Optimising Commercial Farming: crops & livestock

by

MINETTE BRINK
28011342

Submitted in partial fulfillment of the requirements for the degree of

BACHELORS OF INDUSTRIAL ENGINEERING

in the

FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

UNIVERSITY OF PRETORIA

October 2012

EXECUTIVE SUMMARY

Groen Goud Landgoed (Pty) Ltd was established in 1972 and currently consists of twenty farms. These twenty farms accounts for 144 fields, 29 pastures and 12 planted pastures, on which the commercial herd graze. Groen Goud Landgoed (Pty) Ltd has three main ramifications, namely crop enterprises, cattle farming and broiler farming.

Groen Goud Landgoed (Pty) Ltd's crop enterprises ramification consists of sunflower, maize and wheat. These crops account for more than half of the company's gross margin income. To maximise the profit, it is necessary to determine on which fields each of the crops should be planted.

The cattle on Groen Goud Landgoed (Pty) Ltd are a commercial Angus herd. The herd currently consist of 723 cows and 27 registered bulls. Young bulls and the heifers that are not withheld for Mr Van Tonder's own breeding purposes are either sold as weaners, or slaughtered for their meat when they reached the desired weight. Otherwise the heifers are grown until they are ready for the bulls. It is necessary to be able to easily manage the cattle since there are so many. For this reason the cattle should be divided into smaller groups. The smaller groups will be allocated to specific grazing pastures.

Groen Goud Landgoed (Pty) Ltd receives 284 000 day-old broiler chicks at the beginning of each 52-day cycle. The broiler flocks are divided among the eight broiler houses. Each broiler is fed five different rations over a 35-day period to reach the desired weight of 1.8 kg before it is supplied to a processing plant. Hence it is necessary of find the optimal order quantity of each ration to minimise the feeding expenses.

The main objective of the developed Operations Research model was to increase the profitability of Groen Goud Landgoed (Pty) Ltd with regards to the crop enterprise and cattle farming. The model resulted in 18 fields being planted with sunflower, 36 fields being planted with maize, and 50 fields being planted with wheat. The model's output also resulted in 40 fields left uncultivated.

The cattle allocated to pastures, planted pastures and uncultivated fields accounted for 82.27% of the current Angus herd. The Operations Research model's results told one that the remaining 133 cattle should be slaughtered for their meat. It was assumed that all of the cattle to be slaughtered were cows.

The validation of the Operations Research model showed what effect different yields would have on the profit. It was found that one has a 48% chance to realise a profit between 8.5 million and 11.5 million rand.

The assumptions were made that the input costs, yields and selling prices of the crops were fixed. It was also assumed that the income generated from slaughtering a cow was fixed. The profit obtained from the Operations Research model was R8 749 197.00, which is an increase of approximately 14.90% compared to 2011's crop enterprise and cattle farming profit.

To determine the optimal order quantity of each broiler ration required during the five different feed phases of a cycle, an economic order quantity (EOQ) model has been used. The main objective of the EOQ model was to minimise the broiler feed expenses. The results obtained from this model showed that the optimal order quantities were non-integer values.

During the validation of the EOQ model the results obtained were rounded to the nearest ton. This change resulted in fairly small changes in the total cost associated with each order quantity. This model also generated an ordering schedule for each of the five feed phase.

The feasibility of the order quantities were tested against constraints like available storage capacity and whether or not the order quantities could be received at any given time. The conclusion drawn was that it has been found feasible to order 42 tons of pre-starter, 60 tons of starter, 187 tons of grower, 205 tons of finisher and 169 tons of post-finisher on the calculated days as it is stated in the ordering schedule. If these quantities are ordered the annual broiler feed expenses decreased by R1 746 870.49 (or 11.36%) when compared to 2011's broiler feed expenses.

ACKNOWAGEMENTS

First and foremost I would like to thank my Heavenly Father for His strength, ingenuity and perseverance. Without Him nothing would be possible. Thank you for all the wonderful people set on my path, whom will be thanked below.

I would like to thank my parents and brother for their support throughout my years at the University of Pretoria. If it were not for you I would not have made it this far. Thank you for your love and motivation.

I would like to thank Dr P.J. Jacobs and Miss E. van Wyk for their input and guidance throughout my project, it was of great value. Thank you for always having an open door.

I would like to thank Mr J.J. van Tonder and Mr B. Brink for their willingness to help me with any information or data I required. Thank you for all the time you set aside to help me understand the agricultural industry better.

I would like to Mr R.L. Smit, Miss Z. van Reenen and Mr L. Erasmus for their time and input. Without you I would not be able to improve my document as I did with your help. Thank you for being prepared to help me whenever I needed help. It is greatly appreciated.

Lastly, I would like to thank Mr R. Botha and Mr S. Underhay for their help with the graphics used in this document and in my presentation. I appreciate your readiness to help whenever help was needed.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

1.1 INTRODUCTION and BACKGROUND

South Africa covers approximately 1.2 million square kilometres of land ('South African Agriculture', 2008), of which 13% can be used for planting crops. According to 'South African Agriculture' (2008) only 22% of the mentioned 156 thousand square kilometres of land is high-potential arable land. Agricultural activities on this high-potential land include crop enterprises and livestock farming.

According to 'South Africa's Farming Sectors' (2008), the agronomy sector produces 25-33% of South Africa's gross agricultural production. Maize is most widely grown, followed by wheat, sugar cane and sunflowers ('South African Agriculture', 2008).

The largest South African agricultural sector is livestock ('South Africa's Farming Sectors', 2008). Livestock include cattle, sheep, pigs, and poultry. Cattle farming can be subdivided into beef- and dairy farming. 'South Africa's Farming Sectors' (2008) claims that South Africa's poultry and pig farms are more intensive than sheep and cattle production. Broiler production contributes about 80% to total poultry meat production, with the other 20% made up of mature culls, ducks, geese and turkeys ('South Africa's Farming Sectors', 2008).

An Industrial Engineer is someone who manages people and machines, as well as ensuring that operating systems operate efficiently ('Industrial Engineering', n.d.). There are many opportunities for Industrial Engineers in the Agricultural sector. Most of these opportunities have been created by the complexities of modern farming, such as deciding what crop(s) to grow, and the number of hectares of each crop to plant ('Cropping Decisions', 2004). These decisions are important because it directly influences the profit (or loss) that the farmer will make.

The opportunities come in various forms and may include the use of Operations Research methods (Miller *et al*, 1990) to find the optimal solution for the crop planting problem mentioned earlier. It may also include numeric models in conjunction with other software, which can be used to solve problems by taking into account techno-scientific and economic ('Industrial agriculture', n.d.) requirements. This is especially important since the primary objective of farming is to be profitable.

Mr W. van Tonder started farming on his own on the family farm, Erfdeel in 1959. During the 1960's he started to rent fields from other farm owners. This eventually led to some of these rented farms being bought. Mr W. van Tonder established his first farming company, Groen Goud Landgoed (Pty) Ltd, in 1972. In 1978 Mr van Tonder started to manufacture ploughs, and he established his second company, namely Wilton Ploughs (Pty) Ltd.

Mr W. van Tonder has three sons, Johan, Martin and Wimpie. Mr Johan van Tonder started farming in 1986. Mr Johan van Tonder expanded the cattle farming from 1986 to 1993. In the same period he also gradually took over the crop enterprise farming from his father. Mr Martin van Tonder started farming in 1989, and is responsible for maintenance of the agricultural implements. Mr Wimpie van Tonder joined his two brothers in the farming industry in 1993. At first he was only in charge of the cattle farming. Later on Mr Wimpie van Tonder was responsible for the permanent corps under irrigation. The Van Tonder brothers began farming with broilers in 2004. Mr Wimpie van Tonder had the responsibility of managing the broiler houses.

Mr Wimpie van Tonder immigrated to Australia earlier in 2012. Thus, the remaining Van Tonder brothers took over Wimpie's responsibilities at Groen Goud Landgoed (Pty) Ltd. Therefore, Mr Johan van Tonder now runs the cattle farming and the crop enterprises, while Mr Martin van Tonder is in charge of the broilers, Wilton Ploughs (Pty) Ltd and the workshop.

Other than Mr Wimpie van Tonder leaving South Africa, another change has occurred in Groen Goud Landgoed (Pty) Ltd in the past year. The change being that Mr Johan van Tonder no longer farms with blueberries.

1.2 PROBLEM STATEMENT

The first ramification of Groen Goud Landgoed (Pty) Ltd is the crop enterprises. As a result of the fact that Groen Goud Landgoed (Pty) Ltd no longer produces blueberries, there are fields available on which other corps can be planted. This leads to the re-division of the available fields. The problem which arises from this is that the Van Tonder brothers have to decide which crop should be planted on which field, by taking into account the various risk factors that will affect these decisions.

The second ramification of Groen Goud Landgoed (Pty) Ltd is cattle farming. Cattle can be placed in pastures, planted pastures, wintered fields. The Van Tonder brothers must first decide how to divide the cattle, and then they must decide where the smaller herds should graze. Risk factors influencing the cost of keeping cattle must be minimised while opting for maximum income when the animals are sold off.

The third and final ramification of Groen Goud Landgoed (Pty) Ltd is broiler farming. Broilers are kept in broiler houses, where temperature, ventilation and light intensity are controlled via a computer system. The broilers are fed different rations during different stages of their lives, before they are sold to processing plants. Thus, it is necessary to know exactly when to order what quantity of which form of feed.

1.3 PROJECT AIM

The project aim is to develop models which can be used by the Van Tonder brothers to minimise their expenses, while maximising their income for each of the ramifications mentioned above. This is required to optimise Groen Goud Landgoed (Pty) Ltd's profitability.

Objectives of the model:

- Advise the farmer on which crop to cultivate on which field.
- Advise the farmer on how to divide the cattle amongst the pastures and planted pastures.
- Advise the farmer on quantity of the feed for the broilers, which are required at different phases of the broilers' live cycles.

1.4 PROJECT SCOPE

1.4.1 Inclusion

Groen Goud Landgoed (Pty) Ltd currently has the following ramifications:

- Crop enterprises
  - Sunflower
  - Maize
  - Wheat
- Cattle farming
- Broiler farming
- Pecan nuts

The scope of this project will include only the first three ramifications of Groen Goud Landgoed (Pty) Ltd, namely crop enterprises, cattle farming and broilers.

1.4.2 Exclusion

Wilton Ploughs (Pty) Ltd is concerned with manufacturing ploughs and other implements, and is a company on its own; therefore it is excluded from the scope of this project.

The pecan nuts grown on Groen Goud Landgoed (Pty) Ltd are excluded from the scope of this project because its contribution toward the overall profit is small (refer to Appendix A); Dr Jacobs and Mr Johan van Tonder both decided that it can be excluded from the project scope. As mentioned above, Mr Johan van Tonder does not farm with blueberries anymore, thus it is excluded from the scope.

Groen Goud Landgoed (Pty) Ltd receives its broilers from three different hatcheries and supplies them (once grown out) to CC Chickens (Pty) Ltd, which is a processing plant. The hatcheries and the processing plant are excluded from the scope of this project.

CHAPTER 2

2.1 INTRODUCTION to LITERATURE REVIEW

The Free State is the heart of South African agriculture. Agriculture accounts for approximately 90% of land use in the province (Hoffman & Ashwell, n.d.). This percentage can be broken down into 33% for crop farming and 57% for stock farming. Statistics South Africa (StatsSA) (2009) confirms that the province produces approximately 45.0% of the nation's sunflower, 37.5% of its maize and 38.9% of its wheat on an annual basis.

Groen Goud Landgoed (Pty) Ltd currently consists of twenty farms in the eastern Free State, of which eleven are owned by the Van Tonder brothers. They rent the remaining nine farms from other farm owners. The Van Tonder brothers only rent fields for cultivation purposes.

The farms are grouped in the tables below according to ownership. Table 1 tabulates the farms owned by the Van Tonder brothers, while Table 2 tabulates the farms rented by them. Maps of all the farms can be seen in Appendix B.

F – Field P – Pasture PP – Planted pasture

Table 1: Farms Owned

	F	P	PP
Beketsrus	6	3	0
Bullock	4	3	2
Danielsfontein	4	2	5
Erfdeel	13	4	1
Goodhope	3	1	0
Mike	4	3	0
Pyrmont	3	1	3
Vaalkoppies	17	5	1
Vlakpan	4	1	0
Vlakvallei	10	2	0
Yarima	16	4	0

Table 2: Farms Rented

	F	P	PP
Dankbaar	4	0	0
Dorpslande	10	0	0
Langverwacht	13	0	0
Nuldesperandum	2	0	0
Olivia	4	0	0
Patmos	2	0	0
Rooikraal	10	0	0
Vyfhoek	8	0	0
Waverley	7	0	0

Table 3: Total Area

	Total Area (ha)
Fields	5500
Pastures	1640
Planted Pastures	415

From Tables 1 and 2 it is apparent that there are 144 fields, 29 pastures and 12 planted pastures in total. Table 3 lists the total rounded area of all the fields, pastures and planted pastures that are used by Groen Goud Landgoed (Pty) Ltd.

2.2 ENVIRONMENTAL FACTORS

Many of the specialty crops such as sunflower, maize and wheat are higher risk crops ('Cropping Decisions', 2004). It is therefore important to take into account all factors which might have an effect on the final yields. These factors will be discussed below.

2.2.1 Erosion and Soil Degradation

Groen Goud Landgoed (Pty) Ltd is situated in the Lindley and Arlington districts of the eastern Free State, and is therefore classified to have a semi-arid climate (Hoffman & Ashwell, n.d.). Experiments by Sivakumar and Valentin (1997) showed that soils in semi-arid areas are susceptible to waterlogging and erosion. Waterlogging can be reduced by good drainage of soils, which can be achieved by preventing soil crusting. Sustained farming, strip cropping and contour cultivation, which decelerate the flow of water down a slope, are dependent on soil conservation measures against wind and water erosion. A study conducted by Total SA (2006) found that wind erosion can be reduced by maintaining a trash cover of crop residue at the soil surface, by using crop rotation systems, and by using shelterbelts to lower the wind velocity at the soil surface.

The Free State is the least degraded province in South Africa as stated by Hoffman and Ashwell (n.d.). In most magisterial districts soil degradation is insignificant or light, and in general the rates of soil degradation are decreasing. All the farms of Groen Goud Landgoed (Pty) Ltd fall under the Nketoana Municipality (Lindley), except for Vlakvallei and Yarima, which falls under the Sesotho Municipality (Senekal). It is worthwhile to note that all the farms are less than fifteen kilometres from Arlington.

The study conducted by Hoffman and Ashwell (n.d.) suggests that sheet erosion is the most common form of soil degradation in the province, followed by gully erosion and wind erosion. Their study also point out the reasons for the relatively low levels of land degradation, and include the provision of agricultural extension services, government-subsidised soil conservation works and stock reduction schemes, farm planning, and the strict application of agricultural legislation.

2.2.2 Floods

Floods are not common occurrences in the eastern parts of the Free State. The last flood affecting Groen Goud Landgoed (Pty) Ltd was recorded in the 1999/2000 season. Although it is very unlikely, but not impossible, that a flood will occur in the near future, a discussion on floods will follow below for completeness sake.

Precipitation has many forms and includes rainfall, hail and frost (Eagleman, 1985; Miller, 2001). Sivakumar (n.d.) defines a flood as a temporary inundation of normally dry land with water and suspended matter, possibly caused by groundwater seepage, precipitation, rainstorms, failure of water retaining structures, and overflowing of rivers.

Sivakumar (n.d.) noted that impacts of floods during the non-growing season include loss of topsoil and soil compaction, while impacts on agriculture during the growing season include waterlogging, lodging of standing crops, loss of pasture use, greater susceptibility of crops to diseases and pests, and interruptions to farm operations. Common impacts of floods, irrespective of when they occur, are loss of soil nutrients, soil erosion, and possible permanent damage to perennial crops, trees, livestock, buildings and machinery.

