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DEVELOPMENT OF A CROP PRODUCTION AND ALLOCATION PROGRAM

by

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Executive summary

This report provides a snapshot of the overwhelming evidence for better environmental practices and operations plans to ensure on-going productive agricultural systems and food security in South Africa. It also serves to underpin Waterfall Farm's drive to grow into a sustainable and successful business within the agriculture industry. The main focus leans towards providing the business with a well-defined operation plan (including a practice framework, operational philosophy, crop schedule, and user-friendly operational planning tool) that will transform Waterfall Farm's vision and goals into a reality.

The Waterfall Farm Operations Plan Project, in its first phase of development, relied on problem investigation and research. With regards to the practice framework, in-depth research was performed to broaden the knowledge base on the variety of practices as well as the advantages and disadvantages associated with each. In addition, analysis of the lettuce requirements formed an essential role in terms of the future constraints to be considered. Research was conducted on the various engineering methods/tools that have the ability to contribute towards the investigation process. This generally extended towards the implementation of system dynamics and requirements discovery tools. Each section has its own set of identified problems that may give birth to proposed solutions. The case studies in the literature survey have specifically been documented for that very purpose.

The final stage of the Waterfall Farm Operations Plan Project consisted out of the application of the newly acquired knowledge and engineering tools to develop an operations plan that would satisfy the business' needs and objectives towards becoming a successful and sustainable endeavour. In addition, the problems (poor practices, lack knowledge of management, and inconsistencies during the cultivation period) at Waterfall Farm have received the necessary attention and have been incorporated into the final design. Firstly, the practice framework represents the guidelines that are essential in maintaining a sustainable agriculture operation. Secondly, Waterfall Farm was steered towards a more environmentally, socially, and economically-sound philosophy. Thirdly, Waterfall Farm was subjected to further advisement with regards to their processes which included the solutions obtained from the alternative analysis phase. Finally, an operational planning tool was developed with the sole purpose of enabling Waterfall Farm to accurately schedule their seasonal production and verify whether their crops are cultivated towards high quality products.

By implementing the above mentioned solutions, Waterfall Farm will not only satisfy its needs on an operational level, but also extend the knowledge base and management skills that will prove to be essential in the business' endeavour. The operational plan will enable Waterfall Farm to perform their operations environmentally, socially, and economically-sound and, as a result, metric adherence (throughput of crops, resource efficiency, percentage yield/losses, as well as process performance) will be improved.

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1. Introduction and Background

1.1. Agriculture (R)evolution

Agriculture is known to be the foundation of developing economies and as one of these economies; South Africa has the obligation to ensure that the need for a healthy agriculture industry will be satisfied. Not only will this contribute to the country's gross domestic product (GDP), factors such as food security, social welfare, job creation, and ecotourism will surely be impacted. It should however be noted that the health of the agriculture sector depends greatly on the sustainability of farming methods. Farming methods must therefore not only consider the long-term productivity of the land, but must also ensure profitable yields, as well as the well-being of farmers and farm workers. (Goldblatt, A, 2009)

In Africa, 90% of agricultural production is derived from small farms. If a high percentage of a country's population is engaged in agriculture and derives its livelihood from small-scale farming, the whole sector is mainly subsistence-oriented, which makes livelihoods extremely vulnerable to changes in direct drivers. Improving the performance of small-scale farms in terms of nutritional productivity, resilience to natural and economic threats and environmental sustainability is therefore the most important and most urgent approach to sustainable farming and food systems. (Greenpeace International, 2009)

South Africa is in need for a more sustainable approach. If not adhered to, the welfare of our nation – both current and future generations – is at risk. Miss-managed agricultural industrialisation and intensification could compromise food safety and, in addition, increase unemployment as well as environmental degradation. GlobalGAP, a pre-farm-gate standard, is known to be the key reference for Good Agricultural Practice (GAP) where its function is to translate consumer requirements into agricultural production. It sets voluntary standards for the certification of agricultural products around the globe where the certificate covers the processes of the inputs (e.g. seedlings) and activities (until departure).

1.2. About Waterfall Farm

Agriculture in the Middelrus area has experienced negligence for quite an extensive period of time, where the largest sections of the region only recently commenced with farming practices for the first time in 17 years. Due to the mentioned negligence and non-activity on Waterfall Farm itself, a range of facilities are in the process of being added and upgraded while others are merely developed to a stage of 'working-order' for the time being. Due to climate and fertile loams the region is known for its vegetable farming and thus has been the most favoured selection among farmers.

Waterfall Farm, located (29º 02' 00" S, 30º 14' 00" E) in the province of KwaZulu-Natal near the town of Mooi River, is a start-up lettuce venture that strives to become a sustainable farming operation that applies the necessary practices to contribute towards a healthy agriculture industry. In addition, Waterfall Farm has the intention to address the usage of long term renewable resources and its conservation, adjust to local environments, manage ecological relationships, minimize toxics, value health, diversify to various products, manage entire systems, maximize long-term benefits, and adhere to social considerations.

Waterfall Farm currently produces a variety of lettuce and herb types through a combination of sustainable and intensive practices where the quantities per planting are ± 12500 exotic/week and 6000 crisp/week. Their processes (soil preparation, seed sowing, cultivation, chemical application, and harvesting) are however in a trial-and-error phase due to its recent start-up and requires a great deal of knowledge regarding a range of factors and behaviours, based on the environment, soil drainage capability, and the reactions of nutrients, pesticide and herbicide on their crops. These processes are continuously undergoing alterations and adapt accordingly (e.g. required outputs).

Waterfall Farm's main objective is to achieve a sustainable and successful business by increasing its production and diversifying into new brands of products while adhering to the customer requirements, financial constraints, GlobalGAP standards, and sustainable practices. The metrics that have been identified include throughput of crops, resource efficiency, percentage yield/losses, as well as process performance.

Littlemore Farm, a company that processes and package lettuce/salads and baby leaf products for a number of chain supermarkets, is known to be Waterfall Farm's main client. The level of agreement between the two establishments prevents Waterfall Farm from expanding its client base. This is due to the high demand that must be upheld. The relationship permits the farm to engage in a mutually beneficial arrangement by producing other product lines that Littlemore Farm can push through their existing sales channels.

2. Problem statement

In order to excel in operations, with the purpose of maximising the long-term benefits, Waterfall Farm needs to implement a successful and sustainable operations plan that will increase production while maintaining high product quality. This plan needs to include an appropriate practice framework, operational philosophy, and operational planning tool.

Currently Waterfall Farm runs its operations on a day-to-day basis with regards to the scheduling of seed sowing (currently requires 8 employees), crop rotation and harvesting. In terms of the processes that are currently implemented, continuous alterations are being made with the purpose of identifying the best solution for the business where synthetic chemicals have recently been implemented. Unfortunately these alterations impede on increasing production which limits their customer base to only that of Littlemore Farm (the main reason is due to the requested level of demand). Without the required knowledge on the environment, soil drainage capability, and the reactions of nutrients, pesticides and herbicides Waterfall Farm might reduce its product quality and institute health risks.

If Waterfall Farm continues to run its operations at this pace, there might be no opportunity to expand its client base due to its level of production. As a result, any increase in profit or crop diversification will not become a reality for the business. South Africa's farming industries has shifted towards the trend of intensified agriculture. This gave birth to multiple poorly managed farming practices that have many negative impacts on the natural environment, people's well-being and most importantly the farmer's ability to adapt to change. A dependence and overuse of synthetic fertilisers, pesticides, and herbicides reduces long term soil fertility, causes soil erosion, pollutes water supplies, poisons fragile ecosystems, and exposes farmers and farm workers to toxins. Intensified agriculture often also implies an increased usage of mechanisation and input costs, which in return affects the country's social well-being and the farm's finances. The use of genetically modified (GM) crops that depend on these synthetic supplements may isolate Waterfall Farm from lucrative export markets.

A new sustainable practice framework may surpass the methods introduced by industrial agriculture (known as the 'Green Revolution') such as cover crops, soil enrichment, natural pest predators, and other. Agro-ecological farming practices conserve biodiversity and maintain healthy ecosystems, utilize local knowledge, allow farmers to define their own food systems, and are proven to be productive and economically viable. Thus agro-ecology has the potential to meet food security needs and sustain the current global human population without putting more farmland into production, and without the negative environmental consequences of conventional agriculture. (Surplus People Project Group, 2010). An effective operational plan will translate the business' strategy into everyday execution tactics that will ultimately produce the outcomes defined by the improved strategy and steer Waterfall Farm towards the desired outcomes while managing constraints on time, money, and resources.

3. Project Aim

The aim of the project is to provide Waterfall Farm with a successful and sustainable operations plan (in the production department) that includes a practice framework, operational philosophy, crop schedule, and user-friendly operational planning tool. Existing literature on farming practices, analysis tools, operations management, scheduling, and management tools will be required in order to identify the best practice framework for operations management in agriculture environments. An in-depth study will be conducted on intensive and sustainable practices with the purpose of establishing a baseline for the operational plan. The direction of the project will be steered towards sustainable agriculture (without the use synthetic chemicals) that will produce crops of high quality, meet the GlobalGAP standards, and increase marketing opportunities as well the development of an operational tool that permits management to determine which crops should be planted. The software must consider crop specifications (maturation times, variable lead times for treatment, varying demand, and other), farming practices, intervals of chemical usage, and field capacity.

4. Project approach

The Waterfall Farm operational project will be executed over the duration of the year until its final submission date. The research and analysis of Waterfall Farm's land and environment will be performed to identify the opportunities for crop cultivation. The final analysis will provide the guidelines for crop selection and feasibility studies as well as the practice framework that will most suit Waterfall Farm's vision. In terms of its operations, in-depth analysis will be done on the current and most appropriate processes for implementation which, in return, will enable the development of the operational philosophy and operational planning tool (for the scheduling of seed sowing, rotation, and harvesting).

In terms of the step by step approach, refer to the statement of work. The engineering tools that will be implemented during the analysis stage of the project will include the following:

i. Value Stream Map
ii. Systemi Diagram
iii. PIECES
iv. Use-Case Diagram and narrative
v. Context Data Flow Diagram
vi. Causal Loop Diagram

5. Project Scope

This section of the report will broaden the knowledge in terms of Waterfall Farm's need(s) and objectives as well as the deliverables to be achieved. It should be noted that the introduction and background elaborates on Waterfall Farm's vision and current state and will thus not be repeated in the scope.

Waterfall Farm has the need to improve their current state of operation in the production department to such an extent that effectiveness, efficiency, and sustainability drives them towards a profitable business enterprise that takes social and environmental consideration into account. The objectives are defined in the preceding section where the metrics have been defined as throughput of crops, resource efficiency, percentage yield/losses, as well as process performance.

In order to meet Waterfall Farm's vision (needs and objectives), the project will be steered into particular directions where the development of a fully-functional operational plan will lie at its core and thus provide the necessary baseline for further expansion. This generally includes a practice framework, operational philosophy, crop schedule, and user-friendly operational planning tool.

5.1. Statement of work (SOW)

The statement of work includes the following:

i. Researching Waterfall Farm's land and environment in terms of scale, location, elevation, climate, agricultural region, principle crops, domestic animal/natural predators, soils, natural vegetation, eco-region, and basic principles addressed.
ii. Analysing Waterfall Farm's current processes, practices, methodologies, and constraints in more depth.
iii. Researching and studying relevant farming practices, operations management on agriculture, scheduling of crop cultivation, relevant engineering tools, and management tools. The research will have to be based on the vision of Waterfall Farm and the constraints that accompany the project (financial and environmental).
iv. Analysing the factors that influence the production schedule for each product. An in depth study of the product's technical description, feasibility (commercial and practical), and cultivation requirements (such as maturation times, product demand, environmental constraints, and other) will play an essential role. In addition the requirements of the operational tool will be defined by the use of a Systemi Diagram and PIECES. As a result, the

conceptual design will be defined by the application of a Use-Case Diagram and Context Data Flow Diagram.

v. Recommending an operational philosophy, framework, and schedule that best suits Waterfall Farm's objectives. This will require the establishment of Waterfall Farm's new operations rules, principles, and guides and will be based on the solutions obtained from the alternative analysis phase.
vi. Developing, testing, and finalising of an operational planning tool that will determine the most ideal scheduling of Waterfall Farm's crops. This will entirely be based on the operations framework and practices. The tool must adhere to the capabilities of the staff that will operate the system.

5.2. Deliverables

Deliverables include all the beneficial outputs and recommendations put forth in this project. These will include:

i. Detailed information of Waterfall Farm's environment.
ii. List of the current processes, practices, methodologies, and constraints that accompany the farm.
iii. Research on the available farming practices and their feasibility with regards to Waterfall Farm's constraints (such as available labour, finances, equipment, land, and other) as well as engineering tools that are relevant for implementation.
iv. A practice framework for operations management in Waterfall Farm's agriculture environment. This will indicate the farming practices (industrial vs. sustainable).
v. In-depth description on the products technical structure, feasibility, and cultivation requirements.
vi. Functional and non-functional requirements list coupled with a final design.
vii. An operational philosophy that includes Waterfall Farm's operations rules, principles, and guides.
viii. A practice framework that provides guidelines for maintaining sustainable agriculture.
ix. A sequential crop schedule that provides the procedure from seasonal preparation to harvesting and storage.
x. A user-friendly operational planning tool based on the recommended operational philosophy (including a user manual).

5.3. Project limits and constraints

The project will solely focus on the developing of an appropriate operation plan and the necessary steps to its successful completion. The boundary of the project does not extend to:

i. Supply chain
ii. Facility planning
iii. Marketing opportunities
iv. Business risk management
v. and Business reengineering

The project is accompanied by various constraints such as:

i. Finance – Waterfall Farm is still in its trial-and-error phase and does not allow for any expenditure that will significantly impede on its current profit. The budget for monthly expenses varies from R 65000 – 75000 (fixed and variable cost) where 250kg exotic and 30 boxes of crisp must be sold to break even.
ii. Environment – Every product has its own set of requirements for cultivation and is largely dependent on factors such as climate, soil fertility, and other.
iii. Product standards – GlobalGAP has a set of specific standards that must be adhered to.
iv. Social considerations – The (over)use of synthetic chemicals can institute a health risk to the population and environment.
v. Computer skills – The planning tool must be user-friendly and on a familiar software in order for staff to operate it successfully.

6. Literature Review

6.1. World of agriculture

Agricultural development has surely impacted the food industry throughout the ages, on a financial as well as environmental basis. This section of the literature survey does not attempt to specify every issue, but rather aimed to provide a broad view of the two main categories of agricultural types, practices, as well as the positive and negative impacts of these developments.

6.1.1. Intensified agriculture

Intensive agriculture can be defined as a production system that involves high inputs of labour, capital, or technology usage in the form of pesticides and chemical fertilisers relative to the surface of the land. In this case, the capital and technology categories will be relevant to this project. The aim of such an agricultural system is the maximisation of the farm's yield from its designated land.

The practices of intensive agriculture:

i. Mechanical ploughing/tillage: Tillage is a method used for the preparation of soil before planting as well as controlling unwanted weeds. It should be noted that, if poorly managed, tillage often has unfavourable effects on a farm's soil. This generally involves topsoil erosion and decreased water infiltration due to the formation of a compaction layer which is located below the plough level. The risk of excessive tillage is related to the degradation of a vital soil resource known as organic matter and releases the carbon dioxide into the atmosphere. (Goldblatt, A. 2009)
ii. Monoculture: This type of practice relies on cultivating a significantly small number of genetic variants or cultivars of a specific food crop. In other words, monoculture is known to have a very low form of diversity. The main purpose of applying the practice lies with (ECIFM. no date):
    a. The reduction of the amount of competition for nutrients, solar radiation, and physical space

   b. The control of undesirable living organisms
   c. The reduction of costs by limiting the amount of specialised equipment
   d. Increasing profit by growing high gross margin crops

iii. Chemical application: This practise involves the application of pesticides, herbicides, and synthetic fertilisers and can each be associated with its own objective.
   a. Pesticides: The use of synthetic pesticides in agriculture is known to be the most widespread method for pest control due to its improvement of productivity, protection of crop losses, vector disease control, and other.
   b. Herbicides: Herbicides main purpose is to reduce or eliminate unwanted weeds that compete for the crops' water as well as the nutrient sources in the soil.
   c. Fertilisers: Fertilisers are applied to the crops' soils to promote plant growth as well as enhancement of soil characteristics.

