display, search for and output information in a matter of seconds from enormous datasets.

The frugal information system being proposed in this study focuses on the main point of developing an information system with a primary design goal, that pursues transforming a complex system in such a way that all users can take advantage of it. Further, this study contributes in the following ways:

a) The investigation of an approach to allow a large number of users to seamlessly access simulated agricultural information relating to their specific location with the least amount of input required.

b) The examination of several implementation issues of an online crop-decision support platform, including data structures for storage of simulated information, efficient retrieval of this information and providing a secure environment for this.

c) The experimental evaluation of the proposed frugal information system demonstrates that the direction taken in moving information online and how it's delivered are done in an efficient and safe way.

The frugal crop decision support system therefore presents a framework to solve some of the existing challenges that farmers face in developing countries. The frugal information system provides the benefits to farmers based in sub-Saharan Africa as follows:

a) Farmers have access to post-simulation information from APSIM to a database that is easily accessible by any communication device.

b) A frugal web-based agricultural system that allows subsistence farmers to seamlessly connect to the APSIM-based database for relevant information access.

c) A fully tested information system that ensures the most uptime as possible.

5.3 Future work

As the proposed system is a prototype and employed the frugal methodology, there are obvious improvements that could be made to it. The designing and implementing of the system are efficient. The technologies employed offer good response times to users and in a user-friendly way. The way in which the solution could be improved upon is by altering the output. As the output is in the form of a static image, it doesn't allow for much innovation and the system is held back by this downfall. The recommendation given is that the output given to the user be dynamically generated. This will allow the output to be tailored in a number of ways which include providing a text based output to users based on actual data produced by the simulation as it provides more context to what is supplied back to the user. If statistics need to be collected by this application, then a login/register feature would be useful to acquire location and application usage.

5.4 Concluding Remarks

In this study, the development of a frugal crop planning decision support tool was designed on top of transmuted, post-simulation information to help assist subsistence farmers in making strategic crop planning decisions. This was designed as it was observed through literature that there was an obvious gap in providing agricultural assistance to subsistence farmers through the use of the information technology sector. This led to the selection of a very established and comprehensively verified agricultural simulation platform known as the APSIM and looked at how the outputs produced by this platform could be moved online and altered to vastly expand the number of users that could benefit from such a platform. A frugal, web-based information system was then developed to facilitate this information to users. Through this dissertation, a contribution is made to the research based on crop planning at the more targeted, farmer level. This research

creates a new perspective for creating decision support tools targeted at household farmers.

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APPENDIX

Use case narration for decision support system

USER CASE NAME:	View current location
USER CASE ID:	USC-1
PRIORITY:	High
PRIMARY BUSINESS ACTOR:	Subsistence farmer
OTHER PARTICIPATING ACTOR:	N/A
DESCRIPTION:	This use case describes the process of obtaining user's current location.
PRE-CONDITION:	N/A
TRIGGER:	This user scenario begins when the subsistence farmer wishes to obtain their current location.
TYPICAL COURSE OF EVENTS:	**Actor Action**	**System Response**
	Step 1: The subsistence farmer wishes to discover their current location	**Step 2:** The system derives the user's location from their web browser's geolocation API.
		Step 3: The system then adjusts visually to show where the user is directly located on the geographical map.
ALTERNATE COURSES:	The system will display a prompt, alerting the user that the geolocation feature is currently blocked from the user's browser.
POST CONDITIONS:	N/A
BUSINES RULES:	N/A

CONCLUSION:	The use case concludes when the farmer has been projected to his current location on the map.

USER CASE NAME:	View how web elements function
USER CASE ID:	USC-2
PRIORITY:	High
PRIMARY BUSINESS ACTOR:	Subsistence farmer
OTHER PARTICIPATING ACTOR:	N/A
DESCRIPTION:	This use case describes the process of displaying information about elements on web page.
PRE-CONDITION:	N/A
TRIGGER:	This user scenario begins when the user wishes to obtain information about what elements do.

TYPICAL COURSE OF EVENTS:	Actor Action	System Response
	Step 1: The subsistence farmer wants to know what elements do on page.	**Step 2:** The system displays helpful prompts describing to users what element functions are.