The report compiled by Total SA (2006) confirms that strategies of flood abatement include mechanical land treatment of slopes such as contour ploughing and terracing to reduce the runoff coefficient, reforestation or reseeding of sparsely vegetated areas, and comprehensive protection of vegetation from wildfires, overgrazing and clear-cutting of forest land.

2.2.3 Hail

A study by Dessens (1995) clarified the dependence of hailstorm damage on temperature and precipitation. The results of the study argue that high minimum temperatures are related to increased hailstorm damage. Dessens (1995) suggests that a 1°C rise in summer mean minimum temperature will increase hailstorm damage by roughly 40%, while Botzen et al. (2009) found that hailstorm damage will increase by 46% with an increase of 1°C in mean summer temperature.

Correlated risks and consequent high loss accumulation are smaller for hailstorm damages than for other natural hazards due to the greater geographical spread and variability of hailstorms (Botzen et al., 2009). The study conducted by Murray (n.d.) showed that hail stones can range from 5mm in diameter to as large as 150mm, and are made up of solid ice; therefore it can cause great damage to crops.

Hailstorms destroy approximately 21% of the total annual agricultural production in South Africa (StatsSA, 2009). In an email from Johan van Tonder on 5 May 2012, it was clearly stated that Groen Goud Landgoed (Pty) Ltd suffers more than 50% hailstorm damages to sunflower and maize crops approximately once every five years; otherwise the damages annually account for 30% of these crops. In the same email from Johan van Tonder it was mentioned that the company suffers approximately 55% hailstorm damages to wheat crops once every four years; otherwise the annual damages account for less than 10% of the crops.

2.2.4 Droughts

Semi-arid areas are experiencing an increase in the severity and frequency – approximately once in three years – of agricultural droughts (IPCC, 1995; Total SA, 2006). An agricultural drought occurs when the soil moisture and water levels fall below the minimum required levels to sustain the crops and livestock. The last agricultural drought effecting Groen Goud Landgoed (Pty) Ltd was recorded in 2009. A drought in South Africa is classified as a disaster approximately once in fifteen years (Total SA, 2006).

The most important cause of a drought relates to the quantity of water vapour in the atmosphere, as this is what generates precipitation. When the precipitation is low over a long period of time and winds shift air masses, then warm, dry air moves in over an area – causing a low relative humidity – it results in a scarcity of water (Sivakumar, n.d.).

Droughts can occur early, in the middle of, or late in the cropping season. Effects of early season droughts include delayed field operations, delays in sowing crops, poor germination, low crop stand and weak seedlings. Effects of mid-season droughts include poor tillering and no or delayed flowering. Effect of late-season droughts include poor seed setting, low crop yields and low quality produce. Common effects of droughts, irrespective of when they occur, are decreased crop yields, increased costs for irrigation, increased wind erosion, increased risk of fire because of the drier vegetation, and susceptibility to pests and diseases.

Practical long-term drought strategies can prepare agricultural production to withstand unexpected shortfalls of precipitation. This involves the adoption of appropriate stocking rates, the build-up of a fodder reserve and the improvement of on-farm water supplies. Total SA (2006) highlights that the installation of irrigation systems may also offer some security against drought.

While Groen Goud Landgoed (Pty) Ltd experience droughts, floods and wetter-than-normal seasons; droughts cause the worst harvest losses.

2.2.5 Other Climatic Factors

Other climatic factors which affect the growth and development of crops will now be discussed. Climatic factors include light, temperature, relative humidity, air and wind. Light is essential in the production of chlorophyll and in photosynthesis. Temperature affects all plant growth processes such as germination, flowering and seeding. Air consists of oxygen and carbon dioxide among other gasses. Oxygen is essential in respiration for the production of energy that is utilised in various growth and development processes of the crops. Carbon dioxide is a raw material for photosynthesis. Relative humidity is the amount of water vapour in the air, expressed as the percentage of the maximum amount of water vapour it can hold at a certain temperature. According to Bareja (2011) the relative humidity affects the opening and closing of the stomata of plants, which regulates loss of water from the plant through transpiration and photosynthesis.

2.2.6 Global Warming

Global warming is an unavoidable reality which affects also farming. Climate change is the result of global warming, and is affecting the way in which modern farmers go about their business, namely farming. The study conducted by Total SA (2006) claims that the effects of global warming on South African farming will include decreased rainfall, increased mean temperature, reduced water runoff into main rivers, possible increase in fire frequency, and an increased demand for irrigation systems.

Botzen et al. (2009) suggests that the more the mean temperature rises, the more frequent and severe hailstorms will become. These effects will force farmers to think outside the box in order to find new and sustainable solutions to these challenges. If no solutions are found, farmers will have to be satisfied with diminishing crop yields, and the subsequent decrease in profit.

2.3 CROP ENTERPRISES

2.3.1 Introduction to Crop Enterprises

Sivakumar and Valentin (1997) reason that argo-ecological zones (AEZ) should be used to recognize the multiplicity of agronomic, economic and environmental criteria that determine the performance of an agro-ecosystem, and then determine the nature and extent of changes that need to be introduced to achieve greater productivity. AEZ can also be used in potential yield calculations, land suitability and land productivity evaluation (including livestock productivity), and in assessing and mapping of flood and drought damages to crops.

By accurately determining the potential of the different soil types, one can increase its long-term production potential. Physical analysis (depth, type, texture and water retention) and chemical analysis (pH, nutrients and acid saturation) of the soil form the basis for production planning. By incorporating factors such as climate and production potential, one can plan the next harvest in detail to cut unnecessary costs, thereby increasing profits (Coleman, 2011).

Factors that should be taken into consideration when determining the planting date are the soil temperature, moisture requirements of the crop, rainfall pattern, other crops being cultivated, and the risk of bird damage.

The effective depth of the soils on the farms of Groen Goud Landgoed (Pty) Ltd varies between 550mm and 800mm. The soils have a clay layer in the effective root zone, which improves the moisture retainabilility. Groen Goud Landgoed (Pty) Ltd uses a combination of stubble-mulch, reduced and conservation tillage of the crops. The method used depends on the conditions when tilling is required, e.g. during a dry season conservation tillage will be utilised.

Topsoil is the part of the soil horizon with higher levels of organic matter and nutrients, and usually better structure. Nitrate is known to leach under wet conditions and it only takes a small amount to strip the available boron from the topsoil. Lovel (2011) states that chemical nitrogen fertiliser is the usual suspect where boron is missing, since fertilisers usually oxidise into nitrate; unless soil microbes convert and retain them as amino acids and proteins. South African farmers experience periodic wet and dry cycles, which can cause boron leaching in the absence of nitrogen (Lovel, 2011). During a drought the microbes in the soil dry up, and when it does rain, the built-up microbial protoplasm is released at once. The amino acids in the resulting broth oxidise into nitrates. Only deep-rooted plants can bring boron, along with sulphur, nitrogen and calcium, back to the topsoil. Lovel (2011) maintains that most of these deep-rooted plants are weeds and therefore are removed as quickly as possible once they have been found in the fields or pastures.

Van Rooyen (2011) maintains that production stability can be enhanced by the application of crop enterprise practices which limit moisture stresses as far as possible. The aim of the crop enterprises is to break up limiting layers, destroy weeds, provide a suitable seedbed, and to break the soil surface at the same time to ensure maximum rainfall infiltration, as well as to prevent wind and water erosion. If the compaction is not broken, the crop cannot utilise the full water capacity of the soil profile, because its roots cannot penetrate the compacted layer.

Van Rooyen (2011) confirms that crop insurance against weather related disasters is essential, since droughts and hailstorm damages in South Africa can cause huge losses, not only to the farmer but also to the national economy if these damages are severe enough. Previous studies have shown that a four year crop rotation system, especially in a diverse farming system, is considered optimal. A crop rotation system is one in which the farmer will plant different crops on the same fields in order to minimise soil degradation.

Groen Goud Landgoed (Pty) Ltd annually fertilises approximately 700 hectares of the soil with 1000 tons to 1400 tons of broiler manure. This is done using a rotation system. All the crops are planted using a chemical fertiliser with a nitrogen:phosphate:potassium ratio of 5:2:0. South African soils are reasonably rich in potassium and an increase in grain yields is seldom realised by an increase in potassium fertilisation as stated by Pannar (n.d.), thus there is no need for potassium in the fertilizers.

2.3.2 Cultivar Selection

Cultivar selection is one of the most important considerations in risk management and maximising yields, thereby ensuring higher profits at no extra cost. Cultivars differ from one another with regard to a variety of characteristics. Pannar (n.d.) suggests that the selection of a cultivar is principally an economic decision, where the farmer must find a balance between risk and yield potential. The selection of cultivars should therefore be based on long-term yield potential of a specific field or farm where climate, soil and manageability should be the determining factors. Under irrigation, chemical agents which work against lodging, work with success on cultivars with a high yield potential and an inclination to lodge. An important factor in cultivar selection is aluminium tolerance, especially where the topsoils and/or sub-soils reach Al^{3+} levels that are toxic to sensitive cultivars (Pannar, n.d.).

Du Plessis (2003) highlights that cultivars should be adapted to specific production conditions. Stability and the length of growing season of cultivars should also be considered. Another characteristic that differ between cultivars is susceptibility to diseases. Cultivars with the best levels of resistance or tolerance to a disease should be selected for planning where a specific disease occurs.

Planned yield is defined as the realistic yield that is achievable in the long term. According to Pannar (n.d.) it is important to consider the following aspects when calculating the planned yield: available moisture at planting time, the amount of supplementary spring rainfall that can be expected, and the long-term production history of the specific area. Yield and yield reliability are also important criteria when cultivars are evaluated. The yield reliability of a cultivar at a certain yield potential, is the minimum yield which will be achievable by that cultivar nine out of ten times.

2.4 SUNFLOWER

2.4.1 Requirements

Sunflower is a crop which performs well during droughts. The crop is particularly sensitive to high soil temperature during emergence. A consequence of acidified soil is that molybdenum shortages often occur, and is possibly one of the greatest yield-limiting factors.

Sunflowers are best planted in soil with temperature 10°C to 30°C. Compared to other crops, sunflower utilises soil nutrients exceptionally well (Du Plessis, 2003). It has a deep and finely branched tap-root system, which comes into contact with nutrients which cannot be utilised by other crops. The roots' ability to use water means it can also grow in shallow, clay-type soil, with the sunflower plant taking water from the clay.

Any fertilisation program for sunflower should be based on soil analysis. Fertilisers used for sunflowers should contain sufficient levels of nitrogen, phosphorus, potassium, molybdenum and boron.

In soil with high clay content (more than 20% clay), seeds are planted at a depth of 25mm. In sandy soils, seeds are planted at a depth of up to 50mm. Sunflower is very sensitive to wind damage in the seeding phase. They are very sensitive to waterlogging and high aluminium levels, thus it should not be planted in soils with a pH lower than 4.6 (Du Plessis, 2003).

An uniform plant density with sunflower is the basis of a good yield. Although the plant is able to compensate by head size and the number of seeds per head, a very low plant density (less than 20 000 plants per hectare) often limits yield. High densities of 55 000 plant per hectare and more cause a higher occurrence of waterlogging. Groen Goud Landgoed (Pty) Ltd plants sunflowers with a density of 45 000 plants per hectare. It is essential that sunflower be spaced evenly. Harvesting should commence as soon as approximately 80% of the sunflower heads are brown in order to minimise damage caused by birds, lodging and shattering.

2.4.2 Pests and Diseases

Soil insects such as cutworms, dusty surface beetle and ground weevils may cause damage to the sunflower plants during emergence. The study conducted by Du Plessis (2012) showed that *nysius natalensis* is a sporadic pest of sunflowers. Sunflowers are mainly attacked by this pest during the following three phases: first, a few cases were reported where seedlings were damaged. Second, if severe infestations occur during the bud phase, some plants may die in the field. And third, economic losses occur when severs infestations during and after the seed development phase occur.

Seed development and physiological maturity occurs when the heads are bowed down. The best time for controlling *nysius natalensis* is during the few days after flowering, and before the heads bow down. An insecticide with long residual action should be applied in this period, thereby preventing that it is sprayed too early and before damage is done to the plants (Du Plessis, 2012).

Weed control is achieved by a combination of mechanical and chemical practices. The first six weeks after planting are a crucial period for the crop. Yield can be increased significantly by keeping fields free of weeds during this time. The use of herbicides has many advantages, of which the most important is that effective weed control can be applied during wet periods when mechanical weed control is impossible.

2.5 MAIZE

Maize is the most important crop in South Africa (StatsSA, 2009). According to Du Plessis (2003) approximately 12 million tons of maize is produced in South Africa annually. The production consists of 60% white maize and 40% yellow maize. White maize is for human consumption, while yellow maize is used to feed animals. Groen Goud Landgoed (Pty) Ltd currently only plants yellow maize.

2.5.1 Requirements

Maize needs 450mm to 600mm of water per season, which is mainly acquired from the soil moisture reserves. No other crop utilises sunlight more effectively than maize, and its yield per hectare is the highest of all crops (Du Plessis, 2003).

The critical temperature detrimentally affecting yield is approximately 32°C. Du Plessis (2003) points out that frost can damage maize at all growth phases, therefore a frost-free period of 120 to 140 days is required to prevent damage. If a minimum temperature of 10°C to 15°C is maintained for seven consecutive days, germination should proceed normally.

Maize has a profusely branched, fine root system. Planting depth of maize is 50mm to 100mm, depending on the soil type and planting date. Groen Goud Landgoed (Pty) Ltd plants maize with a density of 22 000 plants per hectare. Fertilisers used for maize should contain sufficient levels of calcium, magnesium, nitrogen, phosphorus, potassium and zinc.

Du Plessis (2003) agrees that finely structured topsoil is susceptible to both wind and water erosion, while a coarse structure limits erosion. In South Africa, maize is usually left in the field until moisture content of 12.5% to 14% is reached before it is harvested and delivered to a silo.

2.5.2 Pests and Diseases

As hail damage to kernels increase, so does the severity of the ear rots; and with ear rots, the presence of certain mycotoxins. Fields should be regularly checked to monitor development of ear rots, and plans should be made to harvest the crop as soon as possible if more than 10% of ears in a field are considerably mouldy (Murray, n.d.).

Schoeman (2011) found that s*tenocarpella maydis* normally breaks out as an epidemic. It is very harmful under maize monocultures and under conditions where maize residues are wintered on the fields, associated with early dry conditions followed by wet weather late in the season. Infected maize has a lower rating value, resulting in a possible economic loss (Schoeman, 2011). The kernels are much lighter in weight than it normally is, thus leading to lower yields.

By planting a more resistant maize cultivar, *stenocarpella maydis* can be reduced. Schoeman (2011) confirms that if it is a seasonal epidemic, it is beneficial to harvest the maize early, and to let the kernels dry artificially in a silo to 11% moisture content. The removal of infected stubble can help to reduce the inoculums in the fields. The spores of black *piknidia* can survive on the maize residues, and it can form the primary inoculums in spring or early summer for the new season (Schoeman, 2011).

Damage at the root system of the maize plant, which was caused by nematodes, usually result in yield loss. Economic control of the nematodes in maize is difficult, mainly because of the high cost of nematicides. Maize price fluctuations, different crop enterprise practices and differences in production potential must be taken into account to determine economic justification of chemical nematode control (Du Plessis, 2003). When infestation levels are high, chemical control can readily be recommended from an economic point of view.

Du Plessis's (2003) findings showed that weed control during the first six to eight weeks after planting is crucial, because weeds compete vigorously with the maize for nutrients and water during this period. The annual yield loss for maize because of weed problems is estimated to be approximately 10% (StatsSA, 2009). Weeds can be removed mechanically by implements, or by hand. Ploughing during winter or early spring is an effective method of destroying the majority of the weeds. Chemical liquids, granules or gasses can also be used to kill germinating or growing weeds.