The advantages of intensive agriculture:

i. The use of the practices/methods designated to intensive agriculture introduces a crop yield that is high opposed to that of other. The use of fertilisers (organic and synthetic) positively impacts soil fertility and plant growth, provided that they are correctly applied to the land, and were known to be the main drivers of the Green Revolution (20^{th} century). In addition, fertilisers protect the environment from any form of agricultural expansion by increasing the production potential of the land. (Goldblatt, A. 2009)

ii. By introducing intensive agriculture to a country, farm produce in the form of poultry products, vegetables, and fruits have become less expensive. As a result, these foods are affordable to populations of a high- to low income. It should however be noted that food prices are increasing rapidly due to increased transport, electricity and synthetic chemical costs which are all inputs costs assigned to intensive agriculture. (Pillai, M. 2013)

iii. The space requirement for intensive agriculture is less than that of organic cultivation. (Pillai, M. 2013)

iv. Intensive agriculture promotes a larger productivity of food, while requiring a great deal less land. As a result, this enables the agriculture industry to meet the growing demand for food supplies in less-developed countries such as South Africa. (Pillai, M, 2013)

The disadvantages of intensive agriculture:

i. The introduction to intensive agriculture has given rise to poorly managed practices associated with this agricultural system. This resulted in the dependence and overuse of synthetic fertilisers, pesticides, and herbicides which are responsible for causing soil erosion, poising fragile ecosystems, exposing employees to toxins, reducing long-term soil fertility, and polluting water supplies. (Goldblatt, A. 2009)
   a. Water: If the fertilisers (organic and synthetic) are overused, the elements can run off into neighbouring rivers or lakes and in return result in groundwater pollution.
   b. Atmosphere: The nitrogen present in fertilisers will be released into the atmosphere in the form of nitrous oxide (300 times the impact than carbon dioxide) when the doses of fertiliser are applied in single large amounts.

c. Soil fertility: The manner in which the fertility of the soil is determined is by its organic matter content and soil life. Due to the overuse of synthetic fertilisers, the organic matter declines to a state where the soil itself is drained of life and merely provides a physical support to the plants. At this stage high dependence on these fertilisers sets in order to regain the soil's original state of fertility. This practice will result into acidic and salty soils or even increased levels of radioactive elements and toxic metals.

d. Species diversity: Pesticides are chemicals that are used for pest control, yet its poor management will result in the reduction of species diversity and the functionality of the ecosystem. According to research, merely 0.1% of the pesticides reach their intended target, the remainder can be found in the environment for an extended period of time. The species that feed on the targeted pests are severely impacted as well due to the elimination of one of their food sources and might negatively affect farm productivity. In addition, a secondary outbreak becomes a reality due to the pest predators' susceptibility to these chemicals and the pests' swift resistance. It should be noted that due to the short generation time and mutation ability of pests, the percentage of crops lost to pests have not varied significantly despite the increase in the use of pesticides. This generally may give rise to the pesticide treadmill cycle. The same concept applies to herbicides only with regards to weeds.

ii. As stated earlier, the input costs associated with intensive agriculture are increasing. Intensive practices are highly dependent on fuel, nutrition, water, and synthetic chemicals where the farm feeds have been labelled as the largest expenditure followed by fuel and fertilisers. These costs are known to be exposed to changes in the oil price, rand/dollar exchange rate fluctuations, and the price of raw materials which are beyond the control of a farmer. As a result, food prices increase to such an extent that those in the lower income class (33% of their income is assigned to the purchase of food) are burdened on a financial basis. (Goldblatt, A. 2009)

iii. Intensive farming has expanded to the increase in mechanisation which, as a result, has led to a greater level of unemployment in the agriculture industry. It has been documented that agriculture' contribution to employment has decreased by 75% between the years 1993 and 2005, or from 8.3% to 1.3% (statistics are based on South Africa's agriculture industry). This phenomenon severely affects the country's social well-being due to the fact that agriculture aids in poverty mitigation and job creation. In addition, the introduction of minimum wages has impeded on farm employment and resulted in the substitution of permanent employment by that of temporary. (Goldblatt, A. 2009)

iv. On a commercial basis, the use of genetically modified crops and certain synthetic chemicals may isolate the farms in South Africa from beneficial export markets. The reason for this is due to the many pesticides registered for use in South Africa that have in fact been banned in a great deal of other countries across the world due to their high levels of toxicity. As a result, those countries will refuse to purchase the products cultivated from the South African farms. (Greenpeace International, 2009)

v. Pesticides and herbicides are reportedly a health risk to the population. By the year 1997, eight of the 26 pesticides that are in use in South Africa have been classified as carcinogenic by the International Agency on Cancer. In addition to cancer, other health risks are associated with the use of pesticides and herbicides. (Goldblatt, A. 2009)

6.1.2. Sustainable agriculture

Sustainable agriculture can be defined as a production system that sustains the health of soils, ecosystems and the population by utilising the best of the latest knowledge and technologies. Rather than applying intensive practices to increase crop yield, control pests, eradicate unwanted weeds, and promote plant growth, sustainable agriculture relies on the ecosystem's cycles, processes and biodiversity.

The practices of sustainable agriculture:

i. Crop rotation: The purpose of crop rotation is extended towards maintaining the health of the soil by alternating to a different crop after harvesting. As a result, soil replenishment occurs due to the fact that the nutrients that have been depleted by the previous crop may now be restored by one that is less demanding (e.g. alternating between vegetables and grains). In addition, crop rotation aids in preventing the transmission of diseases, where it is known that each type of crop is accompanied with its own set of potential diseases and pests. By switching to another crop, these diseases will be deterred from the environment and thus increases the chance of survival. (Bocco, D. No date)
ii. Crop diversity: In order to ensure genetic diversity, farmers are able to plant a variation of the same species. As a result the crops will acquire a greater amount of strength which enables them to fend off diseases and pests more effectively. Crop diversity reduces or eliminates the need for pesticides to be applied to the crops. This will result in the reduction of any form of financial distress that would have been incurred if not implemented. (Bocco, D. No date)
iii. Integrated pest management: The practice itself can be defined as a mixture of varying techniques that creates an effective pest control system. Integrated pest management does not merely extend towards environmental techniques (such as crop rotation, beneficial predators, and pest-resistant crops); rather it combines sustainable and intensive agriculture in such a way that it does not significantly impact the environment. For example, in addition to sustainable techniques, chemicals in the form of pesticides are applied to the crops in smaller doses. (Bocco, D. No date)
iv. Natural pest predators: This type of practice involves introducing natural predators to the environment where the crops are located. These animals or insects are known to prey on harmful pests that prove to be a risk and thus in return protects the potential products. Typically, these predators can be purchased in bulk especially if they are classified as insects. In terms of animals such as birds, they merely require a form of shelter in order to be prevailed to stay. (Bocco, D. No date)
v. Soil enrichment: The main purpose of applying this type of practice is simply to improve yields and produce robust crops that are less vulnerable to pests by ensuring that the soil maintains its richness in organic matter. There are various methods that are available and generally include: leaving crop deposits in the field after harvest, tilling under cover crops, or adding composted plant material or animal manure. With regards to cover crops, the method itself

prevents soil erosion, suppresses the growth of weeds, enhances soil quality, and prevents water from precipitating at an undesirable rate. (Union of Concerned Scientists, 2008)

The advantages of sustainable agriculture:

i. Sustainable agriculture uses the ecosystem to assist in increasing crop yield, pest control, weed eradication, plant growth, and other. In other words, no synthetic chemicals are applied to the environment which in return mitigates any form of pollution. This includes benefits such as:
    a. Reduction in toxin exposure
    b. Increase in water-use efficiency
    c. Increase in soil fertility as well as nutrient-holding capacity
    d. Reduction in soil erosion
    e. Carbon sequestration
    f. Protection of ecosystem in terms of species diversity

ii. Opposed to intensive agriculture, the input costs associated with sustainable practices are significantly reduced and predictable in nature. As a result, farmers are not subjected to large amounts of variation in terms of the costs incurred. This is due to the independence with regards to fuel, nutrition, water, and synthetic chemicals. (Goldblatt, A. 2009)

iii. Sustainable agriculture is classified as a labour-intensive production system and, as a result, contributes towards job creation as well as poverty alleviation. Opposed to intensive agriculture's high unemployment levels, sustainable practices aids towards the country's social well-being. (Goldblatt, A. 2009)

iv. Due to a lucrative market (local and international) for organic produces, sustainable farms are able to expand their client base towards consumers that are willing to pay premium prices. This trend includes exporting across international borders and even appeals to local businesses that only specialise in the purchasing of environmentally-friendly products. (Goldblatt, A. 2009)

v. As mentioned previously, sustainable agriculture does not apply synthetic chemicals to their crops. As a result, any trace of potential toxins will not contaminate the soil in which the products are cultivated and thus poses no potential risk to the population when consumed. Sustainable practices adhere to the social considerations that mitigate potential health risks by providing high quality products with the needed nutritional value. (Goldblatt, A. 2009)

vi. The characteristics derived from the products of sustainable practices differ significantly to that of intensive in the form of: (small-farm-permaculture-and-sustainable-living. No date)
    a. Mineral content: Organically grown products are far superior in mineral content to that grown by modern conventional methods due to the fact that sustainable agriculture fosters the life of the soil. Chemically grown products have illustrated a profound upward trend in the occurrence of diseases associated with exposure to toxic chemicals in industrialized societies.
    b. Taste: Opposed to conventionally grown products, organic products exceed in taste due to the high quality that is maintained during the production process. This quality of vegetables and fruit can empirically be measured by subjecting the product's juice to a technique referred to as Brix analysis (a measure of specific gravity/density).

c. Resistance: Sustainable agriculture permits the crops to develop a natural resistance against drought, diseases, and pests. This is due to the fact that the crops itself are able achieve such strength over time without the dependence on synthetic chemicals that severely impede on the process of resistance.
d. Shelf-life: Organically grown products are nourished naturally, rendering the structural and metabolic integrity of their cellular structure superior to those conventionally grown. As a result, organically grown foods can be stored longer and do not show the latter's susceptibility to rapid mould and rotting.

The disadvantages of sustainable agriculture:

i. Intensive agriculture is known for its superiority in terms of productivity due to the application of synthetic chemicals to the crops and the surrounding soil. It should however be noted that this practise merely proves to be beneficial on a short term basis until the soil is no longer viable for equivalent production. (Goldblatt, A. 2009)
ii. Sustainable agriculture requires a greater amount of interaction between a farmer and his crop in terms of observation, timely intervention, weed control, and other. As mentioned previously, sustainable agriculture is classified as a labour-intensive production system and, as a result, sustainable practices cannot compete with that of intensive agriculture in terms of production. (Goldblatt, A. 2009)
iii. Sustainable agriculture requires a large amount of knowledge and skill in order to successfully drive a business of such a delicate nature. Various factors play a significant role in the cultivation of organic products and require the necessary research and experience. (Goldblatt, A. 2009)

6.1.3. Case studies

This section of the study elaborates on the various approaches individuals implemented into their business which has led to new-found knowledge in the agricultural industry.

6.1.3.1. No-tillage and cover crops

Dan Forgey, the manager of the 8 500-acre Cronin Farms in Gettysburg, has implemented a sustainable approach with the sole purpose of improving soil health and crop yields. To date he utilises a well-balanced combination of best practices that promotes improved crop yields while operating on less fertiliser and herbicides. Dan Forgey's initial approach was the introduction of no-tillage and crop diversification, where the experimentation with long crop rotations quickly followed. As a result, he has created himself a system that optimises moisture availability and soil health while simplifying the weed control process. The implementation of no-tilling has not only improved the efficiency of Cronin Farms, but proves to be time-and cost efficient (less on labour, equipment, and fuel). In addition the farm's yield improved substantially, even in years of below-average rainfall. In the year of 2006, Dan Forgey added to his current operation by conducting trials with cover crop mixes with the purpose of identifying a formula that would coincide with his system. (SARE. No date)

In terms of the results, the use of no-tillage during the past 15 years has increased Cronin Farms' crop yields by at least 30% above that of the previous tillage practice. In addition, the use of cover crops (turnips, cowpeas, and lentils mixture) has improved his corn yields to 18-20 bushels per acre compared to control plots. As a result, the profit increased by $14 per acre. It should be noted that due to the ability of cover crops to prevent nitrogen loss and supress the appearance of weeds, Forgey has started purchasing a great deal less fertiliser and herbicides. (SARE. No date)

The no-tillage practice has also contributed towards the soil's health which can be derived from the 1.3% increase in organic matter over the 10 years of implementation. In terms of the cover crops, the biological diversity of the soil has indicated a strong increase and aids in keeping nutrients out of the local waterways. Forgey has taken a calculated approach with regards to the application of synthetic nutrients and has thus established a philosophy of applying these nutrients only where they belong. This was determined by carefully analysing the environments in order to identify the best timing and location. (SARE. No date)

6.1.3.2. Perimeter trap cropping

Jude Boucher, who was completing his horticulture PhD at the University of Connecticut in the late 1990s, analysed potential methods to prevent maggots form destroying sweet and bell pepper crops. The "business as usual" approach simply involved the application of pesticides which, as a result, often led to alternate pest outbreaks that proved to be detrimental to the crops. Boucher experimented with the concept of planting rows of hot cherry peppers between the crops and tree line that would attract these particular maggots. This approach enabled him to eliminate the pest by applying smaller, well-timed sprayings in those areas instead of the entire crop. This soon gave birth to an improved strategy which involved the use of a "poisoned fence" called perimeter trap cropping. (SARE. No date)

This innovative technique increased the yields of cucumbers and other vine crops by 18% while reducing the use of pesticides by 96%. As a result, the average earnings increased by $11 000 per grower. It should be noted that this technique is only applicable to conventional practices and should thus not be implemented by businesses that focus on organically certified products. (SARE. No date)

6.1.3.3. Greenhouse innovations

Don Bustos, who operates the Santa Cruz Farm in New Mexico, has used his sensitivity toward ecosystems and tradition to transform the business into one that flourishes. Bustos strategy steers towards diversifying his crops, identifying market opportunities, and utilising cost-efficient solar heating networks. (SARE. No date)

The use of solar panels enables Bustos to produce throughout the entire the year, reduce greenhouse heating cost from $2 000 to a trivial amount, and increase crop yields 30-40% beyond the standard cold frame. In addition Bustos utilises mulches and drip irrigation with the sole purpose of conserving water. The use of mulches is known to aid in the reduction of soil erosion which generally results in reducing soil fertility. During the existence of the Santa Cruz Farm, Bustos has implemented numerous alternate practices to improve the production of his crops and have been defined as integrated pest management, crop rotation, and cover crops which incorporate organic alfalfa hay as well as cotton seed. (SARE. No date)

6.2. All about the products

This section of the literature survey will be extended towards the universal facets and cultivation practices of lettuce, which has been identified as Waterfall Farm's principle product. By performing an in-depth study, the operations management surrounding its cultivation can be developed.

The following illustrates the factors that are of essence in lettuce production and must be adhered to in order to ensure the successful growth of such a product in South Africa.

6.2.1. Environmental requirements

i. Climatic: Lettuce is known to be a cool season crop where its optimal temperature ranges from 12°C to 20 °C. Lettuce does not suffer from any form of frost during its cultivation. However, when it reaches maturity it becomes susceptible to the severe cold. Temperatures that reach above 27°C are known to affect the development of the head as well as the plant edible quality. In terms of the seeds, high temperatures tend to promote premature seed stalk development which will impede on production. In addition, germination and tipburn are readily present at temperatures >27°C. (Department of Agriculture, Forestry & Fisheries. No date)
ii. Soil: Lettuce has the ability to grow in a variety of soils, yet it prefers fertile loams that are supplied with sufficient organic matter. The optimal soil acidity (pH) should range from 5.5 and 7. In addition, soils with high water-holding capacity as well as proper drainage are required which can be achieved by raising beds or laying underground pipe drains. (Department of Agriculture, Forestry & Fisheries. No date)

6.2.2. Cultivation requirements

i. Soil preparation: The soil should not be prone to crusting due to the fact that the seed of the lettuce itself is small in size. Thus, the soil should be worked evenly into a fine structure and be removed of any presence of clods. (Department of Agriculture, Forestry & Fisheries. No date)
ii. Planting: As mentioned earlier, raised beds are known to be ideal for the production of lettuce and, as a result, aids in the prevention of damage due to soil compaction and flooding. In addition, the use of raised beds improves airflow around the plants which in return results in the reduction of disease occurrences. The depth in which the lettuce is spread ranges between 10 to 15 mm, where the seedlings are thinned out to the preferred spacing at a later stage. In terms of transplantation, the seedlings have the option to be raised in seed trays and then transplanted 5 week after sowing. (Department of Agriculture, Forestry & Fisheries. No date)
iii. Fertilisation: The application of fertilisers is entirely based on the state of the soil, which can be determined by conducting a soil analysis. It has been documented that a fertiliser combination of 2:3:4 (30) at a rate of 500 to 1000 kg/ha can be applied. It should be noted that this mixture solely depends of the fertility of the soil itself. In addition, lettuce is known to respond well to the use of organic fertilisers. (Department of Agriculture, Forestry & Fisheries. No date)

iv. Irrigation: Lettuce is known to have shallow root system (300 mm into the soil) and, as a result, requires a constant supply of water during the cultivation period except at the stage of head maturity. A variable supply of water will result in uneven growth rates as well as variable nutrient uptake (could cause tipburn). Irrigation should thus take place during the morning (4:00 am – 8:00 am) to minimise the impact of poor water quality, maximise nutrient absorption, and eliminate the occurrence of diseases. (Department of Agriculture, Forestry & Fisheries. No date) & (Department of Environment & Primary Industries. 2009)

v. Weed control: Weed control can either be performed mechanically, chemically, or manually. Each are associated with their own set of advantages and disadvantages and should be applied accordingly. (Department of Agriculture, Forestry & Fisheries. No date)

vi. Windbreaks: This method is recommended in areas that experience winds with the strength to cause damage to the crops and promote soil erosion. Permanent windbreaks can be implemented by planting trees or constructing nylon nettings, or temporary windbreaks can be used that are merely developed for the windy seasons. (Department of Environment & Primary Industries. 2009)

vii. Pest and disease control: Table 1 and 2 indicate the variety of pests and diseases that lettuce is the most vulnerable as well as the methods associated with deterring them from the environment. (Department of Agriculture, Forestry & Fisheries. No date)

Table 1: Pest control solutions

Pest	Control
Curworms Agrotis spp.	✓ Baits ✓ Pesticides
Aphids	✓ Pesticides
American bollworm	✓ Pesticides

Table 2: Disease control solutions

Disease	Control
Septoria leafspot (Septoria lactucae)	✓ Copper hydroxide
Downy mildew (Bremia lactucae)	✓ Resistant cultivars ✓ Disease-free seeds ✓ Crop rotation
Powdery mildew (Erysiphe cichoracearum)	✓ Resistant cultivars ✓ Disease-free seeds ✓ Crop rotation
Sclerotina rot	✓ Non-host plant rotation ✓ Resistant cultivars ✓ Registered chemicals
Bacterial rot complex	✓ Resistant cultivars ✓ Disease-free seeds ✓ Weed control
Lettuce mosaic virus	✓ Resistant cultivars ✓ Disease-free seeds ✓ Weed control

viii. Harvesting and storage: The harvesting of lettuce merely involves a cutting process above the soil surface, where the solid heads are trimmed to 4 to 5 wrapped leaves. It should be noted that due to its tendency to rapidly wilt, harvesting should be scheduled during the early morning hours. In terms of storage, the harvested lettuce, packed into waxed cartons containing 12 to 16 heads per carton, are stored at temperatures ranging from 0.5°C to 4°C and a relative humidity of 95%. If adhered to the lettuce storage duration can lead up to 3 weeks, where crisp and cos lettuce types are known to have an extended shelf life opposed to the other. It should be noted that lettuce types are not permitted to be stored with products that emit ethylene due to its increasing effect for russet spotting. (Department of Environment & Primary Industries. 2009)

6.3. A system dynamics approach

6.3.1. General overview

Systems dynamics has been defined as a computer-aided approach to policy analysis and design. Its application relates to forming an understanding of complex dynamic problems that arise from social, economic, ecological, or managerial systems. Generally this can be applied to a variety of dynamic systems as long as they are categorised by mutual interaction, circular causality, interdependence, and information feedback. (System Dynamics Society. 2011)

6.3.2. The approach

The system dynamics approach includes the following (System Dynamics Society. 2011):

+ Defining dynamic problems in terms of graphs over a period of time.
+ Endeavouring for an endogenous, behavioural view of the undercurrents of a system, where the focus lies on defining the characteristics of a system that intensify the perceived problem.
+ Rationalising that of all concepts in the real system are defined as continuous quantities interconnected in loops of information feedback and circular causality.
+ Determining independent stocks in the system as well as their in- and outflows.
+ Formulating a behavioural model that has the capability of replicating the dynamic problem that is of immediate concern. The model itself usually takes the form of a computer simulation model that is expressed in nonlinear equations, however, with occasion is left un-quantified as a diagram portraying the stock-and-flow/causal feedback structure of the system.
+ Developing an understanding with regards to the policy insights from the model itself.
+ Implementing modifications from what has been learned.