ALTERNATE COURSES:	N/A
POST CONDITIONS:	N/A
BUSINES RULES:	N/A
CONCLUSION:	The use case concludes when the farmer has been notified about element functions on page.

USER CASE NAME:	View different layers on map
USER CASE ID:	USC-3

PRIORITY:	Low	
PRIMARY BUSINESS ACTOR:	Subsistence farmer	
OTHER PARTICIPATING ACTOR:	N/A	
DESCRIPTION:	This use case describes the process of displaying different layered information on a geographical map.	
PRE-CONDITION:	N/A	
TRIGGER:	This user scenario begins when the subsistence farmer wishes to view different information available on map.	
TYPICAL COURSE OF EVENTS:	Actor Action	System Response
	Step 1: The subsistence farmer wishes to access other overlay information on map.	**Step 2:** The system displays specific information in accordance with layer selected.
ALTERNATE COURSES:	N/A	
POST CONDITIONS:	N/A	
BUSINES RULES:	N/A	
CONCLUSION:	The use case concludes when the specific information is visible on the map.	

USER CASE NAME:	Search for specific location
USER CASE ID:	USC-4
PRIORITY:	High
PRIMARY BUSINESS ACTOR:	Subsistence farmer
OTHER PARTICIPATING ACTOR:	N/A
DESCRIPTION:	This use case describes the process of the subsistence farmer locating themselves via the use of a geocoder.
PRE-CONDITION:	N/A

TRIGGER:	This user scenario begins when the user wishes to locate a specific location on the map using an identifying characteristic.	
TYPICAL COURSE OF EVENTS:	**Actor Action**	**System Response**
	Step 1: The subsistence farmer wishes to search for a location.	**Step 2:** The system displays a number of possible locations based on the characteristics entered.
	Step 3: The subsistence farmer has the option to select one of the search results.	**Step 4:** The system redirects the map to the user's specified location.
ALTERNATE COURSES:	N/A	
POST CONDITIONS:	N/A	
BUSINES RULES:	N/A	
CONCLUSION:	The use case concludes when the specific location that the user has searched for, is displayed.	

USER CASE NAME:	Perform optimization
USER CASE ID:	USC-5
PRIORITY:	High
PRIMARY BUSINESS ACTOR:	Subsistence farmer
OTHER PARTICIPATING ACTOR:	N/A
DESCRIPTION:	This use case describes the optimization process to view specific, transmuted post-simulated information according to location.
PRE-CONDITION:	N/A

TRIGGER:	This user scenario begins when the subsistence farmer wishes to view specific, transmuted post-simulated information according to location.	
TYPICAL COURSE OF EVENTS:	**Actor Action**	**System Response**
	Step 1: The subsistence farmer wishes to view specific, transmuted post-simulated information according to location.	**Step 2:** The system displays a list of possible crop combinations along with various other specific questions in regards to agriculture.
	Step 3: The subsistence farmer then selects the criteria for which they prefer.	**Step 4:** These parameters are passed into the system in which they are processed.
		Step 5: The result of the specific, transmuted post-simulated information according to location is made viewable for user.
ALTERNATE COURSES:	N/A	
POST CONDITIONS:	N/A	
BUSINES RULES:	N/A	
CONCLUSION:	The use case concludes when the specific, transmuted post-simulated	

	information according to location, is displayed.

USER CASE NAME:	Perform compatibility check
USER CASE ID:	USC-6
PRIORITY:	High
PRIMARY BUSINESS ACTOR:	Subsistence farmer
OTHER PARTICIPATING ACTOR:	N/A
DESCRIPTION:	This use case describes the process of checking whether the user's device meets the implementation's requirements.
PRE-CONDITION:	N/A
TRIGGER:	This user scenario begins when the user wishes to browse the implementation.

TYPICAL COURSE OF EVENTS:	Actor Action	System Response
	Step 1: The subsistence farmer wishes to visit the web implementation.	**Step 2:** The system performs a compatibility test to see if both hardware and software requirements are met.
		Step 4: The system displays the main interface.

ALTERNATE COURSES:	The system displays an error page.
POST CONDITIONS:	N/A
BUSINES RULES:	N/A
CONCLUSION:	The use case concludes when the compatibility test has finished.