2.6 WHEAT

2.6.1 Requirements

Previous studies showed that good wheat germination will occur at soil temperatures of 4°C to 25°C. The minimum temperature for seeding development is -2°C, while the maximum temperature is 34°C. The minimum temperature for leaf, stem and root development is 5°C, while the maximum temperature is 43°C, with an optimum of 26°C. Pannar (n.d.) claims that the optimum temperature for pollination is between 10°C and 25°C, with a minimum of 10°C and a maximum of 32°C.

Soil preparation is the largest input in wheat production. Pannar (n.d.) proposes preparing a plan with specific objectives in mind, such as conserving the ground moisture, alleviating soil compactions, liming, seedbed preparation, weed and plant disease control, and controlling of wind and water erosion. Groen Goud Landgoed (Pty) Ltd plants 25kg of wheat seeds per hectare.

Acidic soil has a disadvantageous effect on the wheat plant due to the associated high levels of aluminium. This results in excessive aluminium uptake, which is toxic to the wheat plant. According to Pannar (n.d.), if the pH of the soil is lower than 4.5 and/or the acid saturation is greater than 8%, lime should be administered. If the lime requirements are greater than four tons per hectare, it is advantageous to apply it over two production seasons (Huber, n.d.).

Fertilisers used for wheat should contain sufficient levels of nitrogen, phosphate, potassium, sulphur, calcium, magnesium, boron, iron, copper, zinc, manganese and molybdenum (Huber, n.d.). High nitrogen fertiliser applied along with the seed may be unfavourable to germination. The application of nitrogen during the flag leaf to flowering phases of the wheat plant development is important to ensure that sufficient nitrogen is available for kernel growth and development; and for acceptable levels of protein in the grain Pannar (n.d.).

2.6.2 Pests and Diseases

The Russian wheat aphid is considered the most important aphid where dryland wheat is cultivated, especially in the central and eastern Free State (Pannar, n.d.). There are seed treatments and systematic soil agents registered for the control of early aphid populations. Huber (n.d.) agrees that some of these agents are effective for a period of approximately 100 days.

Brown wheat mites spend the evening in or under the soil, therefore inspections must be carried out during the afternoon when the mites are most active (Pannar, n.d.). Rain storms of 12mm or more can drastically lower the mite population, which makes chemical control unnecessary.

False wireworm is the larva of large black beetles. The larva is the most damaging stage of this pest, and feeds on the seed, roots and seedling stems of the wheat. Seed treatments can be effective where seedlings grow actively in moist soil. Pannar (n.d.) emphasizes that direct and indirect yield losses can occur on account of damaged grain with the consequent downgrading of the grain.

Black maize beetles chew on the base of the seedling stem, which causes a decline in the stand. Given the mobility of the adult beetle, seed treatment agents are registered as a pre-planting method of adult beetle population management.

Leafhoppers can transmit maize streak virus from infected maize or certain grass species. Virus transmission usually occurs on early wheat plantings that are planted near infected grass, maize or self-sown maize (Pannar, n.d.). There are no chemical agents registered for the control of leaf-hoppers on wheat. Infestation can be avoided by later planting, away from maize. The alternative is to consider wheat cultivars that are tolerant to maize streak virus (Pannar, n.d.).

Fungal diseases on wheat can be controlled by planting resistant cultivars or by the use of chemical agents.

- The disease-causing fungus of stripe rust (or yellow rust) is an obligate parasite and can therefore only survive on living plant material (Huber, n.d.). Various triazole-containing agents are registered against stripe rust. Chemical control must be applied after correct disease identification.

- The fungus responsible for stem rust (or black rust) is also air-borne. Infection takes place when dew and/or misty wet conditions are accompanied by temperatures of 15°C to 24°C. The risk of stem rust infection can be minimised by planting resistant cultivars. Chemical control of this disease can only be successful if the tiller area is covered properly with the fungicide.
- *Fusarium* head blight is caused by fungi where *fusarium gramenearum* is identified as the primary disease-causing organism under local conditions (Pannar, n.d.). This disease is particularly prevalent in irrigation systems where wheat is alternated with maize. The most effective way to avoid *fusarium* head blight is by crop rotation with non-host crops, as well as the destroying of wheat and maize stubble. Preventative ear spraying during flowering can help to reduce the infection to inhibit disease development.
- The leaf rust-causing fungus is air-borne. The risk of leaf rust (or brown rust) can be managed by cultivar selection. When chemical control is used, it is important to protect the flag leaf.

2.7 LIVESTOCK

Livestock farming is an important agricultural activity in South Africa. Livestock is the collective name for farm animals, and include horses, cattle, sheep, pigs, goats, chickens and other poultry. The Free Online Dictionary defines livestock as domesticated animals kept for use or profit.

2.7.1 Cattle

Fundamentals for successful management in commercial beef enterprises are breed choice, breeding method, breeding cycle, nutrition and health management (Phillips, 2012; Bergh, 2008). Techniques require sporadic adjustment to the changing farming conditions and market requirements.

2.7.1.1 Breed Choice

The cattle on Groen Goud Landgoed (Pty) Ltd are an extensive commercial Angus herd. Southwood (2011) describes Angus cattle as a docile, fertile, early maturing and easy calving breed that can handle the harsh Free State winters.

2.7.1.2 Breeding Method

Phillips's study (2011c) points out that approximately 20% of all heifers will not conceive during the breeding season, due to the fact that the bull in a particular herd might not have been able to cover all the cows coming in heat. This percentage can be reduced by overmating, of which the aim is to ensure that the only pregnant heifers are used as replacements. Approximately 20% of cows on Groen Goud Landgoed (Pty) Ltd are culled each year and must be replaced. With overmating, 20% to 30% more heifers than the number needed for replacement are mated and kept as replacement heifers.

All the heifers in a herd are evaluated annually based on the goals set for Groen Goud Landgoed (Pty) Ltd, usually at weaning, and grouped into “top cows”, “middle cows” and “lower cows” (Coleman, 2011b). The “top cows” are kept as replacement heifers, while the “lower cows” are sold according to quality. The “middle cows” have to be evaluated with care because they have some defects, but are still fully functional breeding animals able to produce calves. It is known that the production level of the calves from heifers is lower than that of mature cows. According to previous studies, the weaning mass of calves from heifers was 15% to 20% lower than the weaning mass of calves from mature cows, which means that the quality of the replacement heifers must be appreciably better than that of the “middle cows” they are to replace. A higher percentage of replacement heifers in a breeding herd results in a higher percentage of first calvers in a herd.

There are currently 600 cows in production on Groen Goud Landgoed (Pty) Ltd, and approximately 150 replacing heifers are reared each year. The type of heifer selected will determine the type of cow comprising the breeding herd; therefore heifer selection is not only based on Groen Goud Landgoed (Pty) Ltd’s goals, but also on other important factors such as:

- Age – older cows tend to produce calves that are poor performers because the cows are no longer able to supply sufficient milk for the calves to grow well.
- Adaption to local environment.
- Calf quality – calves are selected annually as replacements for a breeding herd. Should a cow regularly produce a weaner that does not adhere to the requirements of the company, she should be culled.
- Fertility – cows that do not re-conceive are unproductive and a burden. A good practice is to allow a cow one skip in her lifetime, excluding skips that could be attributed to other causes.
- Injury – where injuries to heifers cause functional defects, they must be culled.
- Udder conformation.

When it comes to bull selection the best choice is a short-legged, stockier body type, masculine bull that gains weigh fast and reaches sexual maturity early according to Zietsman (2012). The bulls on Groen Goud Landgoed (Pty) Ltd are registered bulls which are bought annually from breeders.

Selection criteria should not be too harsh, as it has been demonstrated that strict selection has the effect of narrowing down a gene pool. Phillips (2011b) agrees that replacement heifers must be put in a different herd to their mothers, in order to control bloodlines and genetics.

2.7.1.3 Breeding Cycle

Heifers are usually mated at either fifteen or twenty-seven months of age to calve down for the first time at two or three years of age respectively. As a rule of thumb, heifers should first be mated when they weigh at least 60% of their mature mass, which is between 260kg and 300kg for an Angus herd (Freking, 2000). To ensure that all heifers reach these weights before mating, they should be fed separately from the mature cow herd, as they need additional energy and protein from the feed to grow to full maturity.

The ideal calving time is approximately six to eight weeks before adequate green grazing can be expected, which is approximately one month before to about one month after the first effective rains have fallen (Bergh, 2008).

A calf is born after a period of approximately nine months of pregnancy. After calving, a cow should not be brought to the bull before at least fifty days have passed (Joubert, 2011a). Thus, there is a period of approximately a month during which the cow must re-conceive in time to calve the following year at around the same time of the year. Bergh (2008) states that on average a cow comes on heat every twenty-one days, and it lasts between six and eighteen hours, which implies that the cow has at most two chances during this period to re-conceive.

First calvers are heifers that have calved and are brought to the bull for the second time. First calvers are known worldwide to have notoriously low conception rates. It has been demonstrated that conception rates in first calvers can be improved by breeding heifers fifteen to twenty days before breeding the mature cow herd (Freking, 2000).

2.7.1.4 Nutrition and Health Management

Nutrition accounts for 40% to 70% of the cost of raising replacement heifers (Freking, 2000). Without forage testing, feeding a balanced ration is impossible; subsequently heifer performance may suffer, and costs may be necessarily high. Freking (2000) maintains that feeding during the suckling period should not be given to heifers, as fat may be deposited in the developing udder, lowering subsequent milking ability. Close attention should be paid to heifers' nutritional needs, thus it will result in milk production from an earlier age (Joubert, 2011a). Heifers need to be grown rapidly, but not fattened; thus high quality hay and forages should be fed.

The cost of rearing a heifer include milk/milk replacer, concentrate, roughage (including pasture), labour, vet costs (inoculations and sundries such as ear tags, syringes and wound sprays), bedding, insurance (usually against lightning), electricity, fencing, feed and water troughs, and vehicle running costs (Joubert, 2011a).

Phillips (2011b) confirms that a good vaccination program is essential. At Groen Goud Landgoed (Pty) Ltd the heifers are vaccinated twice for brucellosis, six weeks apart. The cattle of three years and younger are vaccinated annually against blackquater. All cattle are vaccinated every year against anthrax, botulism and lumpyskin disease.

The tick load of the Angus herds on Groen Goud Landgoed (Pty) Ltd is visually evaluated in order to decide when to dip the animals. During summer, this is usually every six weeks. Phillips (2011c) recommends using pour-on dips applied in a crush. Previous studies showed that it is beneficial to alternate the active ingredients – amitraz, flumethrin and amitraz – with cypermethrin and piperonyl butoxide at each dipping.

2.7.2 Broilers

The South African Poultry Association (SAPA) (n.d.) points out that the broiler industry contributes to the economy in the following ways:

- Gross producer value of the industry is over R5 billion per annum.
- Per capita consumption increased over ten years from 15.5kg to 18.5kg.
- The broiler industry contributes 16.2% to the total gross value of agricultural production.

According to SAPA (n.d.) a functioning, integrated broiler industry comprises of the following components:

- The *hatching* (or egg farm) provides the eggs to the hatchery.
- The *hatchery* incubates the fertile eggs to produce day-old chicks (DOCs).
- *Broiler grow-out facilities* receive the DOCs, which are raised for about five weeks before they are slaughtered or sold live.
- At the *processing plant* the broilers are slaughters and either converted to ready-to-cook chicken (or cut-up parts), or further processed.

Groen Goud Landgoed (Pty) Ltd's third ramification is broiler farming, which can be classified as a broiler grow-out facility. The broiler farm is situated on Vaalkoppies, and consists of eight broiler houses. Each of the houses is oriented on an east-west axis to reduce the temperature fluctuation within the house as much as possible.

Groen Goud Landgoed (Pty) Ltd receives 35 500 DOCs per broiler house from one of three hatcheries at the beginning of each 52-day cycle. All eight broiler houses follow the same 52-day cycle, and receive DOCs at approximately the same time. The cycle can be broken down to the growth phase and the cleaning phase. The growth phase comprises of the first thirty-five days on the broiler farm during which the DOCs are fed to the target weight of 1.8 kg. The duration of the cleaning phase is seventeen days. It comprises of depopulating the house, cleaning and disinfecting the house before the next flock is placed.

During placement, the light intensity is lowered to reduce the stress of the DOCs. They should the evenly distributed throughout the house, because incorrect stocking density can lead to leg problems, scratching, bruising, mortality and litter integrity will be compromised (Walne 2002). The maximum stock density that can be achieved at Groen Goud Landgoed (Pty) Ltd's broiler farm is 21.6 broilers per square meter.

2.7.2.1 Heating

A consistent housing environment comprises of consistent ambient and floor temperature for the broilers. To ensure consistent temperatures throughout the house, one or more of the following heating systems can be used (Aviagen Limited, 2002):

- *Forced air heaters* need to be placed in the middle of the houses. It should be placed at a height of 1.4m to 1.5m above the floor, to avoid drafts on the broilers.
- *Radiant* or *spot brooders* are used to heat litter within the house.
- *Under floor heating* systems operate with hot water circulating through pipes in a concrete floor.

The broiler farm ramification of Groen Goud Landgoed (Pty) Ltd makes use of forced air heaters and under floor heating within the houses. At approximately fourteen days of age, the forced air heater can become the primary heat source, depending on the season (e.g. summer, autumn, etc.).

2.7.2.2 Lighting

Kleyn (2009) agrees that lighting programs are a key factor for good broiler performance and welfare. The amount of light and light intensity (measured in lux) alters the broiler activity. It is recommended by Aviagen Limited (2002) that 20 lux, as measured at broiler height, be used during brooding to encourage early weight gains. After seven days of age, light intensities should be diminished gradually. It is important to note that the lighting should be oriented in such a manner as to provide an even distribution of light at the floor level.

Aviagen Limited (2002) defines two types of lighting programs, namely short day and intermittent. The short day is generally imposed from seven days of age, to stimulate the feed intake and consequently the growth of broilers. Intermittent programs consist of blocks of time containing both light and dark periods, which are repeated throughout the 24 hours. The light period within each block of time is increased as the broilers age, to enable them to eat sufficient food to maintain the desired growth rate (Aviagen Limited, 2002). Note that there is only one dark period of a predetermined length each day.

Groen Goud Landgoed (Pty) Ltd uses a short day lighting program which is summarised in the table below.

Table 4: Groen Goud Landgoed (Pty) Ltd's Lighting Program

Age (days)	Intensity (lux)	Light (hours)	Dark (hours)
0-6	20	23	1
7-21	20-10 (gradual reduction)	20	4
22-35	10	23	1

A light intensity of less than 0.4 lux should be achieved during the dark period (Aviagen Limited, 2002). The transition from light to dark and *vice versa*, should be completed over a period of 40 to 50 minutes, in at least five steps (e.g. dark to light: 0.4 lux → 1.0 lux → 3.2 lux → 6.5 lux → 10.5 lux → 15.0 lux). These steps are necessary to simulate dawn and dusk. The feed and water should b made available to all the broilers as soon as the lights come on (Aviagen Limited, 2002).

2.7.2.3 Ventilation

Ventilation distributes heat throughout the house and maintains good air quality in the brooding area. Young broilers are very susceptible to drafts, therefore air speeds as slow as 0.5m/s can cause a significant wind-chill effect on them (SAPA, n.d.).

The broilers should always have adequate oxygen and minimum amounts of carbon dioxide, carbon monoxide, ammonia and dust. High levels of ammonia can negatively affect the broilers. According to Aviagen Limited (2002) some of these negative effects are breast blisters, poor uniformity, foot pad burns, eye burns and blindness.

The broiler houses on Vaalkoppies use tunnel and cross ventilation systems. Tunnel ventilation is used to moderate the effects of seasonal temperature fluctuations. It is particularly effective during the hot summers of the Free State. The aim of a cross ventilation system is to increase house air exchange without creating high air speeds across the broilers (Aviagen Limited, 2002).

2.7.2.4 Water and Feed

Water consumption is evaluated daily at the same time, thereby best determining the general performance trends and broiler well-being. Aviagen Limited (2002) points out that the ideal water temperature to maintain adequate water consumption is between 10°C and 14°C.