6.3.3. The tools

6.3.3.1. Stock and flow diagrams

Stocks and flows are defined to be a system's rational tool which lies at the core of operational thinking. It is generally related to the structural understanding with regards to the system and reveals information in terms of the rates of change that the elements of the system tend to experience as well as the measures of the variables. (Lexicon. No date)

The implementation of such a tool enables the identification of potential interrelationships between the elements of the system and includes (Lexicon. No date):

+ A change in one particular element may positively influence that of another
+ A change in one particular element may negatively influence that of another
+ A proportional change may occur, which can be defined as either reinforcing or balancing, between the interacting elements

These types of diagrams depict the behaviour of the system and how each defined element may alter its current state by undergoing a state of change.

6.3.3.2. Causal loop diagrams

Causal loop diagrams (CLD) indicate the cause and effect relationships between the set of variables that are present in a system. It has been documented that two basic feedback loops make an appearance at the root of all systems behaviour, balancing and reinforcing loops. In terms of balancing loops, they tend to maintain the system's current state while reinforcing loops' focus is to compound change in one direction. (Lexicon. No date)

Causal loop diagrams have the ability to identify the causes of the system's behaviour and, in addition, illustrate its knowledge in a graphical manner. By utilising this tool one will be able to (Lexicon. No date):

+ Understand the true functioning of the system under observation as well as the reason how the outcomes are produced by the cause and effect relationships.
+ Reveal the interrelationships between the various parts in the system itself.
+ Utilise the new-found knowledge to improve the decision-making process in terms of achieving the desired results from changing the system.
+ Increase management skills in terms of the relationships and systems that are clearly visible as well as explicit, opposed to invisible and assumed.
+ Utilise the representation of the system in such a manner that the whole of the system can be revealed which will lead towards a greater amount of knowledge on the subject itself.
+ Improve the system in such a manner that a favourable amount of benefits will be gained.

6.3.4. Case studies

This section of the study elaborates on the various approaches individuals implemented which have led to new-found knowledge in the agricultural industry.

6.3.4.1. Low external input strategies

A study was conducted with the sole purpose of assessing the influence(s) of low external input strategies (LEIS) on farming households in Kenya (small-scale basis). The method was based on developing a conceptual model to assess the relationships within the system (e.g. soil nitrogen changes effects on household incomes). At that stage, a systems dynamic model was created to establish the influence of LEIS on the farms in Kenya. This enabled the researchers to derive the relevant conclusion as to what LEIS entails an whether it proves to be a viable option for the farmers. The results indicate that in this type of scenario, minimal benefits will be reaped due to the lack of knowledge with regards to the implementation of LEIS. However, on a long term basis the household will start to increase as it progresses in maturity while an additional source of income will be available. (Yengoh, G. Tambang. & Svensson, M. G. E. 2008)

6.3.4.2. Sustainable development in China

A study was conducted with the purpose of simulating the long-term viewpoint of environmental agricultural development in China. A system dynamics approach was implemented and, as a result, identified that the diversification of land-use patterns, government low interest loans, and support for training are important strategy measures in endorsing sustainable development. In addition, the case study emphasises the need of combining the systems approach with an ecological economics framework (effective policy-making). (Shi, T. & Gill, R. 2005)

The Agricultural-Institutional-Social-Ecological-Economic Model (AISEEM) has been identified as a useful tool in the decision process regarding the development of sustainable agriculture. Its main function relates to making informed decisions with regards to the management of agriculture with the purpose of maximising ecological, economic, and social outcomes. By applying systems dynamics, the model will have the ability to take factors such as the range of options for the agricultural practices, their social and economic risk, and environmental benefits into consideration. In addition, the model will enable policy-makers to focus their attention on the characteristics of the particular region(s), apply need identification, and recommend opportunities with regards to the future development and adherence to the objectives of sustainable agricultural development. It identifies the factors responsible for impeding on the implementation of ecological agriculture, such as lack of funds, limited human resources, poor knowledge and awareness, and other. (Shi, T. & Gill, R. 2005)

In conclusion, the study identified that expanding agricultural production activities, increasing confidence and trust in these practices, and expanding biogas project development are vital strategy decisions for the county’s long-term ecological, economic and social sustainability. (Shi, T. & Gill, R. 2005)

7. Setting the scene

Operating a business requires a specific set of skills. Without the proper utilisation of the employees' expertise and capabilities it is unlikely to optimise Waterfall Farm's success, despite the significant value of the products and location. This section evaluates the skills and resources that Waterfall Farm contributes to the enterprise as well as the type of agricultural practices that drive their passion.

7.1. Background

7.1.1. Assessing skills and knowledge

Waterfall Farm has currently employed eight (8) female workers and two (2) male workers, where they have been assigned to perform manual labour on the farm in the form of sowing, cultivation, harvesting, and transportation. Due to Waterfall Farm's current financial state, the employment of more workers does not prove to be feasible at this stage of their development. Management has been assigned to a member of the family that has volunteered to transform the farm into a viable and successful business. Table 3 elaborates on resource assignment.

Table 3: Resource assignment

Job/Skill	Lead Person	External assistance
Operations management	Supervisor	-
Forecasting of demand	-	Littlemore Farms
Land preparation	Supervisor	-
Plantation	Female Employees (8)	-
Cultivation	Supervisor	-
Harvesting	Female Employees (8)	-
Transportation	Supervisor and Male Employees (2)	-

7.1.2. Capital resources – Land, equipment, and financial resources

The exploration of human resources has been addressed in the previous section, and thus leads to the analysis of the current availability of the financial and physical resources of Waterfall Farm.

7.1.2.1. Access to land

Waterfall Farm is currently in possession of its own land which may impede on the type of agriculture operation(s) that will be suited for the land. In general, field crops require relatively even and well-drained land, where those with hills or less well-drained lands are better suited to livestock production or non-soil based crop production. The land itself extends towards 33 Ha, where the pastures, grassland, unusable (due to the 87' flood that caused significant erosion), and arable land compromise approximately 5, 4, 2, and 22 Ha respectively.

7.1.2.2. Access to equipment

Farming is known to be an asset-intensive business with a large amount of challenges faced by smaller start-up farms like Waterfall Farm. This is due to the fact that the equipment cost must be justified over a smaller revenue base and thus requires reflection on the mechanical and maintenance skills of the employees when considering the acquisition of farm equipment. Waterfall Farm is currently in possession of the following equipment:

i. Tractor
ii. Plough
iii. Disc harrow
iv. Ridger/Bed-shaper (1.8m wide)
v. Rotovator
vi. 2.5D Ford Ranger (Capacity of 60-65 Boxes)
vii. 4m Trailer, 1.7m Wide (Capacity of 140-150 Boxes)

Waterfall Farm's current state only enables services in the form of purchasing used equipment, leasing, and borrowing/bartering for equipment. The purchase of used equipment does not curtail finances as that of new equipment, yet the strong growth in small and medium sized farms has increased its demand and thus reduced the supply. As a result, the price of some used equipment now exceeds their value relative to that of new ones. An alternative challenge lies with acquiring equipment that fits the operational needs of the farm. In terms of leasing equipment, although the financial aspect will exceed on a long term basis opposed to an outright purchase, it proves to be an attractive option in certain circumstances. Borrowing the required equipment proves to be ideal when Waterfall Farm's cash flow is unable to support a new piece of equipment, or when it is only required for a few short periods during the year. Bartering is known to be cost-effective by hiring farming neighbours to e.g. plough the field. It enables the farm to purchase a smaller more agile tractor for other work.

7.1.2.3. Financial resources

The financial resources are dependent on the size/magnitude of the operations as well as the type of agriculture production that has been chosen for the endeavour. The three sources are known to be:

i. Personal/family cash or equity
ii. Loans/lines of credit from financial institutions
iii. Operating credit from suppliers

For small start-up farms, such as Waterfall Farm, the financial resources that fund the operations take the form of personal savings, personal lines of credit, and cash flow. If necessary, Littlemore Farms may provide a short term credit over a growing period which creates the opportunity to reduce the farm's cash flow needs.

Waterfall Farm is still in its trial-and-error phase and does not allow for any expenditure(s) that will significantly impede on its current profit. Table 4 indicates that the budget for monthly expenses currently varies from R 65 000 – R 75 000 (fixed and variable cost) where an increase for the following months have been anticipated due to the expansion of irrigation and other.

Table 4: Monthly expenses

Nature of Expense	Value on a Monthly Basis (in Rand)
Tractor operations	R 7000
Purchase of seedlings	R 22800
Purchase of fertiliser	R 3000
Purchase of chemicals (e.g. Pesticides and herbicides)	R 3000
Electricity consumption	R 4000
Fuel usage	R 6000
Manual labour (w.r.t. harvesting and plantation)	R 16680
Water consumption rights	R 16680
Total	R 63480

Table 5 illustrates the precise amount of each product Waterfall Farm is currently producing while the remainder of the model indicates the output to be obtained according to the percentage yield and amount sold. It has been documented that in the past Waterfall Farm yielded more than 85% of the exotics and more than 60% of the crisp, yet the sales on those yields were much lower. This was due to the fact that the amount produced far exceeded the amount in demand. In order to break even, Waterfall Farm should produce and sell 250kg's of exotics a day as well as 30 boxes of crisp (360 units). Table 6 indicates the cost of each product's seedling as well as the total amount when multiplied by the amount purchased.

Table 5: Current production

Seedlings per Product	Product Type	Quantity	% Yield	Average Weight	Weight Sold	Selling Price	Income	% Cost	Seedling
6000	Iceberg	3000	50	1000	3000	R 3	R 9000		14
1000	Butter	500	50	200	100	R 9	R 900		31
3000	Reds	1500	50	150	225	R 9	R 20250		43
4300	Green Frilly	2150	50	200	430	R 9	R 3870		39
3300	Cos	1650	50	300	495	R 9	R 4455		22
1000	Green Oak	500	50	200	100	R 9	R 900		31
18600		9300	50	0.468	4350		R 21150		

Table 6: Cost per seedling

Cost per Seedling	Total cost of Seedlings
R 215	R 1290
R 280	R 280
R 290	R 870
R 355	R 1526.5
R 300	R 990
R 280	R 280
Total Cost	R 5236.5

7.2. Current operations plan

Waterfall Farm runs its operations on a day-to-day basis with regards to the scheduling of seed sowing, crop rotation and harvesting. In terms of the processes that are currently implemented, continuous alterations are being made with the purpose of identifying the best solution for the business where synthetic chemicals have recently been implemented. An effective operational plan will translate the business' strategy into everyday execution tactics that will ultimately produce the outcomes defined by the improved strategy and steer Waterfall Farm towards the desired outcomes while managing constraints on time, money, and resources.

7.2.1. Current products

As mentioned previously, Waterfall Farm specialises in lettuce production where these products are either assigned to the exotic-or crisp category. Table 7 indicates the various products that are currently being produced, their assigned category, as well as the split quantity per planting (Exotic = ± 12500 per week; Crisp = 6000 per week). In general, the exotic category has a ratio of 70% green classification and a 30% red. It should however be noted that a slower growth rate is to be expected during the colder winter season due to the cultivation requirements of the lettuce products.

Table 7: Current products

Product Type	Category	Quantity
Triple Play	Exotic	3300
Roblesco	Exotic	1000
Ballerina	Exotic	1000
Levistra	Exotic	3300
Versai	Exotic	1000
Concorde	Exotic	2000
Starfigher	Exotic	1000
Tropical Emperor	Crisp	6000
Total		18600

7.2.2. Experimental products

Waterfall Farm has decided to expand their product base to a variety of herbs as well as baby-leaf spinach. Due to the fact that this endeavour is still in its trial-and-error phase, the products are merely being grown in small areas in order to establish the need of these varieties and their sensitivity. The quantities per square meter as well as the yield of each product will be established after the completion of this phase. It has been determined that the need for these growing quantities is to be had every three weeks. Table 8 indicates the experimental products as well as their individual growing areas.

Table 8: Experimental products

Product Type	Area of Growth
Baby Spinach	50-100 m^2
Rocket	30 m^2
Sweet Basil	15 m^2
Dhanya/Corriander	15 m^2
Moss Curl Parsley	15 m^2
Mizuna	15 m^2

7.2.3. Practices and methods

Waterfall Farm currently produces a variety of lettuce and herb types through a combination of sustainable and intensive practices. Their processes however are in a trial-and-error phase due to its recent start-up and requires a great deal of knowledge regarding a range of factors and behaviours, based on the environment, soil drainage capability, and the reactions of pesticide, herbicide, and nutrients on their crops. These processes are continuously undergoing alterations and adapt to the required outputs (e.g. production), the inputs (e.g. planting schedule), and the labour intensive tasks required to produce products that adhere to their quality standards (defined by GlobalGAP).

i. Intensive practices: Waterfall Farm has decided to extend their finances to the purchasing of synthetic chemicals in the form of pesticides, herbicides, and nutrients. Each individual chemical will be identified as well as the purpose of employing these products to the current and experimental crops of Waterfall Farm.
   a. Pesticides: The use of synthetic pesticides in agriculture is known to be the most widespread method for pest control due to its improvement of productivity, protection of crop losses, vector disease control, and other. It should however be noted that various hazards accompany this chemical, which will be discussed at a later stage.
      + Polytrin and Fenvalerate: These broad spectrum chemicals has the purpose of fending aphids, cutworm, bollworm, nematodes, snails, as well as diseases such as downy mildew, leaf spots, soft rot, mosaic and spotted wilt.
      + Lannate: This chemical has specifically been implemented to fend bollworm which presents itself in the early stages of cultivation. Waterfall Farm has only extended this chemical to their crisp lettuce category, which starts from week 4 of growth.
   b. Herbicides: Herbicides main purpose is to reduce or eliminate unwanted weeds that compete for the crops’ water as well as the nutrient sources in the soil.

These chemicals are designed to eliminate broad leaf plants, however all varieties of lettuce are assigned to the same category. Thus due to the absence of registered chemicals for lettuce production, Waterfall Farm has not invested in the use of herbicides at this stage. It should however be noted that alternatives are essential due to the high labour costs associated with the manual removal of weeds from the fields.

c. Nutrients: Nutrients are applied to the crops' soils to promote plant growth as well as enhancement of soil characteristics and is known to be associated with fertilisers (1:3:5 application in granular form) as they serve a main purpose. Waterfall Farm applies foliar feed nutrients and to their existing spray programme and consists out of a combination of:
    a. Calcium (liquid form)
    b. Magnesium (liquid form)
    c. Phosphate (liquid form)
    d. Nitrogen (crystal powder form)

ii. Sustainable practices: Waterfall Farm strives towards sustainable agriculture, yet at this stage no major practices have been implemented. The main considerations leans to the possibility of implementing practices in the form of permaculture and vermiculture (addressed at a later stage). Currently Waterfall Farm introduces the following sustainable practices:
    a. Crop rotation: This practice has moderately been applied to Waterfall Farm due to the fact that lettuce reaches maturity at a fairly swift pace (6-12 weeks depending of the season and type). Therefore the lands are used twice in the lettuce season until alternative products are available for production.
    b. Natural pest predators: These predators are fairly low at this stage, yet during tillage the organic matter is left to die-back which leaves bollworm, cutworm, snail larvae, and fully grown insects exposed to birds, guinea fowl and blue heron. In addition, during the lettuce cultivation the natural presence of lady bugs occurs who are known to prey on surrounding bollworm.
    c. Soil enrichment: Waterfall Farm has conducted tests on their soil, yet the revaluation of the nutrients and element levels lies on the horizon. Microbial carbon pellets are currently planted alongside each product with the purpose of stimulating root growth and 'giving life' back to the soil. In addition, the tillage of organic matter into the soil is a practice utilised by Waterfall Farm during soil preparation.

7.2.4. Process

Waterfall Farm has currently implemented a general process that extends to (1) the preparation of land, (2) seed sowing, (3) cultivation, (4) chemical application, and (5) harvesting where the processes that relate to its cultivation were discussed in the previous section. A value stream map (Figure 1) has been implemented for a visual approach. Aside from the sequential flow of the processes, the diagram elaborates on the value and non-value added time, the resource requirement, cycle time, standards and information flow associated with each section.

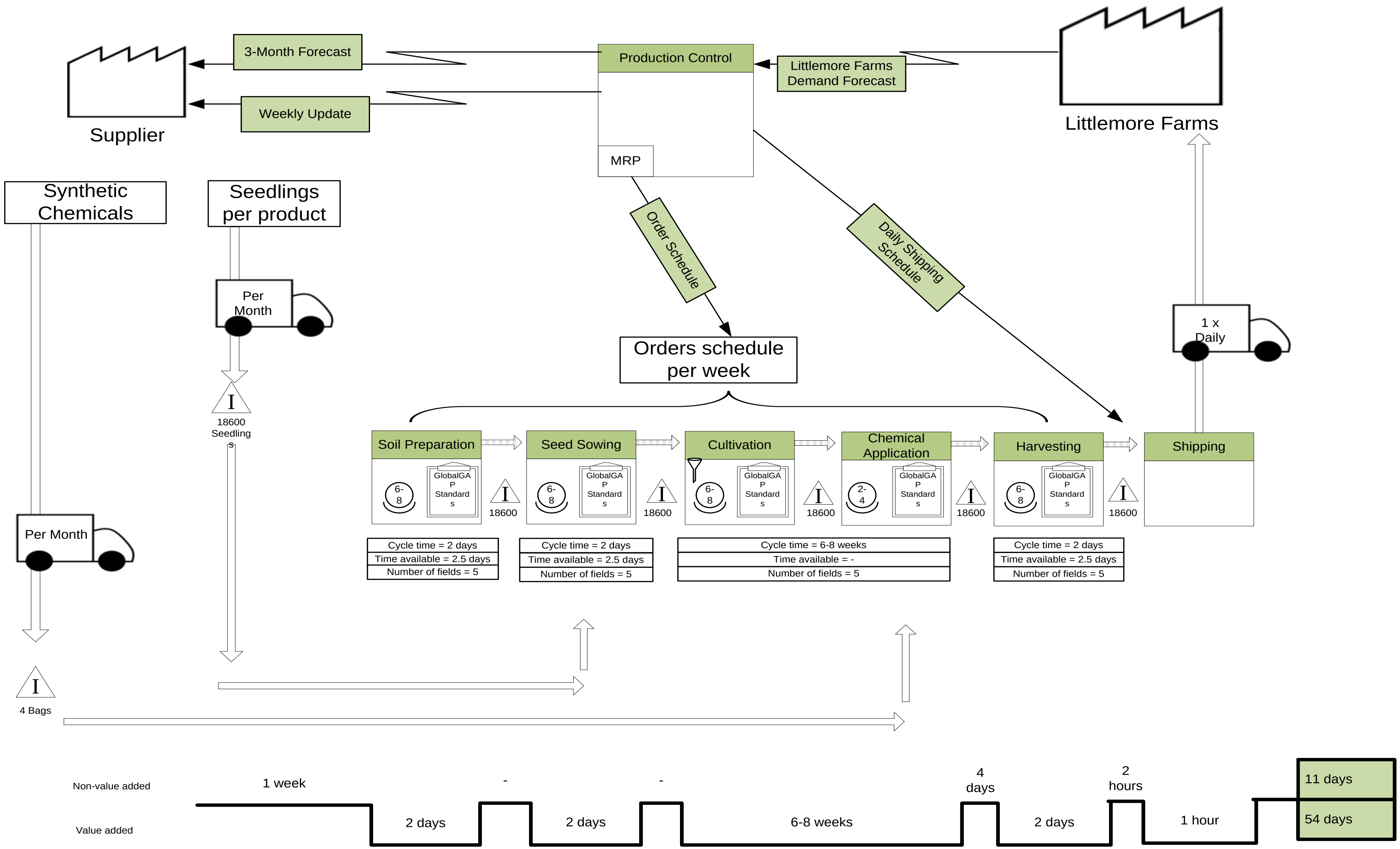


Figure 1: Value stream map

Every aspect and sequence has been documented and analysed and is stated as follows:

i. Soil preparation:
    a. The land of Waterfall Farm is ploughed on occasion due to the long rest period that soils sustained. In general however, ploughing is not an activity that is scheduled at regular intervals unless soil enrichment is required.
    b. The soil will at this stage be exposed to the disc-harrow which is known to cultivate and even out the fields. This transforms the soil into a finer texture opposed to large clots that impede on crop growth.
    c. Beddings (1.5m wide planting area) are created with the use of a 1.8m ridger of which the centre piece is removed. This is to prevent the crops from drowning in excess water.
    d. The rotavator runs over the created beddings with the purpose of creating a fine seed bed by eliminating coarseness in the soil as well as any remaining clots. As a result, the planting process will proceed more swiftly.

Note: Waterfall Farm is contemplating to change the sequence of step 3 and 4. The reason for this is that the rotavator tends to even out the beds to such an extent that they are not raised to their desired level anymore. In addition, an extra step might be implemented which involves the growth of grasses and weeds (by irrigation) to such an extent that they are fully exposed for removal by a chemical known as Gramoxone.

ii. Seed sowing:
    a. The eight female employees punch holes of an appropriate size (6-8cm deep) into the soil.
    b. At this stage microbial carbon pellets are positioned into the holes alongside the seedlings to promote growth.
    c. Finally the employees use small garden spades to compact the soil that surround the seedling(s) in order to fasten them into place.

Note: It has been documented that approximately 8000 – 10000 seedlings can be planted a day with the allocated 8 labourers, depending on the conditions. Irrigation of the seedlings should be scheduled shortly after plantation.

iii. Cultivation: During the cultivation period, irrigation systems have been installed and are placed in the crop field to supply the lettuce with an adequate amount of water. The system merely consists of low positioned sprayers that irrigate a five meter radius in a circular manner.
iv. Chemical application:
    a. Foliar feed nutrients are applied twice on a weekly basis. (magnesium, calcium, phosphate, nitrogen)
    b. Broad-spectrum insecticides are merely applied once a week, where its commencement starts 2 weeks after transplantation (3-4 days withdrawal period).
    c. Lannate insecticide for bollworm is used on crisp only from 4weeks (small turned leaf forms in centre, indicating the start of a head forming) with a withdrawal period of 3-4 days.

v. Harvesting: The final process involves the 8 female workers to select the lettuce that have grown to their desired size. The cutting process involves detaching the lettuce at the base with the use of a sharp knife. The chosen products are then placed in a cardboard box and transported to the storage area.

7.3. Land capability assessment

Agriculture in the Middelrus area has experienced negligence for quite an extensive period of time, where the largest sections of the region only recently commenced with farming practices for the first time in 17 years. Due to the mentioned negligence and non-activity on Waterfall Farm itself, a range of facilities are in the process of being added and upgraded while others are merely developed to a stage of 'working-order' for the time being. Due to climate and fertile loams the region is known for its vegetable farming and thus has been the most favoured selection among farmers.

i. Farm total size: 33Ha
ii. Pastures: 5Ha
iii. Grassland: 4Ha
iv. Non-usable: 2ha - Top soil eroded during floods of 87'
v. Arable land: 22Ha
vi. Elevation: 1348 meter

In terms of the climate characteristics, the Middelrus area has an annual rainfall that fluctuates with a great amount of variability and ranges from 300 to 747 mm, where the raining season stretches from the month of October to that of April. Middelrus is warm and humid (> 0.65 p/PET) during the summer season and dry in the winter with minimum temperature ranging between -5º C to 0º C and maximum temperatures from 32ºC to 35º C (Average Temperature = 16.7ºC).

Middelrus has natural vegetation that has been documented as annual and perennial grass including other herbaceous plants, aloes, broadleaf deciduous, shrub form (minimum height of 1-3 feet that grows in groups or patches), nutsedge (nutgrass), and water grass.

Waterfall Farm requires some additional water during the growing season for the optimum growth of the field crops, yet the required quantity of water may vary depending on the type of irrigation system used. It is a known fact that poorly drained soils reduce the productivity of a great deal of crops, while lands with even gradual slopes tend to improve the drainage of the surface. As a result, drainage greatly contributes to a land's suitability to specific crops. Due to the fact that lettuce requires a constant supply of water during the cultivation period, an effective irrigation system is vital. Water is readily available from the Mooi River stream, which is known to border Waterfall Farm. In terms of its usage, the river is designated as the main source of supply in the Middelrus area and has been made available for use provided that the farmers adhere to the limitations (authorised by Big Mooi Irrigation board).

7.3.1. Environmental characteristics versus production requirements

A deduction can be made whether the products of Waterfall Farm coincide with the environmental characteristics in the Middelrus area. Table 9 illustrates the comparison between the two concepts and indicates the areas of adherence. It should be noted that this section merely applies to Waterfall Farm's principle lettuce products.

Table 9: Criteria comparison

Criteria	Production requirements	Environmental characteristics	Level of adherence
Environmental requirements			
Climatic	Temperature: a. Between 12°C to 20 °C b. Below 27°C	Temperature: a. Summer: 32ºC to 35º C b. Winter: -5º C to 0º	a. Summer: needs attention b. Winter: needs attention Note: Average temperature = 16.7ºC
Soil	a. Sufficient organic matter content b. pH range of 5.5 to 7 c. Sufficient drainage	a. Sufficient organic matter content b. pH range of 5.5 to 7 c. Sufficient drainage	a. Good b. Good c. Good
Cultivation requirements			
Soil preparation	a. Minimum crust formation b. Minimum clods presence	a. Minimum crust formation b. Minimum clods presence	a. Good b. Good
Plantation	a. Raised beds b. Depth 10 to 15 mm	a. Raised beds (majority) b. Depth 6 to 8 mm	a. Sufficient b. Good
Fertilisation	a. Fertiliser combination of 2:3:4 (30) b. Rate of 500 to 1000 kg/ha c. Organic fertiliser	a. Fertiliser combination of 1:3:5 b. NA c. Synthetic fertiliser	a. Sufficient b. NA c. Needs attention
Irrigation	a. Schedule from 4:00 am – 8:00 am b. Constant even supply of moisture	a. NA b. Uneven supply of moisture	a. Needs attention b. Needs attention
Weed control	a. Intensive or sustainable approach	a. Intensive approach	a. NA
Windbreaks	a. Applicable during windy seasons	a. NA	a. NA
Pest and disease control	a. Intensive or sustainable approach	a. Intensive approach	a. NA

Harvesting and storage	a. Trimmed to 4 to 5 wrapped leaves b. Waxed cartons containing 12 to 16 heads per carton c. Temperatures ranging from 0.5°C to 4°C d. Relative humidity of 95%. e. Duration can lead up to 3 weeks	a. Merely select appropriate size lettuce b. Cardboard boxes containing 12 to 16 heads per box c. Environmental temperature d. Environmental humidity e. NA, transported daily	a. Good b. Good c. Needs attention d. Needs attention e. Sufficient

In conclusion, Waterfall Farm is quite capable to produce lettuce but requires some improvements that prove to be detrimental in lettuce production. The areas of concern are labelled as "needs attention" and will thus be considered in the development of the operational plan and philosophy.

7.3.2. Identification of regulatory restrictions

In the agriculture industry a set of regulatory restrictions are present and must be adhered to. They generally take the form of resource utilisation (water from the Mooi River stream) as well as production standards (GlobalGAP).

8. Engineering tools

8.1. System dynamics

This section of the report defines the dynamic problems, identifies the characteristics that intensify the problem, considers feedback and circular causality, and formulates a model that replicates the system. This will conclude towards the development of a simple model that indicates the cause and effect relationships between the set of variables.

8.1.1. Data collection

The relevant data that proves to be imperative to the development of a dynamic model must be collected by Waterfall Farm itself. Due to the business' start-up phase, insufficient data is currently available in order to calculate the levels and rates and thus should be obtained throughout the Waterfall Farm's operation.

8.1.2. Tools and approaches

The tool of systems analysis that will be used for this project includes the causal loop diagram. The reason for this decision is due to that the diagrams indicate the cause and effect relationships between the set of variables that are present in a system. An in-depth understanding will be derived with regards to the true functioning of the system and will increase the ability to reveal the interrelationships, utilise the new-found knowledge to improve the decision-making, increase management skills, and improve the system.

8.1.3. Causal loop diagram

The causal loop diagram indicates the "business-as-usual" scenario which depicts Waterfall Farm's current operations. It provides a clear indication of the factors that interact within the system and, as a result, presents an opportunity for future knowledge expansion.

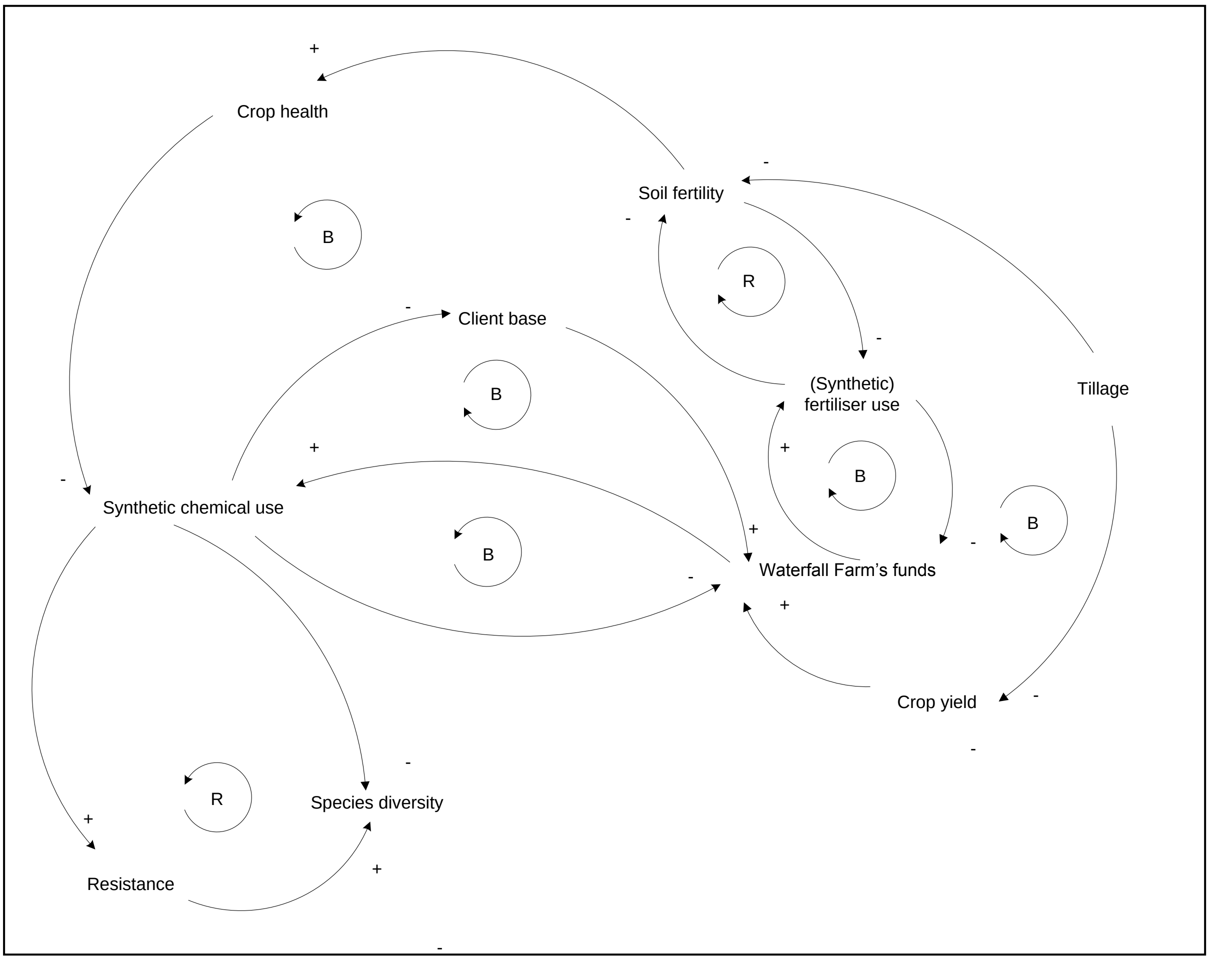


Figure 2: Causal loop diagram

The analysis of the causal loop diagram indicates that the main problem lies with the use of intensive practices such as synthetic chemicals and tillage. Its effects are not limited to merely environmental concerns but that of economical as well. This statement coincides with the case studies in the literature survey. As a result, during the development of the practice framework, the main focus will lie on the implementation of sustainable practices such as cover crops and no-tillage.

In order to convey the changes in the system's behaviour, an alternative causal loop diagram will be developed. The tool will represent the desired scenario, which should be adopted by Waterfall Farm, and the overall improvement of the system.

8.2. Operational planning tool

8.2.1. Introduction

Waterfall Farm's operation necessitates the development of a structured, well-defined, and user-friendly tool that has the ability to store data and schedule crop operations (with regards to the main processes), while taking any form of constraints into consideration. The information supplied in the analysis will clarify factors that are relevant to the development of the tool itself.

This section of the report focusses on problem analysis, requirements discovery, modelling system requirements and data modelling and analysis. The purpose is to construct a framework as to what the functions of the operational tool should be.

8.2.2. Aim

It is evident that a well-structured scheduling system has the ability to improve the current operations of Waterfall Farm by creating a schedule that specifies which tasks should be performed when, where, an how. The main objectives have been listed as follows:

+ Improve scheduling procedure
+ Document relevant data such as, product requirements, land specifications, and other
+ Generate reports on the performance of the harvest
+ Reduce human error
+ Keep track of current practices and procedures

8.2.3. Problem analysis

8.2.3.1. Problem

Waterfall Farm is currently operating without the use of an operational tool which presents a level of difficulty in establishing time-effective crop schedules, monitoring the quality of the products, considering various physical and environmental constraints, and evaluating the performance of the operation. The following section will elaborate on the consequences involved when operating an agriculture practice at such a level by the use of two investigation techniques: Systemi-diagram and PIECES.

8.2.3.2. Systemi-diagram

Figure 4 illustrates the Systemi-diagram that has been applied to Waterfall Farm's current state and thus indicates the relationship between the causes and effects in an agricultural system. This logical reasoning will be extended to quantify the system dynamics. The use of a Fishbone diagram was considered, but discarded since the Systemi-diagram represents the system more effectively.

From the diagram it is evident that poor management of the entire operation will impede on Waterfall Farm's success as an effective, efficient, and sustainable business. Without the adequate amount of knowledge, with regards to agricultural operations, the environment will severely be affected and will ultimately reduce the capability of the land to produce the desired quantity and quality of products in the long run. Factors such as day-to-day scheduling and continuous trial-and-error are causes that contribute to this phenomenon. The reason for this is that day-to-day scheduling does not contribute towards a long term approach that is so vital in the agriculture industry. The trial-and-error approach is mainly due to a lack of knowledge with regards to the products that are produced and thus does not consider the effects on the environment and business in terms of unnecessary expenses due to waste (overproduction and product loss).

In terms of the practices that are currently implemented at Waterfall Farm, they coincide with the dangers regarding the reduction of soil fertility where, if practised ineffectively, will lead to the above mentioned consequences as well as the negative relationships associated with the business' market and income. As mentioned in the literature study, the use of synthetic chemicals isolates Waterfall Farm from lucrative markets which will increase the probability of missing out on beneficial opportunities such as client base expansion.

Waterfall Farm owns 22 Ha of arable land, yet only a fraction is currently being utilised. Although the business is still in its start-up phase, neglecting the remainder of the land will prevent the business from expanding towards a greater variety of products (less maintenance) in order to generate an additional income.

The current methods of cultivation contribute to increasing the risk of yield loss. This is due to the fact that the irrigation does not supply an even amount of water to the entire crop and, as a result, promotes the uneven growth of the products. Another factor relates to the formation of beddings. If not present during crop cultivation, the risk of drowning the crops is substantially increased and will lead to yield loss. Finally, the direction on the fields influences the drainage system. In conclusion, the diagram illustrates the need for an appropriate operations plan and tool.

8.2.3.3. PIECES

Another problem analysis tool was utilised and can be defined as PIECES. The tool yields the following:

P – The need to improve the process: Waterfall Farm has the desire to improve their current process in such a manner that it incorporates its main goals and objectives. Their need relates to creating an operations plan and tool that will enable them to effectively, efficiently, and sustainably run their activities.

I – The need to improve information: This relates to their understanding of running an agricultural business. Waterfall Farm has the desire to increase their knowledge base as well as owning a tool that will be able to convert their data into an appropriate scheduling plan. The tool will include the following:

i. Necessary inputs and outputs: The inputs include seedlings, resources, practices, constraints, land specifications, and current products. In terms of the output, this mainly revolves around summary reports which include cost, schedule, and performance.
ii. Data storage: The tool must be able to store all the data mentioned above as well as demand forecasts and previous summary reports.
iii. Up-to-date information: The tool must remain current in terms of the practices and products that are being considered or are already implemented.