Without clean, cool water intake, feeding consumption will decline and the broilers' performance will be compensated. Groen Goud Landgoed (Pty) Ltd makes use of closed watering systems, as these are more beneficial than the alternative:

- Closed watering systems: High flow nipple drinkers operate at 80mℓ to 90mℓ per minute, and can accommodate 12 broilers per nipple. Low flow nipple drinkers on the other hand operate at 50mℓ to 60mℓ per minute, and can accommodate 10 broilers per nipple. Closed watering systems are less likely to become contaminated, and wasting water is also less of a problem. This type of system does not require daily cleaning.
- Open watering systems: While there is a cost advantage of installing an open drinker system, problems associated with litter quality, condemnations and water hygiene are prevalent. Water purity is also difficult to maintain, resulting in the need for daily cleaning, which is not only labour intensive but also wastes water. Litter conditions are an excellent means of accessing the effectiveness of water pressure settings.

As an input, feed represents almost 85% of broiler production costs (Walne, 2002). The basic nutritional components required by the broilers are water, amino acids, energy, vitamins and minerals (Kleyn, 2009). Working together, these components will assure correct skeletal growth and muscle deposition. Vitamins are supplemented in feeds, and can be grouped as either water-soluble or fat-soluble vitamins (Aviagen Limited, 2002). The first group includes the B-complex vitamins, while the latter includes vitamins A, D, E and K. The mineral requirements of broilers include calcium, phosphorus, potassium, sodium, magnesium, iron, copper and zinc.

Feed distribution and the proximity of the feeder to the broilers are key to achieving target feed consumption rates (Walne, 2002). There are two types of feeders, namely automatic chain feeders and automatic feeder pans. The latter is generally recommended as it allows for unrestricted broiler movement throughout the house. It also has a lower incidence of feed spillage and improved feed conversion, which is why this system is used in the broiler houses on Vaalkoppies.

Rations differ greatly as diets may be prepared as a mash, crumble, pelleted or extruded product. Blending the manufactured feed with whole grains prior to feeding is also common. Nutritionally, further-processed feeds show a noted improvement in flock efficiency and growth rates when compared to mash feeds (Walne, 2002). The table below shows the rations administered during the different feeding phases of the broilers.

Table 5: Groen Goud Landgoed (Pty) Ltd's Feeding Phases

Phase	Ration Description	Duration (days)
1	Pre-Starter	3
2	Starter	4
3	Grower	14
4	Finisher	8
5	Post-Finisher	6

2.7.2.5 Catching

Water must be available until the start of catching. Lighting should be dimmed at the time of catching; if dimming is not feasible, the use of blue or green lights will calm the broilers. Catching broilers at night is recommended because they are less active. Remove or raise all equipment that may interfere with the catch crew.

Welfare considerations should be of utmost importance during catching. Special care should be given to minimise bruising and downgrades (Kleyn, 2009). Broilers should be carefully placed in clean crates or modules to a density that complies with manufacturer's recommendations. These densities should be reduced is summer months.

Feed withdrawal should take place eight to twelve hours prior to processing. The purpose of this is to empty the digestive tract, which prevents ingested feed and facal material from contaminating the carcasses during the evisceration process (Walne, 2002).

2.7.2.6 Sanitation

Healthy parents and hygienic hatchery conditions contribute greatly to disease-free broilers. Aviagen Limited (2002) and Walne (2002) state some guidelines to a successful broiler farm sanitation program:

- Apply insecticide; this is best carried out immediately after depopulation and before the litter and building cools down. Heavy insect infestations may require an additional insecticide application after the disinfection process is complete.
- Dry clean any equipment that cannot be washed directly, and cover it completely to protect it from the washing process.
- External areas such as gutters, roofs and pathways should be cleaned and maintained. Remove any washed out litter or organic matter from the farm compound. Unused and unneeded equipment should be removed from the farm.
- Staff areas, canteens, changing rooms and offices should also be thoroughly cleaned. All footwear and clothing should be given a complete washing and disinfection.

2.7.2.7 Vaccination

Prevention is by far the most economical method of disease control. Prevention is best achieved by the implantation of an effective bio-security program in conjunction with appropriate vaccination. Khula Sizwe (n.d.). Parent stock breeders are vaccinated for a number of diseases to effectively pass on maternal antibodies to broiler chicks. These antibodies serve to protect the broilers during the early stages of the growing period. The timing of vaccinations should be based upon the level of expected maternal antibodies, the disease in question and current field challenges.

Water vaccination guidelines: The flock must ingest all vaccine within one to two hours after administration. The vaccine should be stored at the manufacturer's recommended temperature prior to administration. Vaccinate early in the morning to reduce stress on the broilers. The water pH should be between 5.5 and 7.5 (Khula Sizwe, n.d.). Ensure rapid uptake of vaccine by depriving the broilers of water a maximum of one hour before administering the vaccine. Turn off ultra-violet light, if used, as this may inactivate the vaccine. Vaccination can be performed unevenly if done by a medicator.

Khula Sizwe (n.d.) advices mixing in two teaspoons of powdered skimmed milk per litre of water. Alternatively, commercial stabilizers can be used per manufacturer's recommendations. Prepare skimmed milk solution twenty minutes before administering the vaccine, to ensure the skimmed milk powder has neutralised any chlorine present in the water. Open each vial of vaccine while submerged under the water-stabilizer mixture.

Pour prepared vaccine, stabilizer and colour solution into the header or storage tank, and prime the lines until the stabilizer of dyed water comes through the far ends of the lines (Khula Sizwe, n.d.). Lower the drinker lines and allow the broilers to consume vaccine, making sure to turn the water back on into the header tank just before the tank runs empty.

Aerosol / coarse spray vaccination guidelines: Check that the vaccination equipment is working properly at least one week prior to vaccination to allow time for repairs if need be. The sprayer should only be used for vaccination (Khula Sizwe, n.d.). Vaccinate early in the morning to reduce stress on the broilers. Ensure that the vaccine has been stored within the manufacturer's recommended temperature range prior to vaccination.

Khula Sizwe (n.d.) states that the vaccine stabilizer mixture must be prepared on a clean surface in clean containers, by using fresh, cool, distilled water. Open each vial of vaccine while submerged under the water. Rinse the sprayer with distilled water and dispense a small volume through the unit just before adding the diluted vaccine. Turning off the fans before spraying commences, and dimming the lights will reduce stress on the broilers, as well as allowing the vaccinator easy movement through the house. Pen the broilers along the sidewalls of the house for coarse water spraying. The distance between the vaccinator and the side wall should not be more than four meters (Khula Sizwe, n.d.). Coarse spray should be approximately one meter above the broiler height.

Leave the fan off for twenty minutes after spraying has finished, provided that the broilers are not being heat stressed. After vaccination, rinse the sprayer with distilled water and allow it to dry in a clean, dust-free environment (Khula Sizwe, n.d.). One drawback to this system is that spray may be lost through evaporation, settlement and drift before it reaches the broilers.

CHAPTER 3

3.1 METHOD SELECTION

The best methods, tools and techniques for solving the problems (as stated in the Problem Statement) are:

- For the crop enterprise and cattle farming-problems:
    - Monte Carlo simulation
    - Operations Research model
    - Probability models
    - Distribution fittings
- For the broiler farming-problem:
    - Economic order quantity (EOQ) model

Monte Carlo simulation was selected since it is not always feasible to compute an exact result using a deterministic approach, and it can be used to model phenomena such as the crop enterprise or cattle farming of Groen Goud Landgoed (Pty) Ltd, since it has a great number of variable inputs. The Monte Carlo simulation model will make use of the data with regard to the environmental factors influencing the cultivation of crops, as discusses in section 2.2.

Operations Research was selected because it includes methods like linear programming, which would allow one to develop a model into which calculated inputs can be entered to achieve the goals of Groen Goud Landgoed (Pty) Ltd. This mathematical model will try to find the optimal solution to the objective function, while keeping within the constrains. The objective of this model will simply be to maximise the net profit. The constraints of the model are based on the requirements identified in sections 2.3 to 2.7.

Probability models was selected because it is clear from the chapter 2 that there are numerous risk factors to consider before a crop can be planted or a decision made with regard to keeping or selling cattle. It will enable one to correctly calculate the risk associated with each crop and grazing option for the cattle.

Distribution fittings are also an important tool, as it allows one the select the correct probability distribution for a given set of data points. It will be a very helpful tool when the rainfall data comes into play. Thus, the probability models and the distribution fittings will be use in conjunction with the Operations Research model.

Economic order quantity (abbreviated as EOQ) is a tool often used in inventory management. It simply minimises the total inventory holding and ordering costs, which is ideal since one would want to minimise all expenses in order to maximise the profit in any organisation. For this reason, EOQ is a suitable method to use for the broiler farming problem as stated in section 1.2.

3.2 DATA ANALYSIS

A lot of data was gathered and analysed using various method as needed. Some of these methods include distribution fittings, inventory control, linear programming and Monte Carlo simulation. Some of the relevant data have already been tabulated within the previous chapter of this document. The rest of the analysed data is documented in the relevant sections of the following chapter.

CHAPTER 4

4.1 DEVELOPMENT of CONCEPTUAL DESIGN

The developed mathematical model enables one to advise the Van Tonder brothers on which fields to plant sunflower, maize and wheat respectively. The same model also advises one on how to divide the cattle and where they should graze. Lastly, the developed EOQ model calculated the optimum order quantity, as well as when these orders should be placed to ensure timely delivery.

4.1.1 Crop Enterprises and Cattle Farming

Since it was decided that the crop enterprises and cattle farming problems (as stated in section 3.1) would be modelled by an Operations Research model, it was best to combine the programming in order to avoid confusion later on. The linear programming model is shown below.

$a_{ij} \triangleq$ the area (ha) of crop i ε **I** which can be planted on field j ε **J** = {1,...,144},

where $\mathbf{I} = \begin{cases} 1 \text{ sunflower} \\ 2 \text{ maize} \\ 3 \text{ wheat} \end{cases}$

$b_i \triangleq$ calculated total area (ha) of crop i ε **I** being cultivated

$c_{ij} \triangleq \begin{cases} 1 \text{ if crop } i \in \mathbf{I} \text{ is planted on field } j \in \mathbf{J} \\ 0 \text{ otherwise} \end{cases}$

$d \triangleq$ total calculated area (ha) which is not cultivated

$k_j \triangleq$ calculated area (ha) of field j ε **J** which is not cultivated

$e_j \triangleq$ given area (ha) of field j ε **J**

$f_i \triangleq$ given total input cost (R) of crop i ε **I**

$g_i \triangleq$ given price (R/ton) of crop i ε **I**

$h_i \triangleq$ given yield of crop i ε **I**

$z_p \triangleq$ number of cattle in pasture p ε **P** = {1,...,29}

$y_q \triangleq$ number of cattle in planted pasture q ε **Q** = {1,...,12}

$o_j \triangleq$ number of cattle in uncultivated field j ε **J**

$x_p \triangleq$ calculated number of cattle that can graze on pasture p ε **P**

$w_q \triangleq$ calculated number of cattle that can graze on planted pasture q ε **Q**

$n_j \triangleq$ calculated number of cattle that can graze on uncultivated field j ε **J**

$v_p \triangleq$ given area (ha) of pasture p ε **P**

$u_q \triangleq$ given area (ha) of planted pasture q ε **Q**

$t \triangleq$ total number of cattle sold

$s \triangleq$ total number of cattle grazing on pastures

$r \triangleq$ total number of cattle grazing on planted pastures

$m \triangleq$ total number of cattle grazing on uncultivated fields

$$\max z = [(h_1 \times g_1) - f_1] \times b_1 + [(h_2 \times g_2) - f_2] \times b_2 + [(h_3 \times g_3) - f_3] \times b_3 + [613 \times 0.52 \times 23] \times t - 1137.52 \times (s + m) - 1198.12 \times r \quad (1)$$

s.t.

$$\sum_{i \in \mathbf{I}} \sum_{j \in \mathbf{J}} ((f_i)(a_{ij})) \leq 13\,000\,000 \quad (2)$$

$$b_1 = \sum_{j \in \mathbf{J}} (a_{1j}) \quad (3)$$

$$b_2 = \sum_{j \in \mathbf{J}} (a_{2j}) \quad (4)$$

$$b_3 = \sum_{j \in \mathbf{J}} (a_{3j}) \quad (5)$$

$$a_{ij} = (e_j)(c_{ij}) \qquad \forall\, i \in \mathbf{I},\, j \in \mathbf{J} \quad (6)$$

$$c_{1j} + c_{2j} + c_{3j} \leq 1 \qquad \forall\, j \in \mathbf{J} \quad (7)$$

$$k_j = e_j - a_{1j} - a_{2j} - a_{3j} \qquad \forall\, j \in \mathbf{J} \quad (8)$$

$$d = \sum_{j \in \mathbf{J}} (e_j) - \sum_{i \in \mathbf{I}} (b_i) \quad (9)$$

$$\sum_{j \in \mathbf{J}} (a_{1j}) \leq 1\,049.86 \quad (10)$$

$$\sum_{j \in \mathbf{J}} (a_{2j}) \geq 1\,088.07 \quad (11)$$

$$\sum_{j \in \mathbf{J}} (a_{3j}) \leq 2\,176.14 \quad (12)$$

$$d \geq 945.25 \quad (13)$$

$$5(x_p) \leq v_p \qquad \forall\, p \in \mathbf{P} \quad (14)$$

$$3(w_q) \leq u_q \qquad \forall\, q \in \mathbf{Q} \quad (15)$$

$$5(n_j) \leq k_j \qquad \forall\, j \in \mathbf{J} \quad (16)$$

$$z_p \leq x_p \qquad \forall\, p \in \mathbf{P} \quad (17)$$

$$y_q \leq u_q \qquad \forall\, q \in \mathbf{Q} \quad (18)$$

$$o_j \leq n_j \qquad \forall\, j \in \mathbf{J} \quad (19)$$

$$s = \sum_{p \in \mathbf{P}} (z_p) \quad (20)$$

$r = \sum_{q \in \mathbf{Q}} (y_q)$ (21)

$m = \sum_{j \in \mathbf{J}} (o_j)$ (22)

$s + r + m \geq 617$ (23)

$t = 750 - s - r - m$ (24)

$a_{ij} \geq 0 \quad \forall\, i \in \mathbf{I},\ j \in \mathbf{J}$

$b_i \geq 0 \quad \forall\, i \in \mathbf{I}$

$c_{ij} \in \{0, 1\} \quad \forall\, i \in \mathbf{I},\ j \in \mathbf{J}$

$d \geq 0$

$k_j \geq 0 \quad \forall\, j \in \mathbf{J}$

$z_p \geq 0$ and integer $\quad \forall\, p \in \mathbf{P}$

$y_q \geq 0$ and integer $\quad \forall\, q \in \mathbf{Q}$

$o_j \geq 0$ and integer $\quad \forall\, j \in \mathbf{J}$

$x_p \geq 0 \quad \forall\, p \in \mathbf{P}$

$w_q \geq 0 \quad \forall\, q \in \mathbf{Q}$

$n_j \geq 0 \quad \forall\, j \in \mathbf{J}$

$m \geq 0$

$t \geq 0$

$s \geq 0$

$r \geq 0$

The objective function (1) is set to maximise the profit. Constraint (2) ensures that the cost associated with the planting the crops, stays within budget. Constraints (3), (4) and (5) represent the areas (ha) of the crops (namely sunflower, maize and wheat) being cultivated. (6) is the constraint that prevents the number of hectares of crop $i \in \mathbf{I}$ planted on field $j \in \mathbf{J}$, to exceed the area of each specific field. Constraint (7) ensures that only one crop can possibly be planted on a field.

Constraint (8) calculates the area (ha) of field $j \in \mathbf{J}$ which is not cultivated, while (9) is the constraint which calculates the total number of uncultivated area (ha). In order to simulate the crop rotation system used by Groen Goud Landgoed (Pty) Ltd constraints (10) and (12) set upper limits to the total area (ha) on which sunflower and wheat can be planted, while constraint (11) set a lower limit to the total area (ha) on which maize can be planted. Constraint (13) sets a lower limit to the total area (ha) which should be uncultivated.