E – The need to improve economics, control costs, or increase profits: This section includes the following to be considered:

i. Area of cost reduction: There is a need to control their costs especially with regards to unnecessary expenses (mainly to due experimentation and overproduction). The satisfaction of these needs will decrease costs, increase profit, and thus improve the economics.
ii. Budgetary limits: Waterfall Farm is restricted financially, yet no fixed budget has been set. This is due to the fact that the company is willing to implement the proposed solutions depending on its appeal. The financial guideline will be set in accordance to their current expenses of R 63 480.
iii. Development schedule: Waterfall Farm is still in its start-up phase and thus has no specific time schedule for the development of the operational tool.

C – The need to improve control or security: There is a need for the tool to be secure in protecting any sensitive information of Waterfall Farm. In addition, a sense of security is required at the facility itself to prevent any theft from occurring (equipment is expensive). In terms of the operational tool, the following has been documented:

i. Access: The use of the tool must preferably be limited to management.
ii. Privacy: No privacy requirements are essential to the development of the tool.
iii. Special handling: It is important for the tool to allow backups and off-site storage.

E – The need to improve efficiency of people and processes: Waterfall Farm has the need to develop an operations plan that considers the use of employees in such a manner that the tasks are performed as effectively and efficiently as possible. Same applies to the processes. The tool must eliminate any duplicate steps in the process and, in addition, consider ways to reduce waste in terms of resource utilisation.

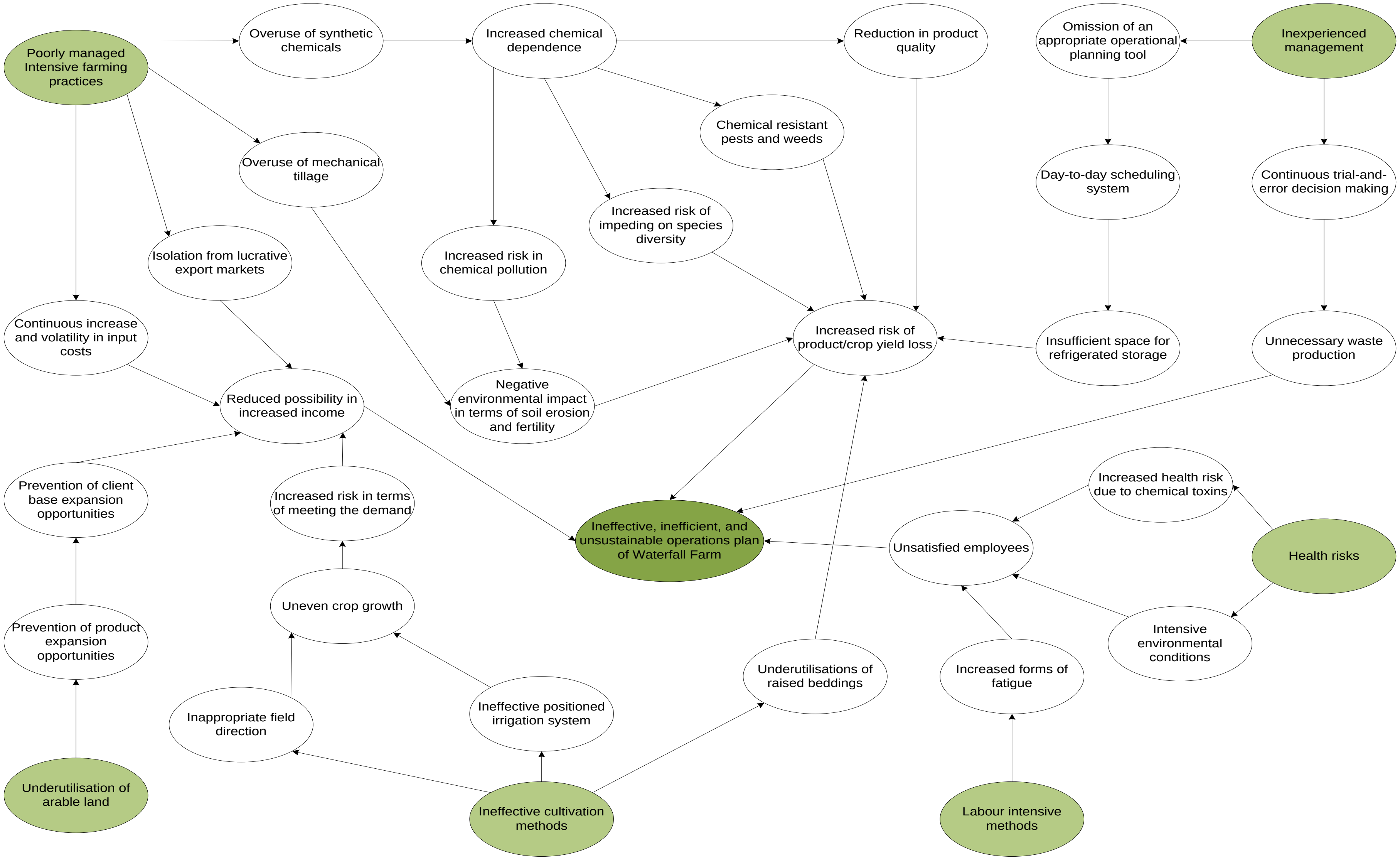


Figure 3: Systemi diagram

S – The need to improve service to customers, suppliers, partners, employees, and other: There is a need to supply the desired quantity of products that are of high quality to their customer, Littlemore Farms. In addition, a strong relationship must be formed with their suppliers as well as employees (in terms of working conditions). In terms of the tool, the following must be considered:

i. Usage: This relates to who will utilise the tool. In this case, only management will provided access to the program.
ii. Human factors: This mainly relates to the ease of use and learning.
iii. Training materials: The tool will be coupled with a user-manual to visually train management.

8.2.4. Requirements discovery

8.2.4.1. Fact-finding techniques

The requirement discovery process involved the use of a fact-finding technique in order to collect information about the system's problems, requirements, and preferences. The types of requirements have been classified into either the functional category (description of the activities) or non-functional (description of other features, characteristics, and constraints) category. The data was collected by developing a questionnaire that includes fixed format questions and was mainly applied to the key personnel involved in Waterfall Farm's operations.

8.2.4.2. Functional requirements

This section involves the description of the activities and services the operational tool must provide in terms of:

i. Process requirements: Use-case modelling was utilised (Figure 5) for this project in order to effectively model the system's functions in terms of business events, who initiated the events, and how the system responds to those events. The use case consists out of three sections, (1) the crop scheduling preparations, (2) crop scheduling operations, and (3) harvest reports. Each section has been assigned its own set of use cases that depict the functions that should be present in the model development stage. Table 10 illustrates each section in greater detail.
ii. Data requirements: This section has been omitted due to the fact that it will not provide any additional data that will be valuable in the development process.
iii. Interface requirements: The Context Data Flow Diagram (DFD) illustrates the operation system's interfaces with its work environment and can be viewed in Figure 6 below.

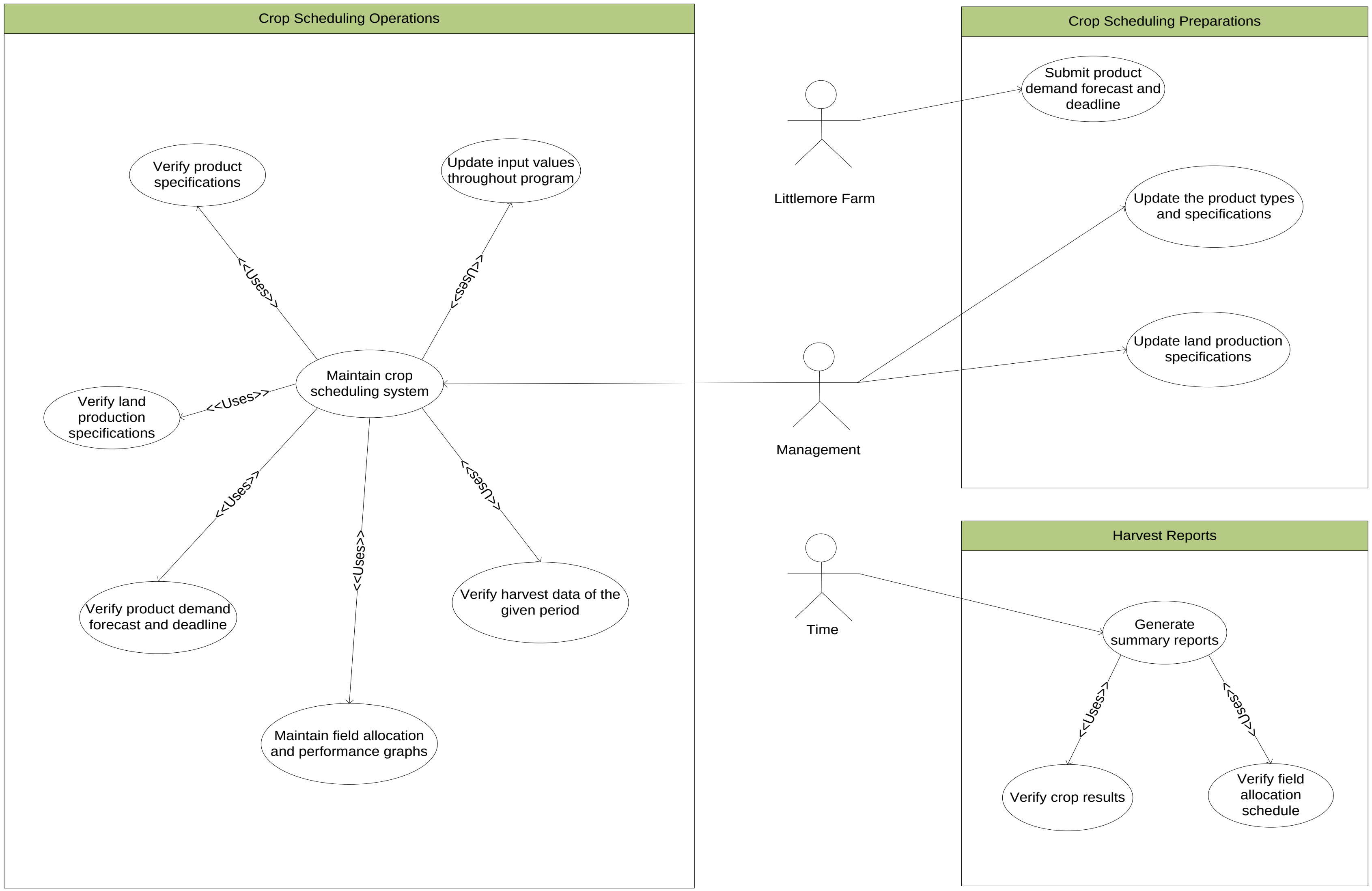


Figure 4: Use case diagram

Table 10: Use case narrative

Use Case	Actor	Description
Crop Scheduling Preparations		
Submit product demand forecast and deadline	Littlemore Farm	This use case represents the product demand forecast and deadline that has been established by Littlemore Farms. The data plays a vital role in the crop scheduling process and thus will be documented into the database.
Update the product types and specifications	Management	The use case indicates that all relevant data in crop production should be entered into the database to ensure that their requirements are adhered to. This generally involves product yield and weight.
Update land production specifications	Management	The use case relates to the land itself and depicts the number of field that are currently used for production, the amount of rows assigned to each field, the capacity of each row in terms of production, and other.
Crop Scheduling Operations		
Maintain crop scheduling system	Management	This is known to be the base use case that “uses” all of those that are required to produce a crop schedule.
Verify land production specifications	-	The use case represents the amount of fields available, the rows assigned to each field, and the individual row capacities. This enables the system to identify the fields’ occupation status as well as the quantity each will produce. Another option to be considered is the capability of the land to produce quality products and could thus be designed with a “flag” system to identify areas that lack in soil health.
Verify product specifications	-	The use case represents relevant data assigned to each product of Waterfall Farm. It enables the system to determine field allocation by considering the product’s yield and weight. In addition, factors such as cultivation time will be included to determine the harvesting date of the specific crop under consideration.
Update input values throughput program	Management	The use case represents the dates assigned to each crop in terms of

Verify harvest data of the given period	Management	The use case represents the results of the harvest period (in weight). It enables management to identify areas which prevented the harvest of lettuce due to the fact that they were not fully grown.
Verify product demand forecast and deadline	-	As mentioned previously, the schedule is dependent on the product demand and the deadline set by Littlemore Farms. Thus the use case ensures that the forecasts are taken into consideration in the schedule development process.
Maintain field allocation and performance graphs		The use case represents the graphs that are generated periodically. Due to the time factor embedded into the program, it must update the graphs after each request in order for management to verify the correct results.
Harvest reports		
Generate summary reports	Time	This is known to be the base use case of the report section. This mainly represents the need to generate the reports that summarise relevant data with regards to the period under consideration.
Verify crop schedule	-	The use case represents the need to depict the newly developed schedule for implementation purposes.
Verify crop results	-	The use case represents the results of crops after the final process has been completed. The idea is to document the amount produced at each field and row to determine factors such as crop yield, product quality, and other.

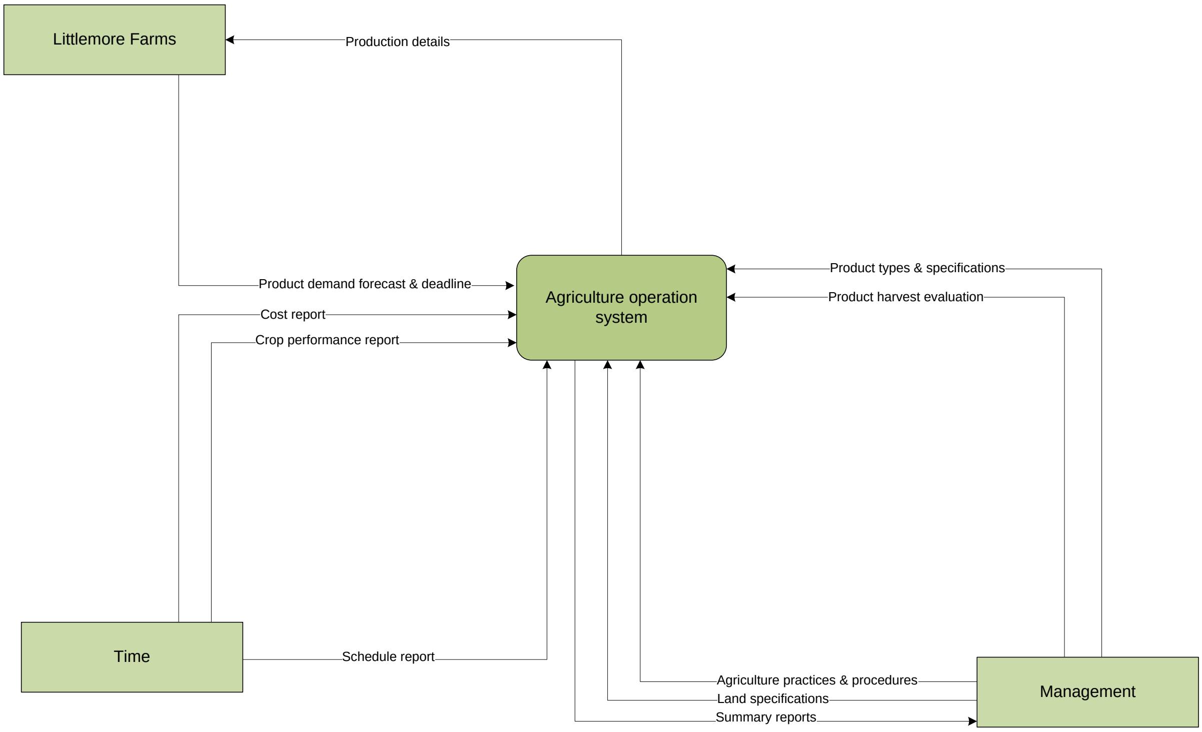


Figure 5: Context data flow diagram

8.2.4.3. Non-functional requirements

A description will be given of the other features, characteristics, and constraints that are known to define a well-structured tool. This includes the following:

- Performance: It is vital that the tool provides accurate schedule, cost, and crop reports to ensure that Waterfall Farm operates at a level that is of a high standard.
- Reliability: The tool must be dependable and consistent to ensure successful operation implementation.
- Supportability: This depends on the software that will be utilised (e.g. Excel forms part of the Microsoft package). In general, the main factor would be annual upgrades if there proves to be a shift in desires of the company in terms of the tool's features.
- User-friendly: The tool must display ease of learning and use to ensure that the level of difficulty coincides with the user's computer abilities.
- Constraints: The constraints have been addressed previously and relates to Waterfall Farm's budgets and deadlines.
- Documentation: The tool must provide a well-structured database for management in terms of collecting, recording, and storing data.

8.2.5. Conclusion

It can be said with certainty that the implementation of an operational tool may truly benefit Waterfall Farm. A well-structured operational plan will enable the company to produce products of a desirable quality while considering physical and environmental constraints. In addition, the generated reports will enable Waterfall Farm to keep track of their current performance and identify any areas of inconsistency. It has been decided that Microsoft Excel will be the software to support the development of the tool.

9. Post-investigation conclusion

Waterfall Farm has numerous areas to address in order to operate at a desirable level. These problems have been highlighted throughout the document and mainly revolve around:

+ Poor practices: Intensive agriculture such as chemical application (fertiliser, pesticides, and insecticides).
+ Lack of knowledge in the management of agricultural industries: Excessive experimentation with products and practices that are poorly managed and result in overproduction and unnecessary expenses.
+ Inconsistencies during the cultivation period: Lack of even water supply, formation of raised beddings, and protection against severe weather that gives birth to irregular growth and increased yield loss.

The remainder of the report will elaborate on the proposed solutions that should be considered by Waterfall Farm. They have specifically been chosen to satisfy the business' needs in becoming a successful and sustainable venture.

10. Solution

This section will consist out of (1) the solutions that have been selected through careful revision (available alternatives, advantages, disadvantages, and cost implications), and (2) the validation of these solutions in terms of the aim and objectives defined previously.

10.1. System dynamics

This section of the report represents the solution with regards to the transformation of Waterfall Farm's business-as-usual approach to that of a sustainable one. An alternative causal loop diagram was developed in order to portray the alterations on a visual basis. The engineering tool illustrates the intricate relationships between the various levels and how the application of sustainable practices positively contributes to the well-being of the environment as well as Waterfall Farm's operations.

Proposed solution:

The behaviour of the system indicates that changing the levels of natural control, composting, drip irrigation, and crop-appropriate tillage will significantly improve the system due to its chain reaction on that of the other levels. The causal loop diagram represents the system in such a way as to:

+ Understand the true functioning of the system under observation as well as the reason how the outcomes are produced by the cause and effect relationships.
+ Utilise the new-found knowledge to improve the decision-making process in terms of achieving the desired results from changing the system.