Constraints (14) and (15) calculate the number of cattle that can graze on each pasture and planted pasture. Constraint (16) calculates the number of cattle that can graze on each uncultivated field. Constraints (17), (18) and (19) ensure that the number of cattle grazing on each pasture, planted pasture and uncultivated field, will be smaller than or equal to the number of cattle that can graze on it (as calculated in (14), (15) and (16)).

Constraint (20) calculates the total number of cattle grazing on pastures, whereas constraint (21) calculates the total number of cattle grazing on the planted pastures. Constraint (22) calculates the total number of cattle grazing on the uncultivated fields. Mr Van Tonder requested that at least 617 cattle be placed in pastures, planted pastures and uncultivated fields, as constraint (23) shows. Constraint (24) calculates the number of cattle which will be sold.

Take note that the amount the cattle are sold for (in the objective function) is calculated by multiplying the average weight (in kilogram) of a cattle-unit (obtained from historic data) by 52%, as this is the percentage meat obtained. The amount is then multiplied by the selling price of R23 per kilogram of meat.

The following values are known values. The values of e_j were taken from the 'Field' columns in Tables 38 to 57.

e_j = 50.65, 25.33, 7.52, 14.34, 83.00, 51.70, 65.10, 74.80, 60.60, 12.70, 67.30, 81.20, 69.00, 42.40, 47.20, 61.90, 39.70, 45.50, 89.10, 20.75, 31.60, 62.50, 21.80, 57.95, 27.70, 26.00, 17.60, 29.10, 10.10, 9.10, 35.20, 53.80, 29.80, 88.60, 49.88, 47.88, 37.95, 84.90, 61.10, 35.80, 20.00, 80.50, 61.30, 36.40, 4.30, 14.20, 29.70, 49.50, 31.60, 61.70, 31.40, 73.90, 19.10, 45.80, 44.42, 29.10, 28.13, 47.37, 35.00, 28.60, 50.00, 30.54, 46.00, 25.00, 38.70, 38.66, 57.00, 64.00, 58.50, 68.00, 34.90, 46.00, 43.00, 74.50, 67.30, 60.30, 45.00, 106.10, 7.60, 61.40, 52.30, 79.30, 16.70, 5.20, 54.39, 20.04, 18.38, 15.19, 62.09, 11.53, 52.96, 16.70, 7.48, 33.46, 32.83, 35.26, 14.55, 23.76, 30.40, 27.50, 18.80, 27.00, 18.80, 27.50, 6.20, 22.50, 19.40, 35.00, 54.50, 11.90, 14.00, 44.67, 76.00, 39.80, 17.42, 34.70, 14.91, 72.50, 42.00, 11.60, 18.87, 56.72, 16.04, 76.31, 5.60, 70.19, 20.70, 7.48, 3.52, 17.40, 5.23, 17.18, 5.40, 14.24, 33.26, 23.51, 4.34, 32.70, 30.21, 40.67, 17.02, 3.98, 72.10, 33.53;

The values of f_i were computed in Table 6. These values were not changed while running any repetition of the optimization model, thus it can be assumed to be fixed values.

f_i = 2628.47, 3171.74, 2340.65;

The values of g_i were taken from Table 7. These values were not changed while running any repetition of the optimization model, thus it can be assumed to be fixed values.

g_i = 3407.22, 1361.43, 2324.09;

The values of h_i were obtained from historic data made available by the Van Tonder brothers. The effects of the crops' yields will be discussed in section 4.3.1.

h_i = 1.70, 3.20, 1.6;

The values of v_p were taken from the 'Pasture' columns in Tables 38 to 48.

v_p = 63.00, 26.50, 74.00, 36.00, 11.00, 18.00, 49.32, 10.60, 29.83, 12.12, 81.26, 18.40, 15.50, 226.71, 71.56, 18.48, 121.00, 85.00, 70.04, 38.10, 99.00, 122.86, 155.76, 31.00, 11.00, 16.00, 43.60, 50.65, 30.01;

The values of u_q were taken from the 'Planted Pastures' columns of Tables 39 to 41, as well as Tables 44 and 45.

u_q = 21.80, 3.25, 6.48, 16.94, 8.60, 26.70, 34.11, 150.50, 25.70, 24.50, 31.60, 65.00;

Table 6: Input Costs per Hectare

Input Costs per Hectare			
Expenses	**Sunflower**	**Maize**	**Wheat**
Air spraying	R 0.00	R 0.00	R 63.04
Contract Work	R 0.00	R 0.00	R 225.52
Crop Diseases	R 97.03	R 35.75	R 37.56
Crop Insurance	R 154.53	R 255.23	R 159.86
Fertilizer	R 1 016.35	R 961.73	R 740.52
Fuel	R 628.73	R 608.39	R 570.37
Insect Control	R 19.59	R 32.34	R 0.00
Lime	R 0.00	R 0.00	R 0.00
Marketing	R 74.44	R 328.86	R 117.55
Seed	R 340.68	R 566.06	R 174.32
Transportation	R 0.00	R 0.00	R 8.41
Weed Control	R 297.12	R 383.38	R 243.50
Total	**R 2 628.47**	**R 3 171.74**	**R 2 340.65**

Table 7: Selling Price of Crops

	Price (R/ton)
Sunflower	3407.22
Maize	1361.43
Wheat	2324.09

4.1.2 Broiler Farming

In order to determine the annual demand for each of the feed phases (as listed in Table 5), the daily feed intake (in kilogram) had to be determined. The feed intake by the broilers for one cycle is listed in Table 8.

There are eight broiler houses on Vaalkoppies. Each broiler house has two 15 ton silos in which the feed are stored. At the beginning of each 52-day cycle the farm receives 284 000 day-old chicks (DOCs). They are divided equally among the broiler houses, i.e. each broiler house receives 35 500 DOCs.

The mortality rate is 0.1443% per day, as based on historical data. The number of broilers (shown in the '# Broilers' column reflects the mortality amongst the broilers on a daily basis. The 'Intake' column shows the rounded values of the calculated feed intake per broiler per day in kilogram. The values in the 'Cum. Intake' column under the 'In Houses' heading was calculated by multiplying the value of the 'Intake ' column with the value in the '# Broilers' column for each day. The different shades of green show the different feeding phases according to Table 5.

Table 8: Daily Feed Intake by Broilers

	Per Broiler		In Houses	
Day	**Intake (kg)**	**Cum. Intake (kg)**	**# Broilers**	**Cum. Intake (kg)**
1	0.050	0.050	284 000	14 154.560
2	0.053	0.103	283 590	15 143.706
3	0.061	0.164	283 181	17 138.114
4	0.068	0.231	282 772	19 126.698
5	0.078	0.310	282 364	22 114.748
6	0.089	0.399	281 956	25 094.084
7	0.100	0.498	281 549	28 064.804
8	0.110	0.609	281 143	31 026.941
9	0.121	0.730	280 737	33 980.406
10	0.142	0.872	280 332	39 919.277
11	0.157	1.029	279 927	43 847.765
12	0.178	1.207	279 523	49 755.094
13	0.196	1.403	279 120	54 651.696
14	0.217	1.620	278 717	60 526.184
15	0.239	1.858	278 315	66 383.694
16	0.263	2.122	277 913	73 213.401
17	0.285	2.407	277 512	79 035.418
18	0.306	2.713	277 111	84 840.304
19	0.331	3.044	276 711	91 613.478
20	0.360	3.403	276 312	99 350.743
21	0.381	3.784	275 913	105 100.780
22	0.409	4.194	275 515	112 795.841
23	0.438	4.632	275 117	120 468.232
24	0.463	5.094	274 720	127 140.416
25	0.484	5.579	274 324	132 816.708
26	0.513	6.091	273 928	140 426.450
27	0.541	6.632	273 533	148 014.177
28	0.559	7.191	273 138	152 662.291
29	0.580	7.771	272 744	158 267.888
30	0.584	8.355	272 350	159 008.824
31	0.623	8.978	271 957	169 429.211
32	0.627	9.605	271 564	170 151.140
33	0.274	9.879	271 172	74 333.669
34	0.274	10.153	270 781	74 226.488
35	0.345	10.498	270 390	93 371.075

As mentioned, each cycle stretches over 52 days, thus there are seven cycles per year. From this information the annual demand could be calculated as shown in Table 9. The 'Total Phase Requirement' column was calculated by adding the values of the 'Cum. Intake' column under the 'In Houses' heading for each phase from Table 8.

Table 9: Annual Demand per Feed Phase

Phase	Total Phase Requirement (kg)	Annual Requirement (kg)	Annual Demand (ton)
1	46 436.380	325 054.660	326
2	94 400.335	660 802.345	661
3	913 245.180	6 392 716.260	6 393
4	1 092 592.003	7 648 144.021	7 649
5	740 520.406	5 183 642.842	5 184

Groen Goud Landgoed (Pty) Ltd has eight possible suppliers from which the feed can be bought. Table 10 shows which supplier can supply feed for each of the phases. Table 11 shows the purchasing price associated with each supplier.

Table 10: Feed Phases Supplied by Suppliers

Supplier	Feed Phases				
	1	**2**	**3**	**4**	**5**
Supplier 1	×				×
Supplier 2		×	×		
Supplier 3	×		×		
Supplier 4		×			×
Supplier 5			×		×
Supplier 6				×	×
Supplier 7	×			×	
Supplier 8		×		×	

Table 11: Suppliers' Purchase Price

Supplier	Cost (R/ton)
Supplier 1	65.20
Supplier 2	115.50
Supplier 3	225.00
Supplier 4	243.75
Supplier 5	144.10
Supplier 6	200.40
Supplier 7	205.00
Supplier 8	97.50

4.2 RESULTS

4.2.1 Crop Enterprise Farming

The linear programming model described in section 4.1.1 was solved by using LINGO 13.0, which is an optimisation tool. The LINGO source code can be seen in Appendix C. The results of the crop enterprise farming problem (as stated in sections 1.2 and 1.3) are shown in the figures below. These results were obtained by using the following crop yields:

- Sunflower: 1.7 tons per hectare
- Maize: 3.2 tons per hectare
- Wheat: 1.6 tons per hectare

Figure 1: Crops Planted on Beketsrus

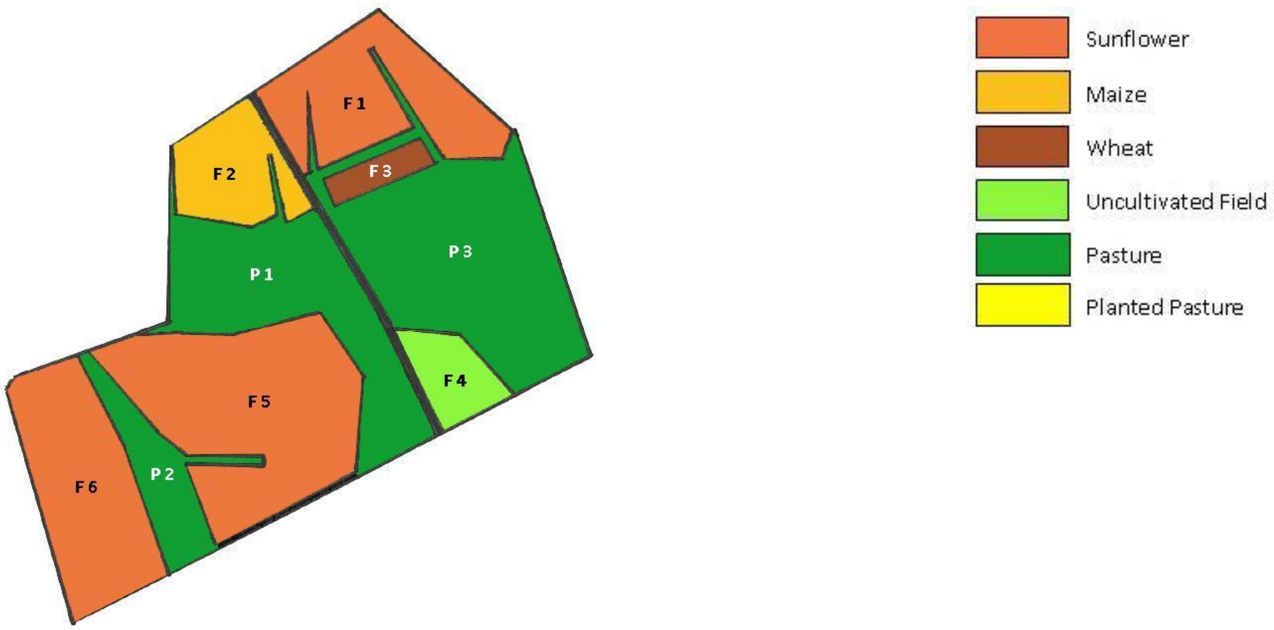


Figure 2: Crops Planted on Bullock

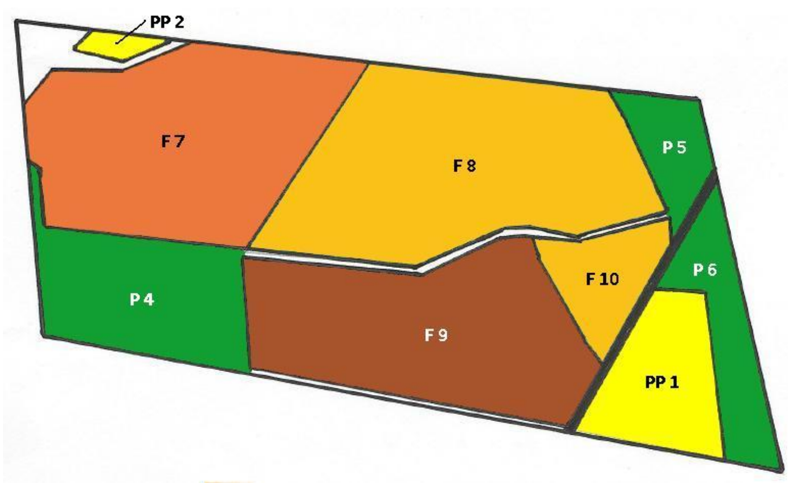


Figure 3: Crops Planted on Danielsfontein

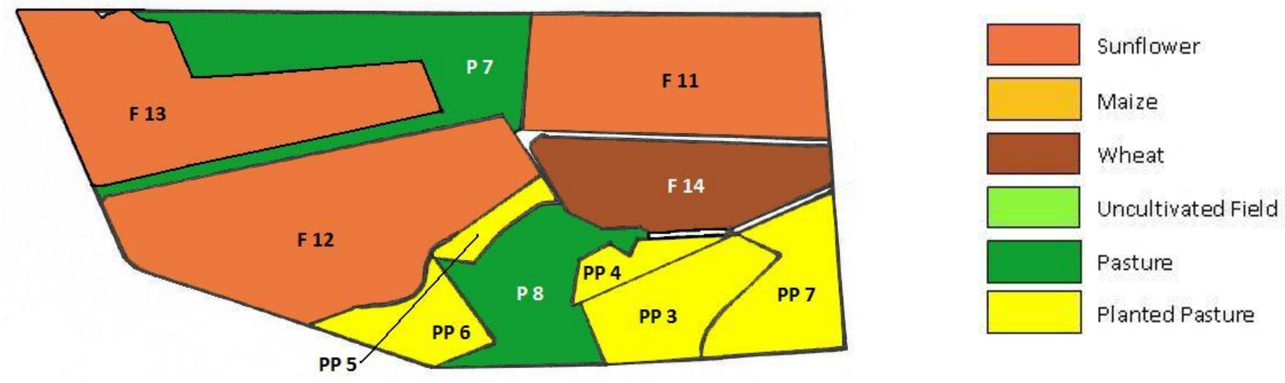


Figure 4: Crops Planted on Erfdeel

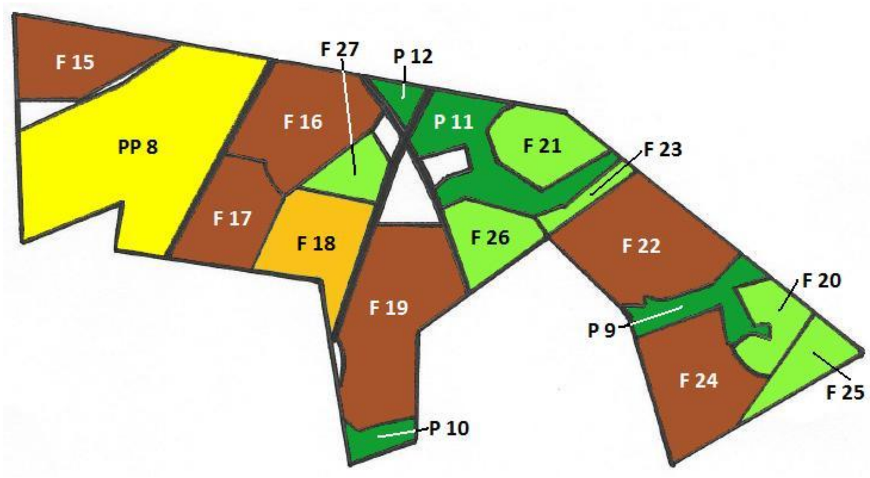


Figure 5: Crops Planted on Goodhope

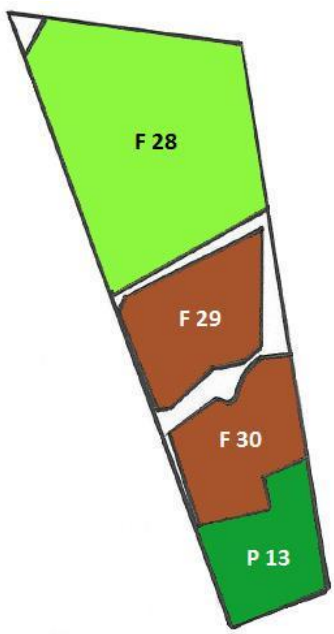


Figure 6: Crops Planted on Mike

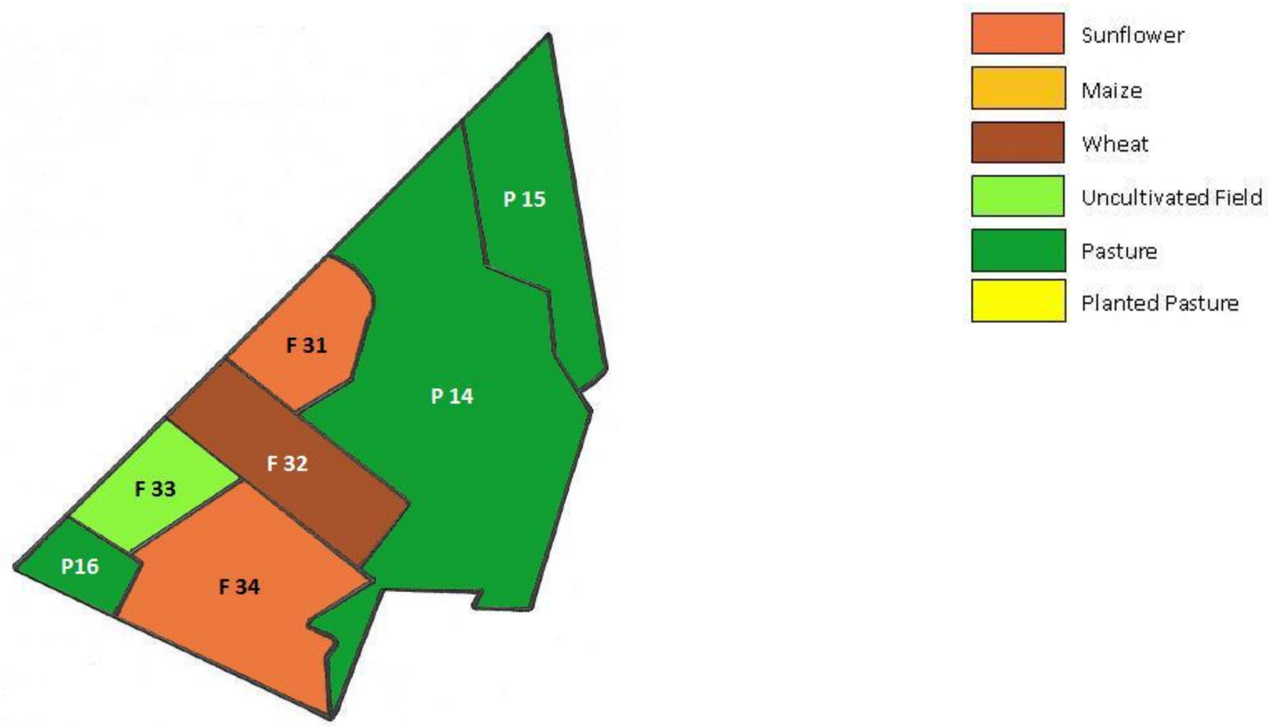


Figure 7: Crops Planted on Pyrmont

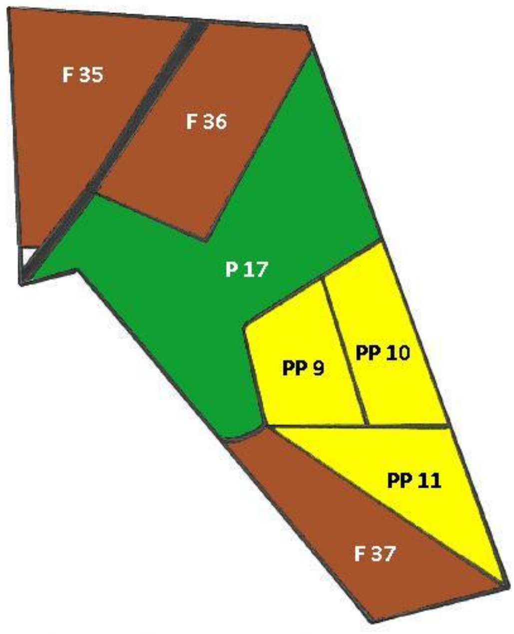


Figure 8: Crops Planted on Vaalkoppies

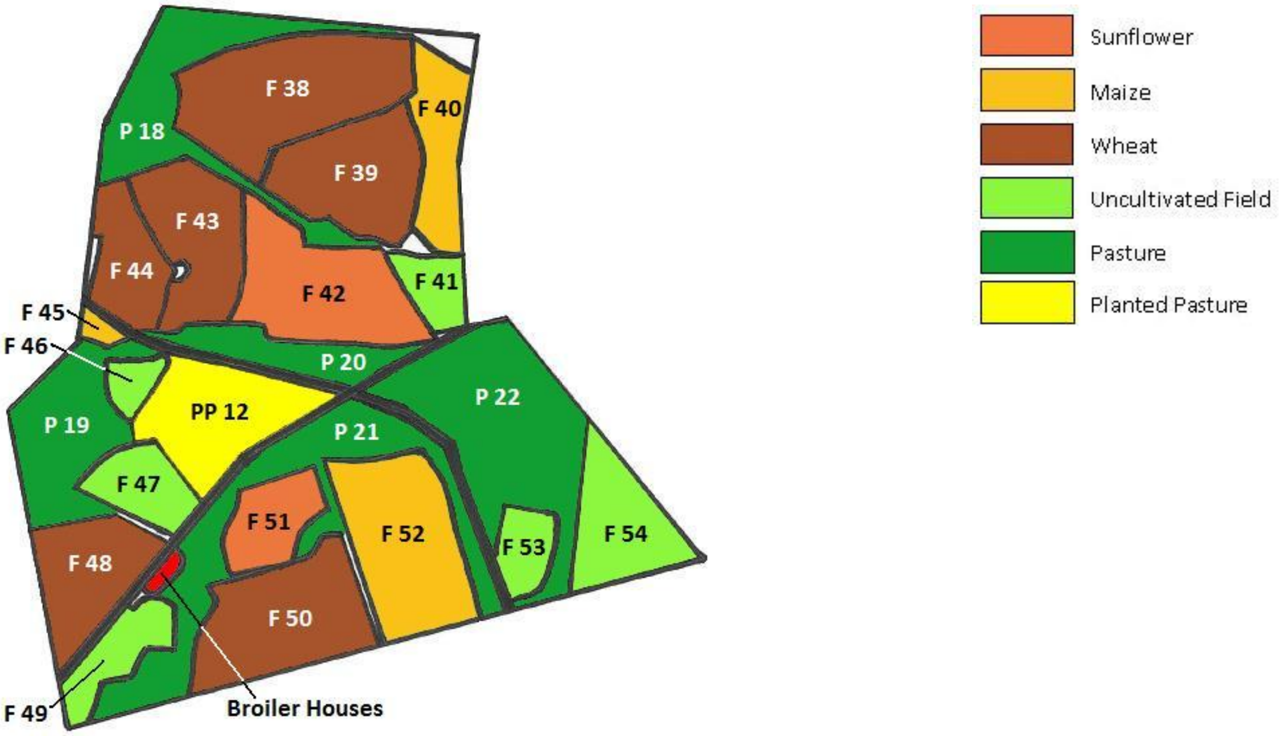


Figure 9: Crops Planted on Vlakpan

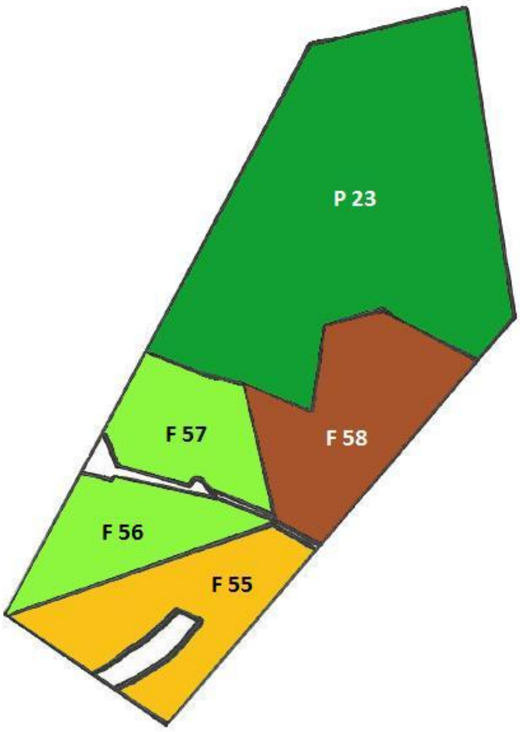


Figure 10: Crops Planted on Vlakvallei

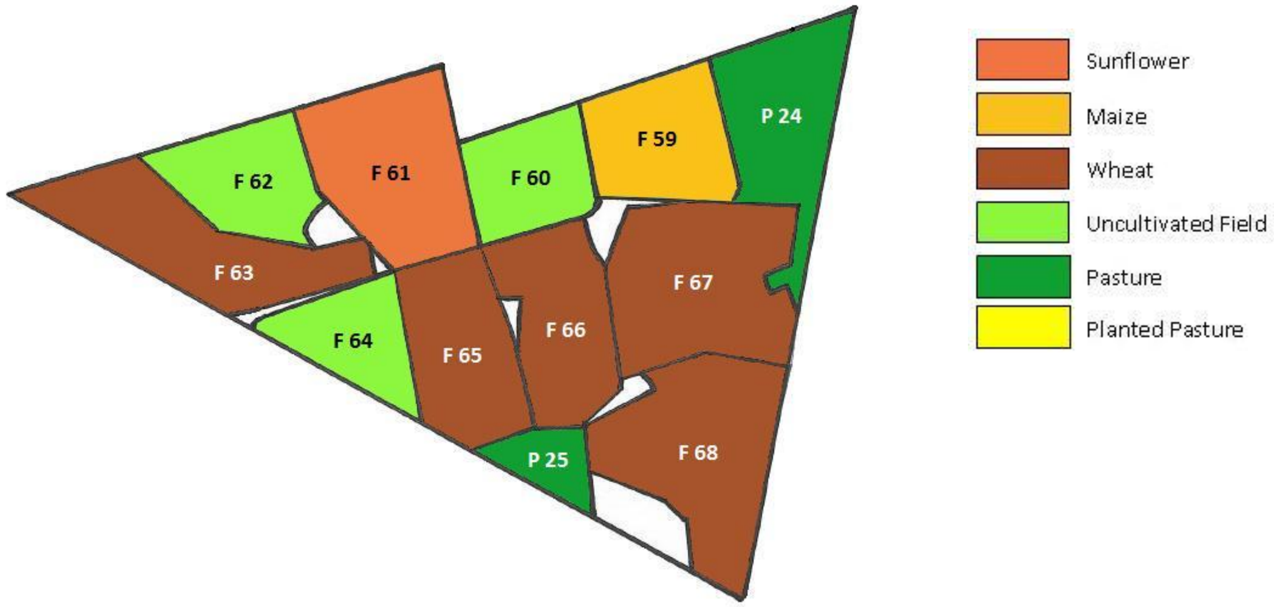


Figure 11: Crops Planted on Yarima

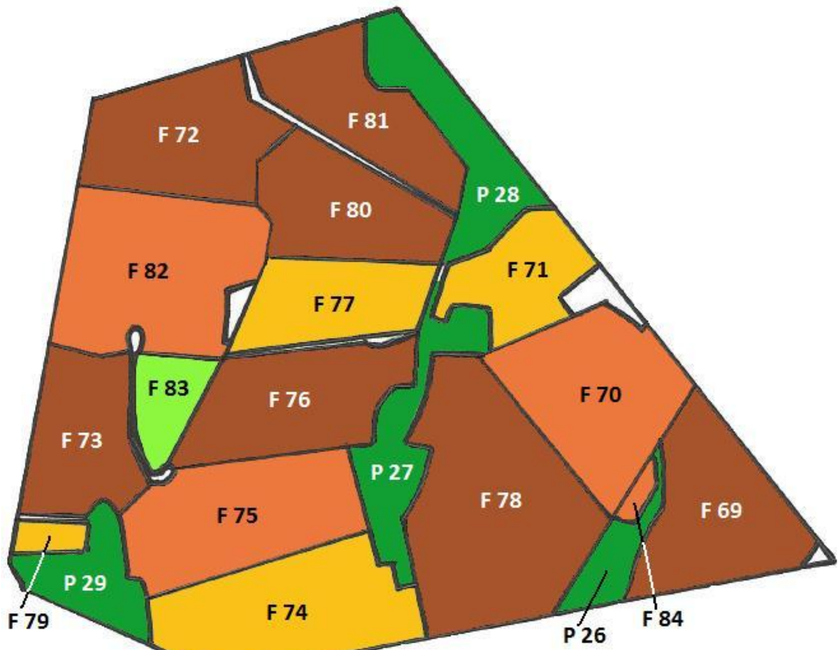


Figure 12: Crops Planted on Dankbaar

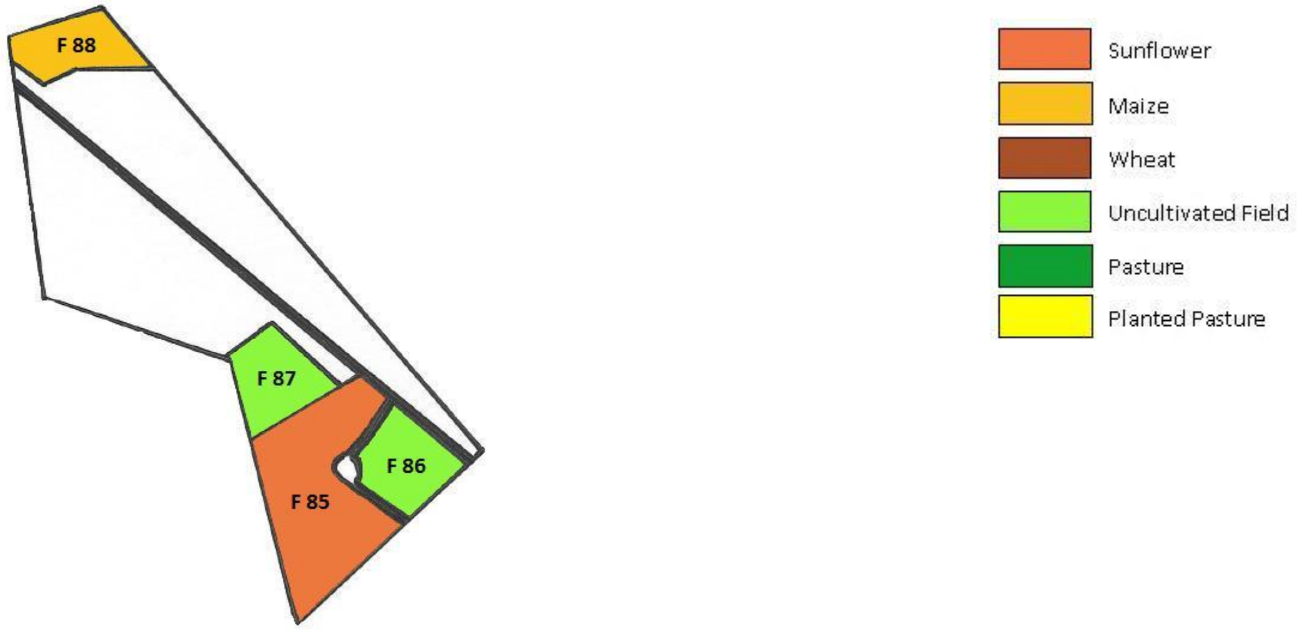


Figure 13: Crops Planted on Dorpslande

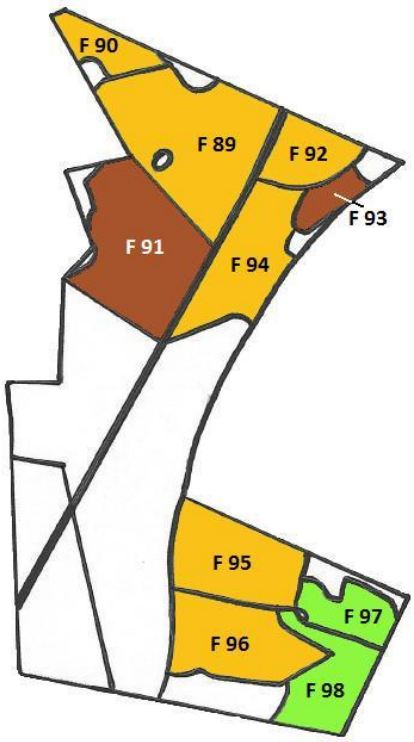


Figure 14: Crops Planted on Langverwacht

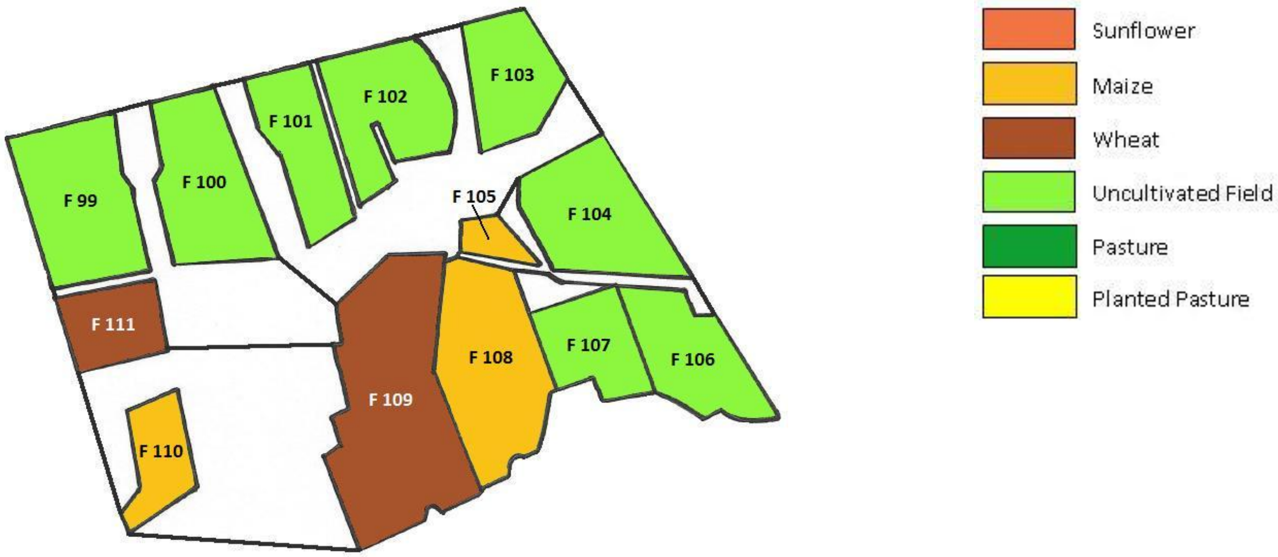


Figure 15: Crops Planted on Nuldesperandum

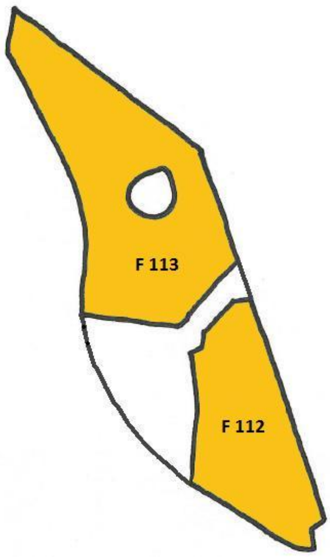


Figure 16: Crops Planted on Olivia

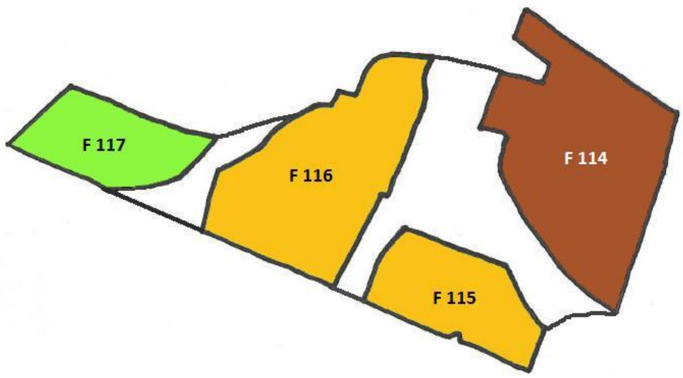


Figure 17: Crops Planted on Patmos

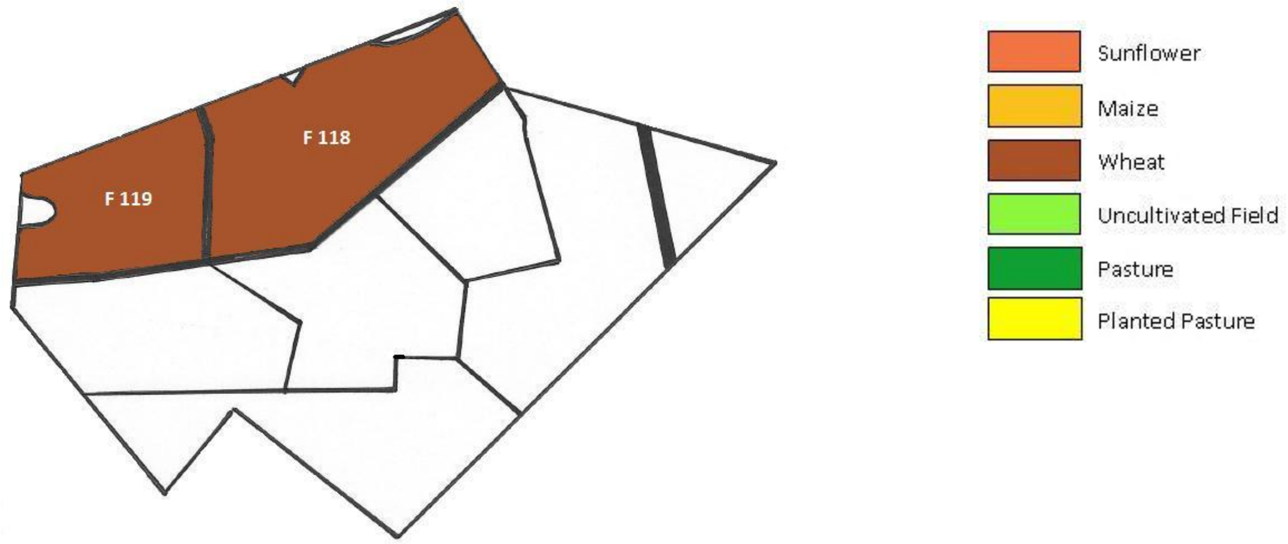


Figure 18: Crops Planted on Rooikraal

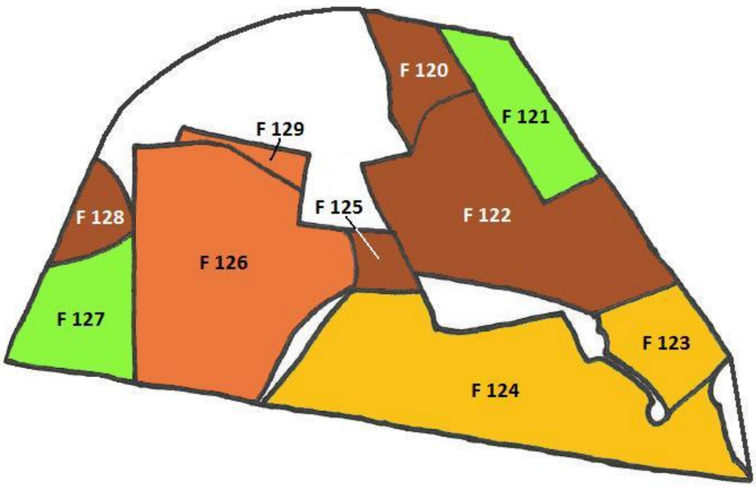


Figure 19: Crops Planted on Vyfhoek

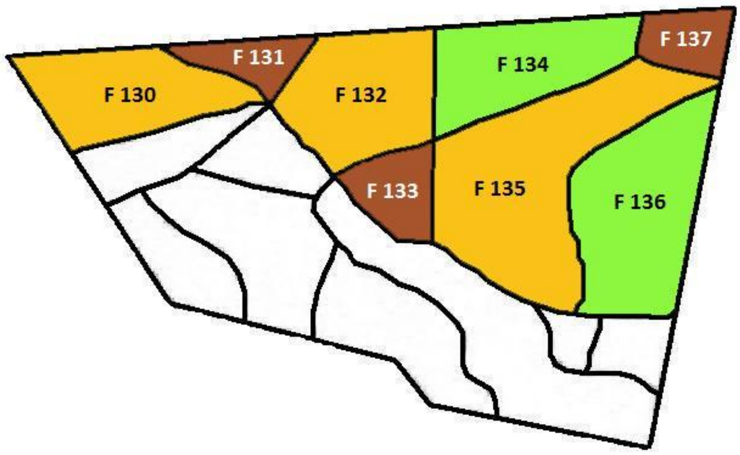
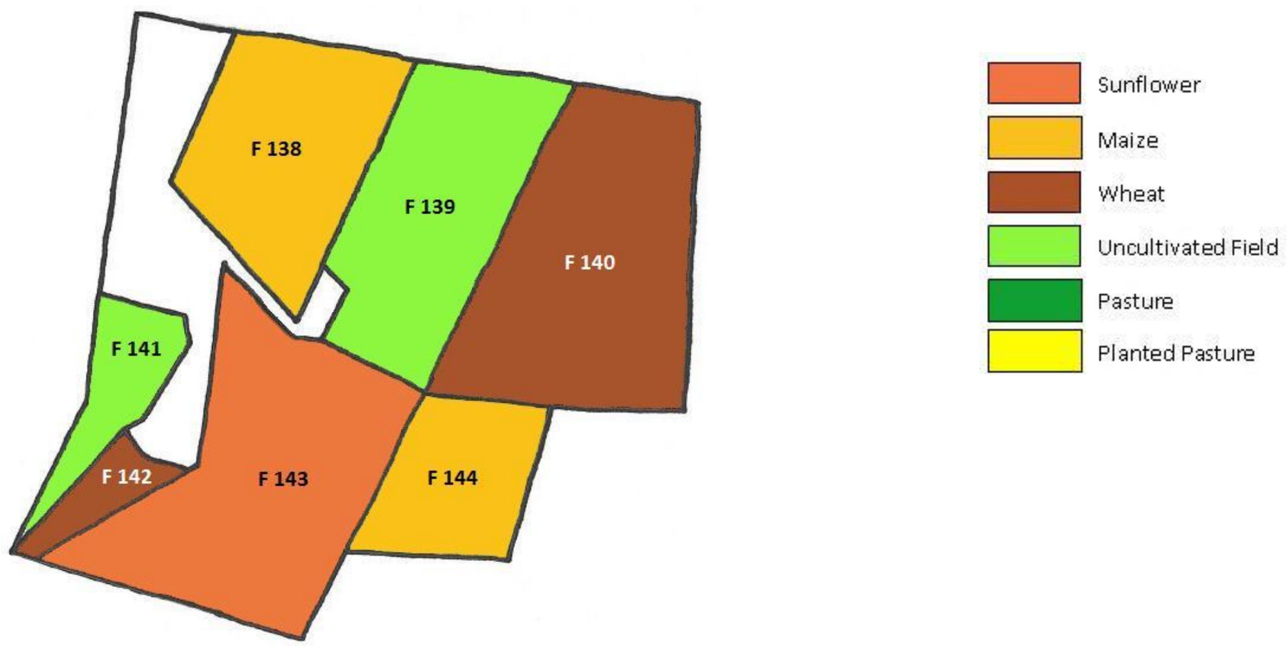


Figure 20: Crops Planted on Waverley