+ Increase management skills in terms of the relationships and systems that are clearly visible as well as explicit, opposed to invisible and assumed.

The development of a stock-and-flow diagram has the ability to plot the behaviour of the system, but due to a lack of data was ignored. In addition, the system itself is supported by an abundance of research which coincides with the results above. The remainder of the report will elaborate on the above mentioned practices and will provide a practice framework, operational philosophy, crop schedule, and operational planning tool.

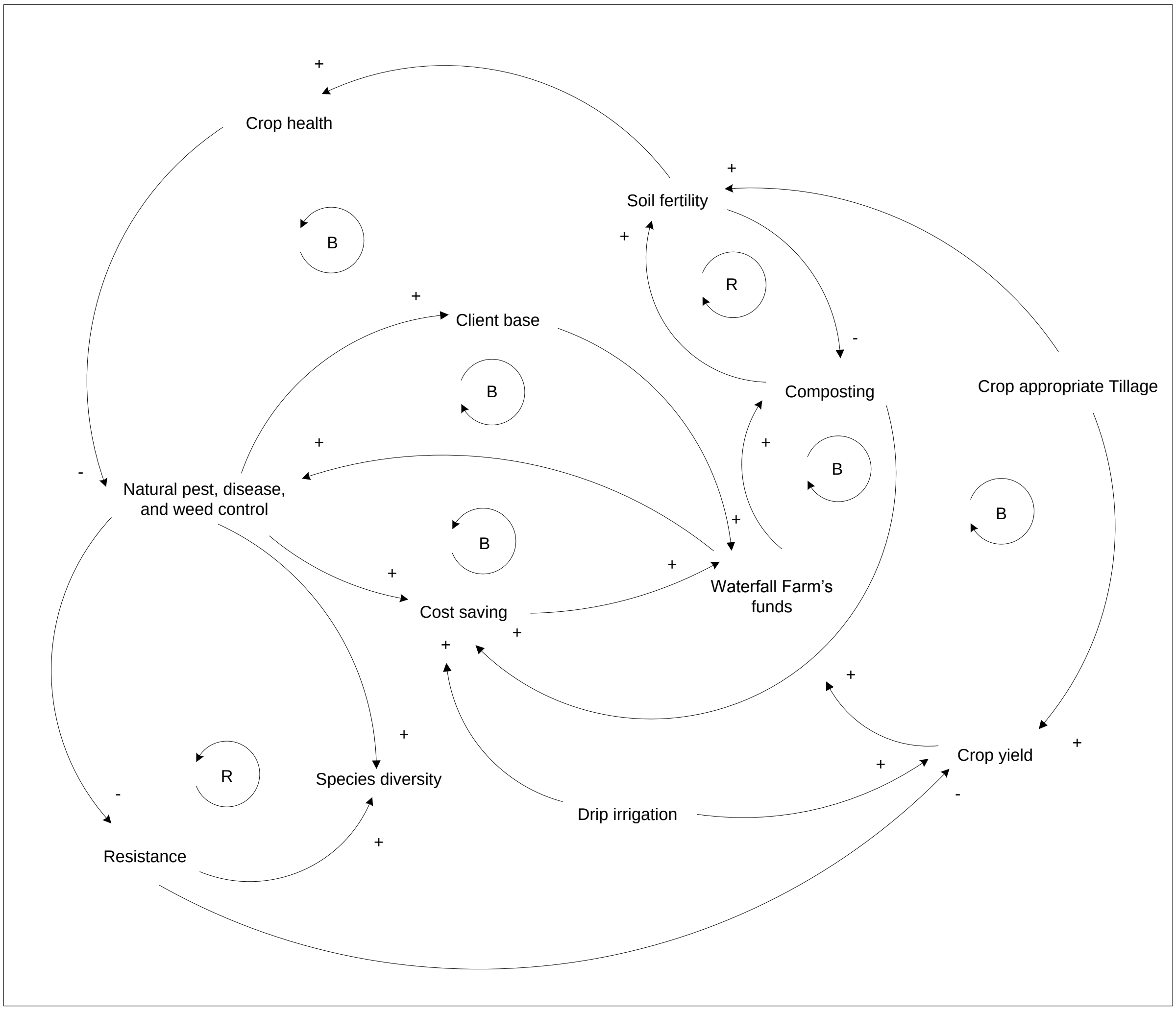


Figure 6: Improved causal loop diagram

10.2. Practice framework

The practice framework represents the guidelines that are essential in maintaining a sustainable agriculture operation and have been divided into five individual sections (soil fertility, soil structure, water usage, biodiversity and ecosystem, and social considerations). Waterfall Farm must strive to adhere to the majority of these practices in order to fulfil their goals and objectives.

10.2.1. Soil fertility

i. Analyse the soil and crop samples as well in order to determine the precise amount and type of fertiliser that is required, and strive to fill the nutrient gaps opposed to simply increasing the total N and P.
ii. Use precision agriculture to determine and calculate the fertilisation regime based on accurate estimates of the products' potential yield.
iii. Accurately time and target fertiliser application that corresponds with maximum plant uptake periods and ensure that the application of fertiliser is performed in regular smaller doses rather than few large doses.
iv. Synthetic fertilisers must be stored on an impermeable floor, and care should be taken to avoid interim storage in open fields, due to its high pollution risk.
v. It is essential that fertiliser spreading machines should never be cleaned in rivers, lakes or near drinking water wells and springs.
vi. Where possible, make use of organic fertilisers that contain a carbon source.
vii. Use crop rotation and inter-cropping to increase soil organic matter and nutrients. (Where possible, aim to rotate between grains and nitrogen-binding legume crops.)
viii. Strive to maintain a permanent soil cover by either using crop covers or mulch.
ix. It is essential to avoid any excessive irrigation and a good water quality must be maintained.
x. Reductions in the use of synthetic chemicals such as pesticides and herbicides, that cause a decline in soil micro-organisms, are advised.

10.2.2. Soil structure

i. Strive to implement crop-appropriate minimum tillage.
ii. If tillage is required, till at the exact speed depending whether the soil has the correct moisture content.
iii. If possible, avoid the type of crops that require soil disturbance to harvest.
iv. Strive to prevent soil compaction by limiting heavy machinery, especially in wet conditions. In addition, use radial-ply tyres with low tyre pressures to minimise soil compaction where traffic is necessary.

10.2.3. Water usage

i. Increase the soil organic matter with the purpose of reducing evaporative water loss and, in addition, maximise the soil's water-holding capacity.
ii. Implement more efficient irrigation systems, such as drip irrigation.
iii. Ensure that efficient irrigation techniques are present that take soil type, crop type, soil water status and weather conditions into account.
iv. Ensure that the irrigation systems are maintained on a regular basis.
v. Register the farm's water use with the Department of Water Affairs.
vi. In addition, ensure that the actual water use is recorder in order to compare against the registered use.
vii. Aim to implement water-harvesting and water-recycling techniques.
viii. Consider the use drought-resistant crop and livestock varieties.

10.2.4. Biodiversity and ecosystem

i. It is advised to identify the natural ecosystems on the farm with the purpose of drawing up a management plan for their protection. This should include activities such as judicious water use, erosion control, invasive alien plant control, pollution control, reconnecting natural systems by establishing corridors and riparian/wetland buffer zones, species checklists, hunting and poaching control, and other.
ii. Where relevant, create a biodiversity stewardship agreement with the area's local conservation agency.
iii. Aim to rehabilitate as well as maintain water sources and wetlands.
iv. Ensure the use of sustainable extraction rates and monitoring systems with regards to the harvesting of indigenous species.
v. Engage into the development of new crops from that of indigenous ones for niche markets and to promote the use and improvement of indigenous animal species.
vi. Aim to minimise the use of herbicides. (e.g. mulching)
vii. Strive to minimise the use of pesticides by encouraging plant health (healthy soil and suitable crop varieties) and populations of pest predators (by leaving passages of natural vegetation throughout the farm).
viii. It is essential to prevent pesticide, herbicide and fertiliser run-off into the environment.

10.2.5. Social considerations

i. Aim to reduce the use of pesticides and, in addition, eliminate or minimise exposure to these products.
ii. In case of the application of pesticides, management should follow the prescribed application directions and wear the appropriate personal protective equipment (PPE).
iii. Aim to prioritise human health when doubt arises about the safety of a product.
iv. Strive to encourage developing farmers to apply sustainable agriculture rather than being dependent on the use of pesticides, herbicides and mechanisation.
v. In addition, encourage farming methods that are dependent on labour-intensive practices.

10.3. Operational philosophy

Waterfall Farm's practices and methods have been subjected to careful revision and, as a result, various improvements have been suggested. Due to the vast benefits of sustainable agriculture, Waterfall Farm will be steered towards a more environmentally, socially, and economically-sound philosophy.

10.3.1. Soil nutrition

Alternatives:

Two approaches are present with regards to improving the characteristics of soil, namely synthetic and organic fertiliser. Table 11 illustrates the advantages and disadvantages associated with each.

Table 11: Alternative methods for field nutrition

Alternative Methods for Field Nutrition		
	Organic fertiliser	Synthetic fertiliser/pellets
Crop yield/throughput	Higher (long-term)	Higher (Short-term)
Space requirement	Higher	Lower
Productivity/land ratio	Lower	Higher
Soil erosion	Typically no	Typically yes
Toxin exposure	Typically no	Typically yes
Long-term soil fertility	Higher	Lower
Water pollution probability	Lower	Higher
Species diversity	Higher	Lower
Proper drainage	Typically yes	Typically no
Water loss	Typically no	Typically yes
Pests and diseases	Lower	NA
Crop quality	Higher	Lower
Soil structure	Higher	NA
Cost	Lower	Higher
Cost volatility	Lower	Higher
Labour	Higher	Lower

Proposed solution:

Waterfall Farm is equipped with the benefits of having livestock and lettuce crops on the premises. The manure of the animals and the waste of the lettuce products will provide matter that is known to be ideal candidates for organic fertiliser. These materials can be used to compile organic compost heaps, indicated in Figure 7 (HDRA.No date), that can be distributed over the fields with the purpose of increasing soil fertility and structure. In addition, the use of compost aids in increased yields, reduced water loss, and reduced pest and disease occurrence. The ideal method will be no-turn composting since it requires less labour and can easily be achieved by the use of sufficient coarse material (straw). The application process should be at soil preparation.

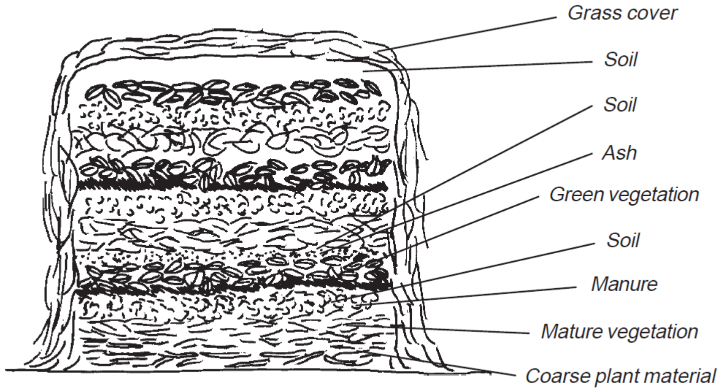


Figure 7: Compost composition

10.3.2. Irrigation

Alternatives:

As mentioned in the problem investigation, Waterfall Farm requires an irrigation system that enables an even water supply in order to reduce unnecessary yield loss. Table 13 compares the alternative irrigation systems with each other. At this stage they are equipped with a sprinkler irrigation system, yet by conducting the necessary research it is evident that a drip irrigation system would be beneficial to the farm's operations. The benefits associated with drip irrigation are:

i. Minimized fertilizer/nutrient loss due to localized application and reduced leaching.
ii. High water application efficiency.
iii. Levelling of the field not necessary.
iv. Ability to irrigate irregular shaped fields.
v. Allows safe use of recycled water.
vi. Moisture within the root zone can be maintained at field capacity.
vii. Soil type plays less important role in frequency of irrigation.
viii. Minimized soil erosion.
ix. Minimized weed growth
x. Highly uniform distribution of water i.e., controlled by output of each nozzle.
xi. Lower labour cost.
xii. Variation in supply can be regulated by regulating the valves and drippers.
xiii. Foliage remains dry thus reducing the risk of disease.
xiv. Usually operated at lower pressure than other types of pressurised irrigation, reducing energy costs.

Table 12: Alternative methods for irrigation system

Alternative Methods for Irrigation System			
	Drip/Micro	Sprinklers	Gravity
Emission device flow rate	GPH	GPM	N/A
Operating pressure	4-60 psi	30-90 psi	Low
Duration of irrigation	Seconds, minutes, or hours	Minutes	Hours, days
Frequency of irrigation	Daily	Weekly	Monthly
Filtration	150-200 mesh	None	None
Quantity of devices	More	Less	N/A
Size/cost of each device	Less	More	N/A
Wetting patterns	.5-40 feet	5-100 feet	Broadcast
Wetting plants	Typically no	Typically yes	Typically no
Wetting non-targeted areas	Typically no	Typically yes	Typically yes
Runoff on slopes	Typically no	Typically yes	Typically yes

Proposed solution:

To irrigate intelligently, one must first choose the right system and then use it properly. Choosing a system can be complicated because each application is slightly different and there are many options available. Figure 8 below illustrates the design of a drip irrigation system Inline Drip Irrigation System 2012). The following will entail the suggested solution in terms of the irrigation system's configuration: (Irrigation Solutions. No date)

i. Emission device: Three alternatives are available for installation, namely drip tape, on-line emitters, and in-line emitters (dripline). For the purpose of Waterfall Farm's operations, the drip tape option is more desirable. The product will incorporate a series of reasonably inexpensive, engineered emission devices into a thin walled tube. The water itself will be evenly distributed along the length of the tube and ejected through the emission devices which can be spaced from 4" to 24" apart. The device can accommodate various types of terrain and crops due to its variations in terms of the tube wall thickness (.004" to .015"), emitter flow rates (.07 to .34 gph), and pipe diameters (5/8" to 1 3/8"). Drip tape is available in standard and pressure compensating models, and is widely used for vegetable and field row crop cultivation. The device can be installed above or underground and, in addition, can be reused if desired. In terms of cost, drip tape is inexpensive and ready for installation without any additional emission device installation labour.
ii. Distribution system: The distribution system will be equipped with the necessary filters, chemical injectors, pipes, valves, and fittings.
iii. Control zone equipment: The irrigation system will be equipped with a system flow meter that will provide instantaneous and cumulative water flow with accuracy. In addition, they can be fitted with electrical analog conversion units in order to transmit the flow rate data to the control computer. This will provide Waterfall Farm with the necessary control over their irrigation system where the data will prove to be indispensable for the analysis of crop response to water and nutrients as well as the system's performance. The system will also be equipped with pressure gauges to provide information on the system's performance in terms of failures.

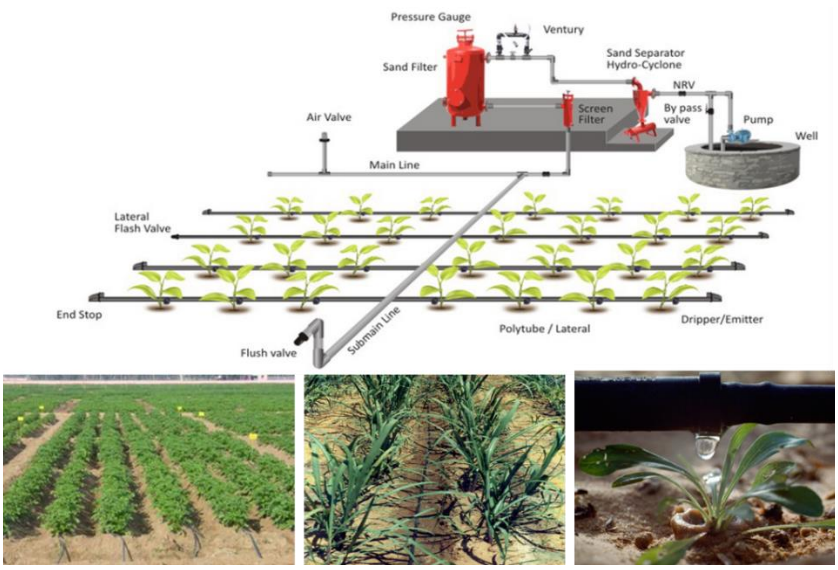


Figure 8: Drip irrigation system

10.3.3. Sun protection

Alternatives:

In terms of providing the appropriate amount of shade to the lettuce crops, various alternatives are available. Waterfall Farm does not provide any protection at this point in time and thus will be strongly advised to implement any of the alternatives provided. The reason for this is due to the fact that lettuce is not suited for high temperatures and often whither in these types of conditions (impacting crop yield). The alternatives are listed as follows:

Table 13: Alternative methods for sun protection

Alternative Methods for Sun Protection		
	Nylon net cover	Sprinkler application
Crop yield/throughput	Higher	Higher
Space requirement	Lower	Lower
Productivity/land ratio	NA	NA
Soil erosion	NA	NA
Toxin exposure	NA	NA
Long-term soil fertility	NA	NA
Water pollution probability	NA	NA
Species diversity	NA	NA
Proper drainage	Typically yes	Typically yes (if controlled)
Water loss	Typically no	Typically yes
Pests and diseases	NA	NA
Crop quality	Higher	Lower
Soil structure	NA	NA
Cost	Lower	Higher
Cost volatility	Lower	Higher
Labour	Lower	Higher

Proposed solution:

The shading structure will be more practical, water efficient, and less time-consuming than the continuously application of water. As mentioned previously, various materials can be used by Waterfall Farm but double thick nylon netting will be advised. Figure 9 illustrates the structure of the shading device and its simplicity. (Organic gardens in South America. 2012)

Figure 9: Shading structure

10.3.4. Weed control

Alternatives:

Three approaches are present with regards to the reduction in weed growth, namely herbicides, cover crops, and mulching. Table 15 illustrates the advantages and disadvantages associated with each.