To summarise the results of the crop enterprise farming problem: there are 18 fields planted with sunflower, to a total of 1 049.85 hectares; there are 36 fields cultivated with maize, to a total of 1 296.92 hectares; and there are 50 fields planted with wheat, to a total of 2 176.07 hectares. The uncultivated fields account for 40 fields, to a total of 945.25 hectares.

4.2.2 Cattle Farming

The Operations Research model was developed to calculate the maximum profit, and to ease the decision-making process with regards to dividing the cattle into smaller groups in order to simplify management. The model's results are tabulated in Tables 12 and 13 for the pastures and planted pastures respectively.

Table 12: Division of Cattle amongst the Pastures

Pasture	Number of Cattle Allocated	Farm
1	12	Beketsrus
2	5	Beketsrus
3	14	Beketsrus
4	7	Bullock
5	2	Bullock
6	3	Bullock
7	9	Danielsfontein
8	2	Danielsfontein
9	5	Erfdeel
10	2	Erfdeel

Pasture	Number of Cattle Allocated	Farm
11	16	Erfdeel
12	3	Erfdeel
13	3	Goodhope
14	45	Mike
15	14	Mike
16	3	Mike
17	24	Pyrmont
18	17	Vaalkoppies
19	14	Vaalkoppies
20	7	Vaalkoppies
21	19	Vaalkoppies
22	24	Vaalkoppies
23	31	Vlakpan
24	6	Vlakvallei
25	2	Vlakvallei
26	3	Yarima
27	8	Yarima
28	10	Yarima
29	6	Yarima

Table 13: Division of Cattle amongst the Planted Pastures

Planted Pasture	Number of Cattle Allocated	Farm
1	7	Bullock
2	1	Bullock
3	2	Danielsfontein
4	5	Danielsfontein
5	2	Danielsfontein
6	8	Danielsfontein
7	11	Danielsfontein
8	50	Erfdeel
9	8	Pyrmont
10	8	Pyrmont
11	10	Pyrmont
12	21	Vaalkoppies

The fields which were not cultivated were obtained from Figures 1 to 20, as it were calculated using the LINGO 13.0 optimisation model. The areas (ha) of these fields were then used to calculate the number of cattle that can graze on each uncultivated field. These results are shown in Table 14.