Table 14: Alternative methods for weed control

Alternative Methods for Weed Control			
	Mulching	Cover crops	Herbicides
Crop yield/throughput	Higher	Higher	Higher (Short-term)
Space requirement	Higher	Higher	Lower
Productivity/land ratio	Higher	Higher	Higher
Soil erosion	Typically no	Typically no	Typically yes
Toxin exposure	Typically no	Typically no	Typically yes
Long-term soil fertility	Higher	Higher	Lower
Water pollution probability	Lower	Lower	Higher
Species diversity	Higher	Higher	Lower
Proper drainage	Typically yes	Typically yes	Typically no
Water loss	Typically no	Typically no	Typically yes
Pests and diseases	Lower	Lower	NA
Crop quality	Higher	Higher	Lower
Soil structure	Higher	Higher	NA
Cost	Lower	Higher	Higher
Cost volatility	Lower	Higher	Higher
Labour	Higher	Higher	Lower

Proposed solution:

For the purpose of Waterfall Farm, mulching will prove to be the best practice in terms of weed control. Mulching involves ground coverage by layering loose material such as crop residues, manure, leaves, compost, straw, or dry grass (located on the premises). The benefits associated with mulching are:

i. Reduction in water loss (due to evaporation)
ii. Reduction in weed growth
iii. Prevention of soil erosion
iv. Increase in micro-organisms located in the top soil
v. Increase in nutrients as well as improvement of the soil's structure
vi. Increase in organic matter

As mentioned previously, composting proves to be a great source of fertilisation and mulching. If no compost is present, straw and dry grass will prove to be ideal due to their abundance on the premises.

10.3.5. Pest and disease control

Alternatives:

Two approaches are present with regards to the reduction in pest and disease occurrence, namely pesticides and crop rotation, intercropping and perimeter trap cropping. Table 17 illustrates the advantages and disadvantages associated with each.

Table 15: Alternative methods for pest and disease control

Alternative Methods for Pest and Disease Control				
	Crop rotation	Intercropping	Perimeter trap cropping	Pesticides
Crop yield/throughput	Higher	Higher	Higher	Higher (LT)
Space requirement	Higher	Higher	Higher	Lower
Productivity/land ratio	Lower	Lower	Lower	Higher
Soil erosion	Typically no	Typically no	Typically no	Typically yes
Toxin exposure	Typically no	Typically no	Typically no	Typically yes
Long-term soil fertility	Higher	Higher	Higher	Lower
Water pollution probability	Lower	Lower	Lower	Higher
Species diversity	Higher	Higher	Higher	Lower
Proper drainage	Typically yes	Typically yes	Typically yes	Typically no
Water loss	Typically no	Typically no	Typically no	Typically yes
Implementation effort	Higher	Higher	Higher	Lower
Crop quality	Higher	Higher	Higher	Lower
Soil structure	Higher	Higher	Higher	NA
Cost	Lower	Lower	Higher	Higher
Cost volatility	Lower	Lower	Lower	Higher
Labour	Higher	Higher	Higher	Lower

Proposed solution:

Crop rotation, intercropping, and perimeter trap cropping are the practices associated with pest and disease control and are accompanied by other benefits such as increase in soil fertility. Waterfall Farm mainly specialises in lettuce products, therefore, crop rotation will be challenging (requires a 3-4 year rotation plan). The products should however not occupy the same beddings for an extensive period of time. Intercropping, indicated in Figure 10 (HDRA.No date), is recommended and simply involves growing the herbs among the main crops. Waterfall Farm should consider the implementation of perimeter trap cropping, which will consist out of onions, chives, or garlic, in order to deter any unwanted pests from the area.

Figure 10: Intercropping

The practice framework highlights the variety of approaches that should be adhered to. The best practices are those mentioned above as they are the main beneficiaries in terms of ensuring a sustainable operation that does not depend heavily on chemicals.

10.3.6. Cost analysis

Table 16 represents the costs that will be incurred depending on the chosen approach. Each approach will be elaborated in order to provide the proper motivation for each expense listed below:

i. Mere estimates were made with regards to the material consumption of organic fertiliser. This is due to the fact that the land itself has the ability to provide materials such as manure, dry grass, vegetation, and other. In terms of the labour, composting does not require attention on a daily basis and, as a result, employing more workers will not be required. Equipment will be accounted for.
ii. The drip irrigation will require high capital during the initial implementation but less on a long term basis. If too expensive, a home-made system can easily be constructed until funds are available.
iii. The nylon net cover will be a once-off investment, depending on the durability of the fabric (other types of netting can be purchased) while the application of water will be daily and dependent on water consumption rates.

iv. Mere estimates were made with regards to the material consumption of mulching. This is due to the fact that the land itself has the ability to provide materials such dry grass. In terms of the labour, an additional worker was accounted. No additional equipment will be required.

v. Crop rotation and intercropping does not incur any additional costs for the company opposed to perimeter trap cropping. The seeds required to create the barrier may prove to be more expensive if accompanied with an additional worker. If all three methods are implemented the excess in funds will be justified by the benefits.

Table 16: Cost analysis

Cost Analysis (Monthly-basis)		
	Sustainable approach	
	Quantity	Cost
Materials		
Compost and mulching:		
Nitrogen-containing material	Field coverage	-
Carbon-containing material	Field coverage	3200*
Perimeter trap cropping:		
Perimeter crop (onion or chives)	Field barrier coverage	3500
Drip irrigation system:		
Water cost	Field coverage	10000
Maintenance and repair cost	System coverage	400
Sun protection:		
Water cost	NA	-
Labour	11 employees	25023.02
Equipment	NA	-
Total		R 42123
Fixed costs:		
Drip irrigation system	5 field layouts	17659.26
Shading structure	5 field layouts	10000
	Intensive approach (current)	
	Quantity	Cost
Materials		
Synthetic fertiliser/ carbon pellets	Field coverage	3000
Pesticides	Field coverage	3000
Herbicides	Field coverage	3000
Sprinkler irrigation system:		
Water cost	Field coverage	18000
Maintenance and repair cost	System coverage	2000
Sun protection:		
Water cost	Field coverage	2000
Labour	10 employees	22748.2
Equipment	NA	-
Total		R53748.2
*If Waterfall Farm decides to purchase, else no cost will be incurred		

It should be noted that various alternative factors play a role in the decision-making process since the majority of benefits cannot be assigned to a monetary value. Factors such as environmental impact, soil fertility, product quality, yield loss, long-term sustainability, and others are influenced by the two approaches individually where the sustainable approach is known to be far superior to that of intensive practices. The causal loop diagram in the previous section, accompanied with the necessary research, validates this statement.

10.3.7 Solution composition

Figure 11 illustrates the layout of the fields when the proposed solutions are implemented. The numbers provide a brief description in terms of identifying the improvement areas and are as follows:

i. Compost (distributed among the soil)
ii. Drip irrigation system
iii. Shading structure
iv. Mulch (distributed between and against beddings)
v. Intercropping
vi. Perimeter trap cropping

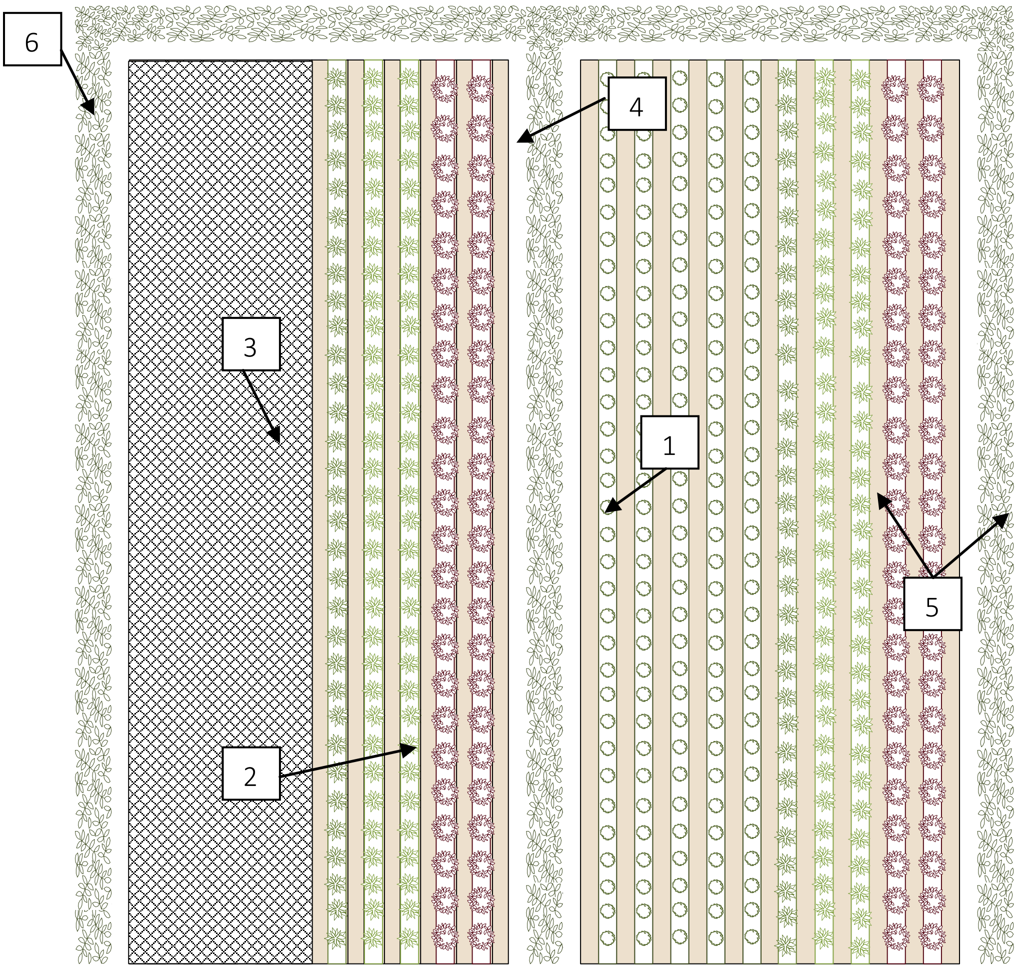


Figure 11: Layout

10.4. Crop schedule

Waterfall Farm will be subjected to further advisement with regards to their processes. The structure will undergo mild changes in order to ensure that all environmental, economic and social considerations have been adhered to.

Seasonal preparation:

i. The compost heaps will be constructed as follows:
   + The site must be well-drained. This can be done by either starting the process on bare soil or creating a layer of sand to ensure the pile is never located on a puddle (only if using a bin).
   + Layers of sticks will be the starting point due to its rapid breakdown quality and allows air penetration from below. All material must be shredded beforehand.
   + The layering process can commence by maintaining a carbon, nitrogen, carbon, nitrogen structure and by mixing chunky and fine material. Note: Each layer must be accompanied with water.
   + The moist materials must be layered with absorbent materials such as sawdust, dried leaves/grass, and other.
   + The addition of rock dust, wood ash, clay, or crushed eggshells is recommended.
   + The process should be finished with a carbon layer such as straw or hay. This reduces odours and the occurrence of insects.
   + The heap must be turned after 10 days and then once more 10 days later. After 10-14 days later, the heap will be ready for use.

   Note: The C/N ratio must be 70% brown, yellow, and dry materials. The remaining 30% must be nitrogen based consisting of green and wet materials.

ii. In order to deter potential pests and diseases, perimeter trap cropping will be implemented by developing an organic barrier consisting out of e.g. onions or chives.
iii. Position the shading structure into place (only the poles are necessary at this point).
iv. At this point, the field allocation must be established for the given period to ensure that the demands will be met. The program will provide this very function.

Soil preparation:

v. The land of Waterfall Farm will be ploughed on occasion in order to address crop-appropriate minimum tillage.
vi. The soil will at this stage be exposed to the disc-harrow which is known to cultivate and even out the fields. This transforms the soil into a finer texture opposed to large clots that impede on crop growth.
vii. When available for use, the compost heaps will be distributed over the field to promote soil fertility.

viii. The rotavator runs over the field with the purpose of creating a fine soil structure by eliminating coarseness in the soil as well as any remaining clots. As a result, the planting process will proceed more swiftly.

ix. Beddings (1.5m wide planting area) are created with the use of a 1.8m ridger of which the centre piece is removed. This is to prevent the crops from drowning in excess water.

Seed sowing:

i. Before the seeds are positioned into place, the soil must be exposed to water in order to promote plant growth.
ii. The eight female employees must punch holes of an appropriate size (10-15mm deep) into the soil and ensure that the seeds are spaced appropriately.
iii. The employees must use their gardening equipment to compact the soil that surrounds the seedling(s) in order to fasten them into place.
iv. At this stage mulching will occur where the employees will distribute the cover material between and against the beddings in order to impede on weed growth and retain moisture.
v. (When the temperatures are beyond the limit for cultivation, the shading structure must be implemented to ensure that the crops are protected against the sun. This merely involves attaching the nylon netting to the pole structure that has been constructed previously.)

Cultivation:

After the above mentioned steps have been completed, the drip irrigation system will be positioned into place and commence with the irrigation process.

Harvesting: and storage:

The harvesting of lettuce merely involves a cutting process above the soil surface, where the solid heads are trimmed to 4 to 5 wrapped leaves. It should be noted that due to its tendency to rapidly wilt, harvesting should be scheduled during the early morning hours. In terms of storage, the harvested lettuce, packed into waxed cartons containing 12 to 16 heads per carton, are stored at temperatures ranging from 0.5°C to 4°C and a relative humidity of 95%. It should be noted that lettuce types are not permitted to be stored with products that emit ethylene due to its increasing effect for russet spotting.

10.5. Operational plan: Excel/LINGO program

The program consists out of 7 sections: (1) Main page, (2) practice framework, (3) crop schedule, (4) user manual, (5) data configuration, (6) field allocation, and (7) crop performance.

10.5.1. Main page

This sheet will be the starting point of the program's operation. It provides management with the ability to navigate to the various sections of the program by clicking on one of the six buttons supplied below. The buttons are simply equipped with a hyperlink that transports the screen to the described sheets. The following two sheets are embedded in the program with the sole purpose of convenience on behalf of management, meaning documents do not have to be revisited.

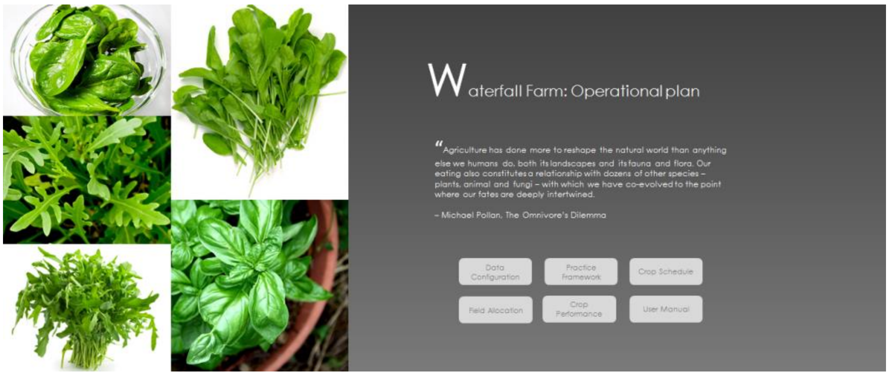


Figure 12: Main page

10.5.2. Practice framework

This sheet clearly outlines the practices that Waterfall Farm must adhere to throughout the business' lifetime. The information presented on this sheet has been documented in the report since this aligns with one of the objectives highlighted previously.

Figure 13: Practice framework

10.5.3. Crop schedule

This sheet provides management with the sequential procedure, from seasonal preparation to the final process of harvesting the crops, in which the farm's operations should be performed. As mentioned above, this section has been documented in the report for revision since this satisfies one of the objectives set out previously.

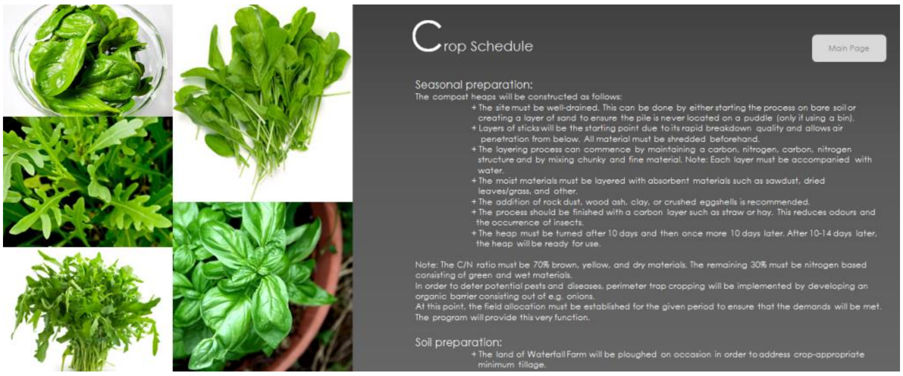


Figure 14: Crop schedule

10.5.4. User manual

The final section is the user manual which will provide Waterfall Farm's management with the necessary information to operate the newly designed interface on Excel.

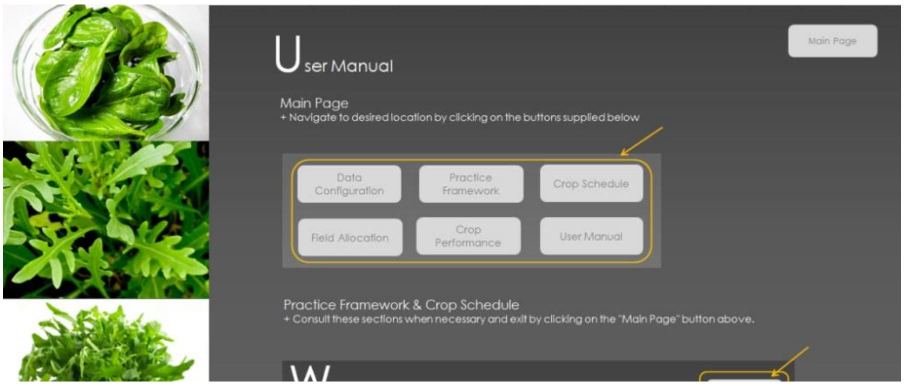


Figure 15: User manual

10.5.5. Data configuration

This section of the program revolves around data entry, where management will be able to define their system by providing information with regards to:

i. Production/demand schedule: The schedule is designed in such a way that management is simply required to enter each product's lead time and forecasted demand. The program will then consider each product's lead time (or cultivation period) in order to commence with production on time, meaning the program will automatically project the value to the desired location by the use of Excel's OFFSET function. Note: Management can only start entering demands from the green arrow and onwards. The reason for this is that Waterfall Farm has to start production in the previous year in order to meet the demand for the first couple of months of next year.
ii. Field capacity: The table provides management with the ability to determine the capacity of each field's row and enter the results into the table which will be used as a constraint in the LINGO program.
iii. Field capacity remaining: The difference between the two capacity tables is that the first one will be considered as the original data while the second table will constrain each period's

capacity. In other words, management will decrease the capacity when products occupy the available space thus leaving less space for the next period to occupy.

iv. Demand summary: For convenience and programing preference, each period's demand will automatically be summarised by the use of Excel's OFFSET function. Management simply must specify which period they desire by entering that value into the allocated cell.

v. Product weight: This table has been created due to the fact that each product is different in terms of their dimensions, thus occupying either more or less space on the fields. Management must simply specify each product's individual weight (not to be mistaken with physical weight in grams).

vi. Product yield: This table will contain each product's yield, depending on the field in which they are located. This will be incorporated into the program to ensure the prevention of product shortage. This links with the program's "Crop Performance" section where the yields will be calculated automatically and projected into the table.

vii. Field/bedding availability: Finally, this table enables management to indicate which beddings are activated in which fields (e.g. field 1 consists out of 10 beddings while field 2 only has 5). In addition, this provides space for field expansions if Waterfall Farm should choose to increase or even decrease the number of beddings situated in each field.

Moss Curl Parsley	Lead time =		Gross requirements																	
	On hand =		Projected available balance																	
	Safety stock =		Net requirements	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Planned order receipts																	
			Planned order releases	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mizuna	Lead time =		Gross requirements																	
	On hand =		Projected available balance																	
	Safety stock =		Net requirements	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			Planned order receipts																	
			Planned order releases	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Field Capacity

	Bedding																			
Field number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Field 1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Field 2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Field 3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Field 4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Field 5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Field Capacity Remaining

	Bedding																			
Field number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Field 1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Field 2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Field 3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Field 4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Field 5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Demand Summary

Demand Period	1

Triple Play	0
Roblesco	0
Ballerina	0
Levistra	0
Versai	0

Figure 16: Data configuration

10.5.6. Field allocation

This section revolves around the solution of the LINGO program. As mentioned previously, the goal of this design is to provide Waterfall Farm with a tool that is able to determine where each product should be located in the fields at a given period in time. First, the LINGO program will be addressed in order to illustrate the functioning of the tool and how each data entry aids in calculating the most feasible solution.

i. The first section illustrates the sets that were used in order to define the variables:
   a. Demand: The demand of product I
   b. Output: The amount of product I planted at bedding K of field J

c. Yield: The given yield of product I at field J
d. field/bedding availability: The given availability of bedding K at field J
e. Capacity: The given capacity of bedding K at field J
f. Weight: The given field occupation of product I

ii. The second section indicates the source of the data which will be the Excel document itself under "Data Configuration".

iii. The final section illustrates the objective of the program, which is meeting the demand that has been provided by Littlemore Farm, and the constraints that help shape the program. The constraints are to ensure that:
   a. The capacity is adhered to
   b. Demand shortage will been prevented
   c. The availability of beddings is restricted to binary numbers
   d. And that the output does not contain decimal numbers

In addition, intercropping has been embedded into the program to promote sustainable agriculture due to the omission of a constraint.

```
SETS:
        I/1..14/:WEIGHT;
        J/1..5/;
        K/1..20/;

        COMBO1(I):DEMAND;
        COMBO3(I,J,K):OUTPUT;
        COMBO4(I,J):YIELD;
        COMBO5(J,K):FB_AVAILABILITY,CAPACITY;

ENDSETS
```

```
DATA:

WEIGHT,DEMAND,YIELD,FB_AVAILABILITY,CAPACITY =
        @OLE('C:\Users\Elke\Documents\Tuks\4th year\Semester 2\BPJ 420\Operational
plan\Operational Plan 0.0.6.xlsx','WEIGHT','DEMAND','YIELD','FB_AVAILABILITY','CAPACITY');

@OLE('C:\Users\Elke\Documents\Tuks\4th year\Semester 2\BPJ 420\Operational
plan\Operational Plan 0.0.6.xlsx')=OUTPUT;

ENDDATA
```

```
MAX = @SUM(COMBO3(N,M,L):OUTPUT(N,M,L));

@FOR(J(M):
        @FOR(K(L):
                @SUM(I(N):WEIGHT(N)*OUTPUT(N,M,L))<=
CAPACITY(M,L)*FB_AVAILABILITY(M,L)));

@FOR(I(N):
        @SUM(COMBO5(M,L):OUTPUT(N,M,L))<=DEMAND(N));
@FOR(COMBO5(M,L):
        @BIN(FB_AVAILABILITY(M,L)));

@FOR(COMBO5(M,L):
        @BIN(FB_AVAILABILITY(M,L)));
```

Figure 17: LINGO coding

The solution has been projected into a table that will be used to create a visual presentation of how the products should be assigned to each field's bedding. A stacked column chart proved to be the best representation of the data and creates a realistic visual layout of the fields. This will decrease the chance of human error since other charts were extremely large to work with.

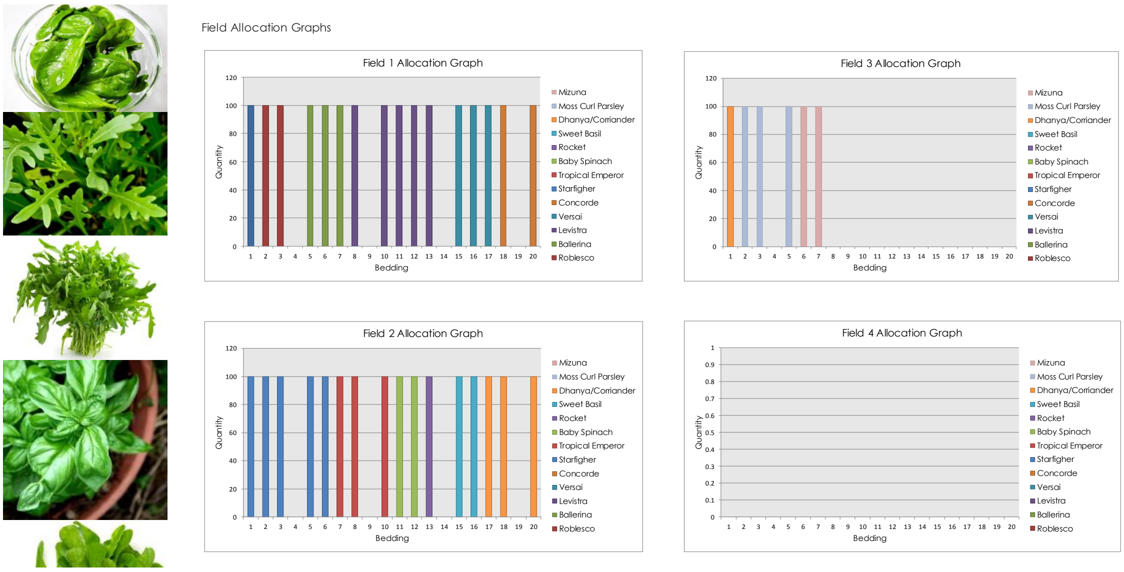
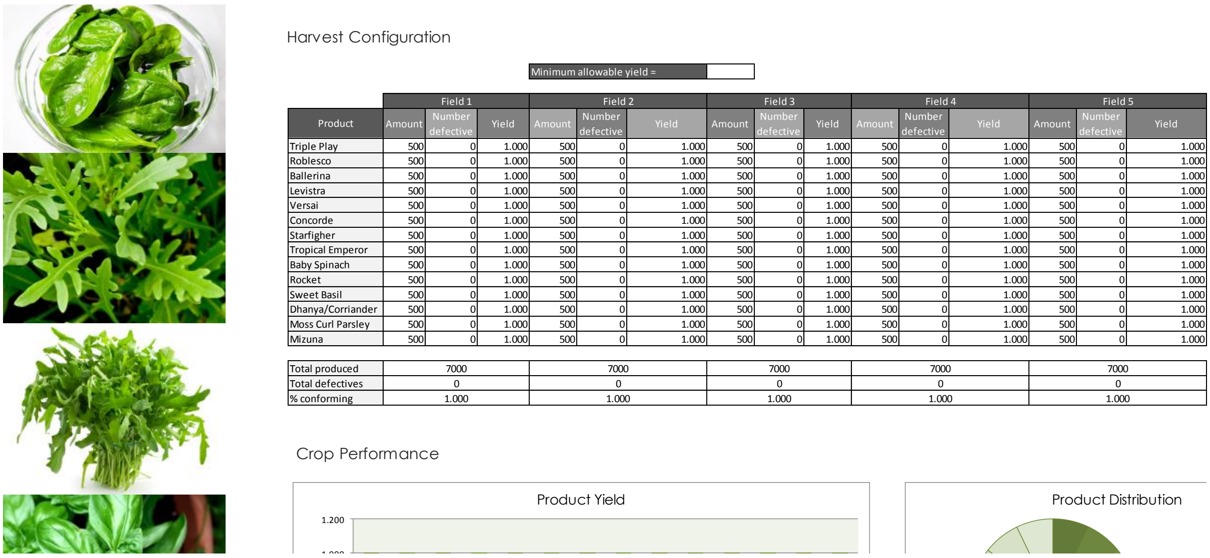


Figure 18: Field allocation

10.5.7. Crop performance

This section revolves around the performance of the crops by providing information on each harvest. The workers will document how many of each product was not according to Waterfall Farm's standards. This will enable management to determine the yield at that harvest period and flag the fields that were detrimental to the product's growth by specifying the minimum allowable yield (conditional formatting highlights the problem areas). Management can then determine the root cause of the problem and, as a result, corrective action can be taken. The yields are calculated automatically by dividing the amount of the product located at the field by the amount that did not conform to the standards.


Harvest Configuration

Minimum allowable yield =

	Field 1			Field 2			Field 3			Field 4			Field 5		
Product	Amount	Number defective	Yield	Amount	Number defective	Yield	Amount	Number defective	Yield	Amount	Number defective	Yield	Amount	Number defective	Yield
Triple Play	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Roblesco	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Ballerina	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Levistra	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Versai	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Concorde	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Starfigher	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Tropical Emperor	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Baby Spinach	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Rocket	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Sweet Basil	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Dhanya/Corriander	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Moss Curl Parsley	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000
Mizuna	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000	500	0	1.000

Total produced	7000	7000	7000	7000	7000
Total defectives	0	0	0	0	0
% conforming	1.000	1.000	1.000	1.000	1.000

Figure 19: Crop performance

11. Solution validation

In order to ensure that the project has been steered into the desired direction, the solutions will be validated by revising the objectives and whether they have been satisfied. Waterfall Farm's main objective is to achieve a sustainable and successful business by increasing its production and diversifying into new brands of products while adhering to the customer requirements, financial constraints, GlobalGAP standards, and sustainable practices. The metrics that have been identified include throughput of crops, resource efficiency, percentage yield/losses, as well as process performance. In addition, the problems (poor practices, lack knowledge of management, and inconsistencies during the cultivation period) at Waterfall Farm have received the necessary attention and have been incorporated into the final design. The objectives have been adhered to by providing a successful and sustainable operations plan that includes:

ii. Practice framework
   + Guidelines in maintaining a sustainable agriculture operation

iii. Operational philosophy
   + Environmentally, socially, and economically-sound improvements to Waterfall Farm's practices and methods

iv. Crop schedule
   + Improved sequential procedure from seasonal preparation to harvesting and storage

v. Operational planning tool (including a user manual)
   + Improve scheduling procedure
   + Document relevant data such as, product requirements, land specifications, and other
   + Generate reports on the performance of the harvest
   + Reduce human error

- Keep track of current practices and procedures

vi. System representation
- Understand the true functioning of the system under observation as well as the reason how the outcomes are produced by the cause and effect relationships.
- Utilise the new-found knowledge to improve the decision-making process in terms of achieving the desired results from changing the system.
- Increase management skills in terms of the relationships and systems that are clearly visible as well as explicit, opposed to invisible and assumed.

12. Final conclusion

Waterfall Farm has numerous areas to address in order to operate at a desirable level. These problems have been highlighted throughout the document and mainly revolve around:

- Poor practices: Intensive agriculture such as chemical application (fertiliser, pesticides, and insecticides).
- Lack of knowledge in the management of agricultural industries: Excessive experimentation with products and practices that are poorly managed and result in overproduction and unnecessary expenses.
- Inconsistencies during the cultivation period: Lack of even water supply, formation of raised beddings, and protection against severe weather that gives birth to irregular growth and increased yield loss.

It should be noted that various alternative factors play a role in the decision-making process since the majority of benefits cannot be assigned to a monetary value. Factors such as environmental impact, soil fertility, product quality, yield loss, long-term sustainability, and others are influenced by the two approaches individually where the sustainable approach is known to be far superior to that of intensive practices. The causal loop diagram in the previous section, accompanied with the necessary research, validates this statement

The report has elaborated on the proposed solutions, which have specifically been chosen to satisfy the business' needs in becoming a successful and sustainable venture. By implementing the above mentioned solutions, Waterfall Farm will not only satisfy its needs on an operational level, but also extend the knowledge base and management skills that will prove to be essential in the business' endeavour. The operational plan will enable Waterfall Farm to perform their operations environmentally, socially, and economically-sound and, as a result, metrics adherence (throughput of crops, resource efficiency, percentage yield/losses, as well as process performance) will be improved.

13. References

i. Bocco, D. No date. *Sustainable Farming Practices*. [Online]. NA. Available: <http://dsc.discovery.com/tv-shows/curiosity/topics/10-sustainable-farming-practices.htm> [Accessed 15 March 2013].

ii. Department of Agriculture and Fisheries. 2009. *Production Guidelines for South Africa*. [Online]. South Africa. Available: < www.nda.agric.za/docs/Brochures/ProdGuideLettuce.pdf> [Accessed 15 March 2013].

iii. Department of Environment and Primary Industries. 2009. *Growing Lettuce*. [Online]. State Government Victoria. Available: <http://www.dpi.vic.gov.au/agriculture/horticulture/vegetables/vegetables-a-z/lettuce> [Accessed 15 March 2013].

iv. ECIFM. No date. *Monoculture.* [Online]. NA. Available: <http://www.ecifm.rdg.ac.uk/monoculture.htm > [Accessed 15 March 2013].

v. Goldblatt, A. 2009. *Agriculture: Facts & Trends South Africa*. [Online]. World Wildlife Fund: Cape Town. Available: <http://awsassets.wwf.org.za/downloads/facts_brochure_mockup_04_b.pdf > [Accessed 15 March 2013].

vi. Greenpeace International. 2009. *Agriculture at a Crossroads: Food for Survival*. [Online]. Greenpeace International: Amsterdam. Available: <http://www.greenpeace.org/international/Global/international/planet-2/report/2009/11/agriculture-at-a-crossroads-report.pdf> [Accessed 15 March 2013].

vii. Irrigation Solutions. No date. *What is Drip Irrigation?* [Online]. NA. Available: < http://www.dripirrigation.org/images/ALT142_What%20Is%20Drip%20article_WEB.pdf> [Accessed 21 August 2013].

viii. Lexicon. No date. *Stock and Flows Diagram*. [Online]. NA. Available: <http://www.createadvantage.com/glossary/stocks-and-flows-diagram > [Accessed 15 March 2013].

ix. Pillai, M. 2013. *Advantages and Disadvantages of Intensive Farming*. [Online]. NA. Available: <http://www.buzzle.com/articles/advantages-and-disadvantages-for-intensive-farming.html > [Accessed 15 March 2013].

x. Shi, T. & Gill, R. 2005. D*eveloping effective policies for the sustainable development of ecological agriculture in China: the case study of Jinshan County with a systems dynamics model*. Ecological Economics 53 (2005) 223– 246. Available from Science Direct at http://data2.xjlas.ac.cn:81/UploadFiles/sdz/cnki/%E5%A4%96%E6%96%87/ELSEVIER/ecological%20agriculture/3.pdf [Accessed 15 March 2013].

xi. Small-farm-permaculture-and-sustainable-living. No date. *Advantages and Disadvantages Organic Farming: Good Things, Barriers and Environmental Effects*. [Online]. NA. Available: <http://www.small-farm-permaculture-and-sustainable-living.com/advantages_and_disadvantages_organic_farming.html > [Accessed 15 March 2013].

xii. Surplus People Project Group. 2010. *Agro-Ecological Farming*. [Online]. Surplus People Project: Cape Town. Available: <http://www.spp.org.za/agro-ecological-farming/> [Accessed 15 March 2013].

xiii. Sustainable Agriculture, Research & Education. No date. *What is sustainable agriculture?* [Online]. NA. Available: <http://www.sare.org/Learning-Center/SARE-Program-Materials/National-Program-Materials/What-is-Sustainable-Agriculture> [Accessed 15 March 2013].

xiv. System Dynamics Society. 2011. *The Field of System Dynamics*. [Online]. NA. Available: <http://www.systemdynamics.org/what_is_system_dynamics.html> [Accessed 15 March 2013].

xv. Union of Concerned Scientists. 2008. *Sustainable Agriculture Techniques*. [Online]. NA. Available: <http://www.ucsusa.org/food_and_agriculture/solutions/advance-sustainable-agriculture/sustainable-agriculture.html> [Accessed 15 March 2013].

xvi. Yengoh, G. Tambang. & Svensson, M. G. E. 2008. *Low External Input Strategies for `Sustainable Small-Scale Farming in Kenya: A Systems Dynamic Approach*. [Online]. NA. Available: <http://www.systemdynamics.org/conferences/2008/proceed/papers/GENES392.pdf> [Accessed 15 March 2013].

xvii. HDRA.No date. *Compost composition.* [Online image]. Available from: <http://www.infonet-biovision.org/res/res/files/488.OrgFarm.pdf> [Accessed 15 March 2013].

xviii. Inline Drip Irrigation System. 2012. *Drip irrigation system.* [Online image]. Available from: < http://www.kotharipipes.co.in/frm_DripIrrigationSystem_EmittingPipes.htm> [Accessed 21 August 2013].

xix. Organic gardens in South America. 2012. *Shading structure*. [Online image]. Available from: <http://articles.washingtonpost.com/2012-02-15/lifestyle/35443738_1_garden-ecosystem-latin-accent> [Accessed 21 August 2013].

xx. HDRA.No date. *Intercropping* [Online image]. Available from: <http://www.infonet-biovision.org/res/res/files/488.OrgFarm.pdf> [Accessed 15 March 2013].

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Department of Industrial & Systems Engineering
Final Year Projects
Identification and Responsibility of Project Sponsors

All Final Year Projects are published by the University of Pretoria on *UPSpace* and thus freely available on the Internet. These publications portray the quality of education at the University and have the potential of exposing sensitive company information. It is important that both students and company representatives or sponsors are aware of such implications.

Key responsibilities of Project Sponsors:

A project sponsor is the key contact person within the company. This person should thus be able to provide the best guidance to the student on the project. The sponsor is also very likely to gain from the success of the project. The project sponsor has the following important responsibilities:

1. Confirm his/her role as project sponsor, duly authorised by the company. Multiple sponsors can be appointed, but this is not advised. The duly completed form will considered as acceptance of sponsor role.
2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective.
3. Review the Final Project Report (delivered during the second semester), ensuring that information is accurate and that the solution addresses the problems and/or design requirements of the defined project.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensures that any sensitive, confidential information or intellectual property of the company is not disclosed in the Final Project Report.

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