Table 14: Division of Cattle amongst the Uncultivated Fields

Uncultivated Field	Number of Cattle	Farm
4	2	Beketsrus
20	4	Erfdeel
21	6	Erfdeel
23	4	Erfdeel
25	5	Erfdeel
26	5	Erfdeel
27	3	Erfdeel
28	5	Goodhope
33	5	Mike
41	4	Vaalkoppies
46	2	Vaalkoppies
47	5	Vaalkoppies
49	6	Vaalkoppies
53	3	Vaalkoppies
54	9	Vaalkoppies
56	5	Vlakpan
57	5	Vlakpan
60	5	Vlakvallei
62	6	Vlakvallei
64	5	Vlakvallei
83	3	Yarima
86	4	Dankbaar
87	3	Dankbaar
97	2	Dorpslande
98	4	Dorpslande
99	6	Langverwacht
100	5	Langverwacht
101	3	Langverwacht
102	5	Langverwacht
103	3	Langverwacht
104	5	Langverwacht
106	4	Langverwacht
107	3	Langverwacht
117	2	Olivia
121	3	Rooikraal
127	4	Rooikraal
134	2	Vyfhoek
136	4	Vyfhoek
139	6	Waverley
141	3	Waverley

The cattle allocated to pastures, planted pastures and uncultivated fields in Tables 12, 13 and 14 respectively, accounts for 617 (or 82.27%) of the whole current cattle herd. The optimisation model's results tell one that the remaining 133 cattle should be slaughtered for their meat. It was assumed that all of the cattle to be slaughtered are cows.

4.2.3 Broiler Farming

The annual demand was calculated and tabulated in Table 9 and the purchasing price per supplier is listed in Table 11. To calculate the EOQ it is also necessary to know the holding cost per ton and the ordering cost per order, which is R59.64 per ton and R163.42 per order respectively (based on historic data). Using all of this information together with Table 10, the following results were obtained.

Table 15: EOQ Calculated per Phase per Cycle

Q*	=	42.26759949
n*	=	7.712763534
Phase 1 Supplier 1		
TC*	=	R 23 776.04
Phase 1 Supplier 3		
TC*	=	R 75 870.84
Phase 1 Supplier 7		
TC*	=	R 69 350.84
Q*	=	60.18655884
n*	=	10.98251857
Phase 2 Supplier 2		
TC*	=	R 79 935.03
Phase 2 Supplier 4		
TC*	=	R 164 708.28
Phase 2 Supplier 8		
TC*	=	R 68 037.03
Q*	=	187.1764196
n*	=	34.1549433
Phase 3 Supplier 2		
TC*	=	R 749 554.70
Phase 3 Supplier 3		
TC*	=	R 1 449 588.20
Phase 3 Supplier 5		
TC*	=	R 932 394.50
Q*	=	204.7392528
n*	=	37.35971435
Phase 4 Supplier 6		
TC*	=	R 1 545 070.25
Phase 4 Supplier 7		
TC*	=	R 1 580 255.65

Phase 4 Supplier 8		
TC*	=	R 757 988.15
Q*	=	168.5509792
n*	=	30.75627341
Phase 5 Supplier 1		
TC*	=	R 348 049.18
Phase 5 Supplier 4		
TC*	=	R 1 273 652.38
Phase 5 Supplier 5		
TC*	=	R 757 066.78
Phase 5 Supplier 6		
TC*	=	R 1 048 925.98

Q* represents the optimal order quantity (in tons). n* signifies the optimum number of orders per year, and TC* represents the minimum total annual cost if the optimal order quantity is ordered. From Table 15 it is clear that Supplier 1 will be used to supply feed phases 1 and 5, since it is the least expensive alternative. Similarly Supplier 2 will be used to supply feed phase 3, while Supplier 8 will be used to supply feed phases 2 and 4. The total annual cost is calculated in Table 16 below.

Table 16: Total Annual Feed Cost

Phase	Total Cost / Phase
1	R 166 432.28
2	R 476 259.18
3	R 5 246 882.91
4	R 5 305 917.04
5	R 2 436 344.26
Total	**R 13 631 835.68**

4.3 VALIDATION of MODELS

4.3.1 Operations Research Model

The Monte Carlo simulation model mainly focused on how the rainfall during specific growth phases, can influence the final yield of the crops. The Monte Carlo simulation model also included the environmental factors which were discussed under section 2.2.

Figure 21 shows the developed Monte Carlo simulation model used to determine the sunflower yield when taking into consideration the various factors. These factors include the environmental factors as discussed under section 2.2, as well as the rainfall figures for each month. The rainfall figures can be seen at the left of Figure 21. Each month's rainfall data has been fitted to a normal distribution, which can be seen in Appendix D. The rainfall data used is the average of the past twenty-five years' rainfall figures from the farms Erfdeel and Yarima.

The cumulative probabilities for each month were used to determine the range of probabilities. These ranges were then divided into quarters. The first quarter's values were used as the minimum range for each month in the Monte Carlo simulation model. The last quarter's values were used as the maximum range for each month in the simulation model. The remaining quarters' values were used as the likely range within the Monte Carlo model.

In Figure 21 the minimum rainfall figure for January has the following formula allocated to it: *IF***(***RAND() <= 0.21326, RANDBETWEEN(43,81), RANDBETWEEN(25,42)***)**. The value '0.21326' is the calculated upper limit of the first quarter, thus any random number generated smaller than or equal to this value will take on any value within the range of 43 to 81 mm. If the random number is larger than 0.21326, then the minimum rainfall figure for January will display any integer value within the range of 25 to 42 mm. A similar approach was used to determine the minimum rainfall figures for the other months; the only difference being the "smaller than or equal to" value for each month (e.g. 0.21326 for January).

The likely rainfall figure displayed for January in Figure 21 has the following formula: *IF***(***RAND() <= 0.63400, RANDBETWEEN(112,178), RANDBETWEEN(82,111)***)**. The value '0.63400' is the calculated upper limit of the third quarter, thus any random number generated smaller than or equal to this value will take on any integer value within the range of 112 to 178 mm. If the randomly generated number is larger than 0.63400 then the likely rainfall figure for January will display any integer value within the range of 82 to 111 mm. A similar approach was used to determine the likely rainfall figures for the other months; the only difference being the "smaller than or equal to" value for each month (e.g. 0.63400 for January).

The maximum rainfall figure for January in Figure 21 has the following formula: *IF***(***RAND() > 0.63400, RANDBETWEEN(259,442), RANDBETWEEN(179,258)***)**. The value '0.63400' is the calculated lower limit of the fourth quarter, hence any random number generated greater than this value will take on any integer value within the range of 259 to 442 mm. If the randomly generated number is not larger than 0.63400 then the likely rainfall figure for January will display any integer value within the range of 179 to 258 mm. A similar approach was used to determine the maximum rainfall figures for the other months; the only difference being the "greater than" value for each month (e.g. 0.63400 for January).

The environmental factors included in the Monte Carlo simulation model are listed below, along with its respective formulae:

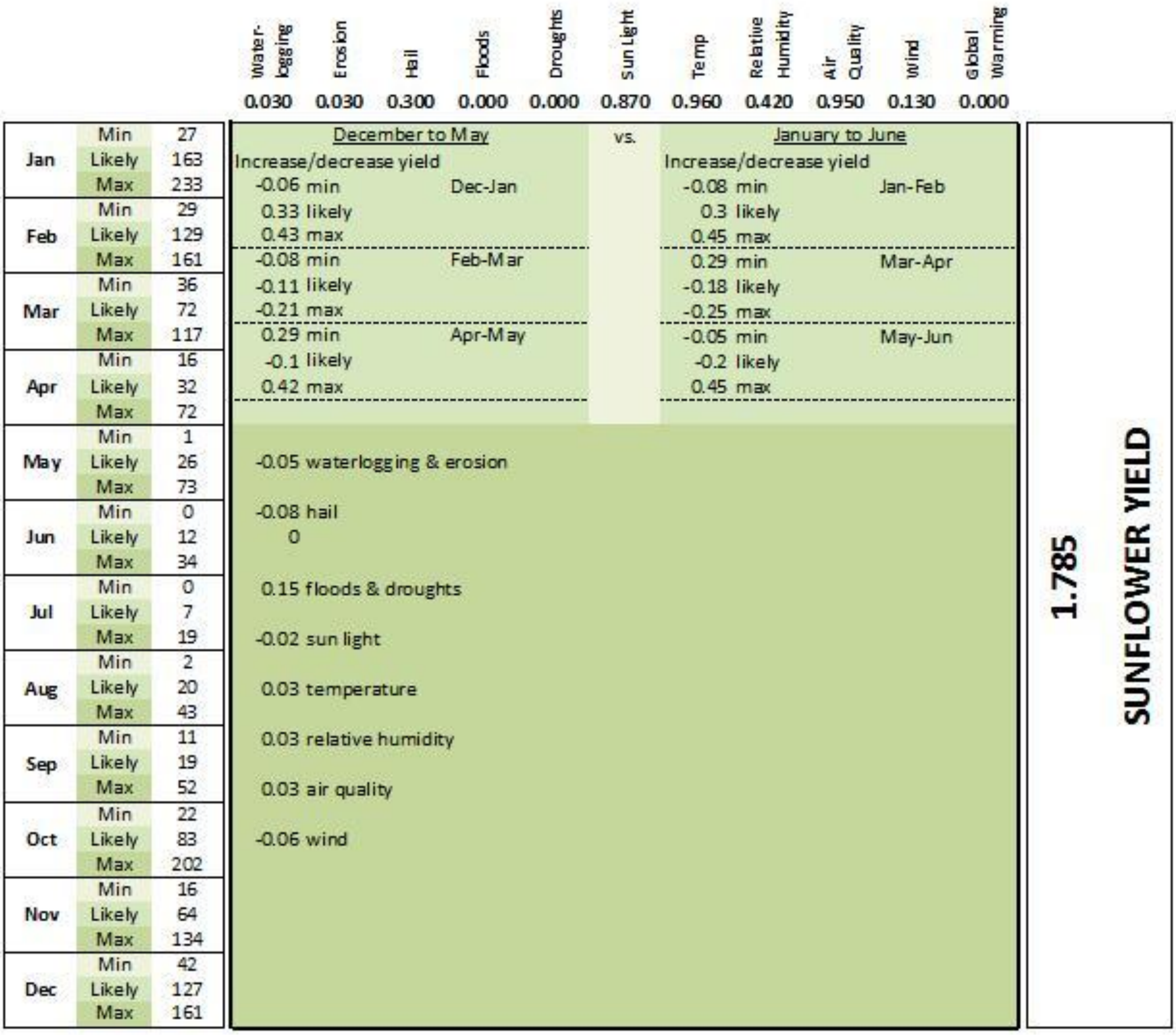
- Waterlogging has the formula: *RANDBETWEEN(1,8) / 100*.
- Erosion has the formula: *RANDBETWEEN(1,4) / 100*.
- Global warming has the formula: *IF***(***RAND() >= 0.96, 1, 0***)**.
- Hail is much influenced by global warming ('*P3*'), and thus has the formula: *IF***(***RAND() > 0.25, IF (P3=0, RANDBETWEEN(1,10) / 100, (1 + (RANDBETWEEN(40,46) / 100)) * (RANDBETWEEN(1,10) / 100)), IF(P3=0, 0.55, (1 + (RANDBETWEEN(40,46) / 100)) * 0.55)***)**.
- Floods have the formula: *IF***(***SUM(D7, D10, D13, D16, D19, D22, D25, D28, D31, D34, D37, D40) >= 1450, 1 / RANDBETWEEN(13,20), 0***)**.
- Droughts and floods cannot occur simultaneously, and therefore have the formula: *IF***(***9 * (SUM(D7, D10, D13, D16, D19, D22, D25, D28, D31, D34, D37, D40) / SUM(D5, D8, D11, D14,*

D17, D20, D23, D26, D29, D32, D35, D38)) / (SUM(D5, D8, D11, D14, D17, D20, D23, D26, D29, D32, D35, D38) / 9) >= 3.5 ,1/3, 2/3).

- Sun light has the formula: ***(****100 − RANDBETWEEN(2,16)****)*** */ 100*.
- Temperature has the formula: ***(****100 − RANDBETWEEN(4,12)****)*** */ 100*.
- Relative humidity has the formula: *RANDBETWEEN(15,45) / 100*.
- Air quality has the formula: ***(****100 − RANDBETWEEN(5,15)****)*** */ 100*.
- Wind has the formula: *RANDBETWEEN(5,16) / 100*.

The entire Monte Carlo model is based on random numbers within the mentioned ranges. The block in the centre of the model analyses these random generated numbers and converts it to an increase or decrease in yield. The number on the right of Figure 21 is then one added to the sum of these increases and/or decreases in the yield, multiplied by the yield used in the Operations Research model (e.g. sunflower yield used was 1.7 tons per hectare).

Figure 21: Monte Carlo Simulation for Sunflower Yield



Now the 'December to May' and 'January to June' blocks of Figure 21 will be discussed. Sunflower is planted either in December or January and harvested either during May or June. The '-0.06' is the decrease in sunflower yield when the minimum rain falls during December-January. The formula for the minimum yield increase or decrease is: *IF(SUM(D38, D5) / SUM(D38, D5, D8, D11, D14, D17) <= 0.46, −RANDBETWEEN(5,15) / 100, RANDBETWEEN(20,30) / 100)*. A similar approach was used to determine the minimum yield increases or decreases for February-March and April-May under the 'December to May' heading, as well as January-February, March-April and May-June under the 'January to June' heading. The only difference being the "smaller than or equal to" value for the specific months (e.g. 0.46 for December-January).

The '0.33' is the increase in sunflower yield when the likely (or expected) rain falls during December-January. The formula for the likely yield increase or decrease is: *IF(SUM(D39, D6) / SUM(D39, D6, D9, D12, D15, D18) <= 0.45, −RANDBETWEEN(10,20) / 100, RANDBETWEEN(30,40) / 100)*. A similar approach was used to determine the likely yield increases or decreases for February-March and April-May under the 'December to May' heading, as well as January-February, March-April and May-June under the 'January to June' heading. The only difference being the "smaller than or equal to" value for the specific months (e.g. 0.45 for December-January).

The '0.43' is the increase in sunflower yield when the maximum rain falls during December-January. The formula for the maximum yield increase or decrease is: *IF(SUM(D40, D7) / SUM(D40, D7, D10, D13, D16, D19) <= 0.45, −RANDBETWEEN(15,30) / 100, RANDBETWEEN(35,50) / 100)*. A similar approach was used to determine the maximum yield increases or decreases for February-March and April-May under the 'December to May' heading, as well as January-February, March-April and May-June under the 'January to June' heading. The only difference being the "smaller than or equal to" value for the specific months (e.g. 0.45 for December-January).

How the environmental factors increase or decrease the sunflower yield will now be discussed. The waterlogging and erosion were combined, and its formula is *IF(SUM(F3:G3) <= 0.05, 0, −RANDBETWEEN(3,6) / 100)*. Hail is greatly influenced by global warming as stated earlier in the document. The prior calculation for hail already takes the effect of global warming into account, thus it is not necessary to do so here. Hail increases or decreases the yield according to the following formulae: *IF(H3 <= 0.47, −RANDBETWEEN(2,8) / 100, 0)* and *IF(H3 >= 0.48, −RANDBETWEEN(11,15) / 100, 0)*.

Floods and droughts have been combined, and its formula is *IF(I3 + J3 = 0, RANDBETWEEN(15,30) / 100, IF(I3 + J3 <= 0.35, −RANDBETWEEN(4,13) / 100, −RANDBETWEEN(15,22) / 100))*. Sun light increases or decreases the yield of sunflower according to the formula: *IF(K3 >= 0.9, RANDBETWEEN(3,5) / 100, −RANDBETWEEN(1,2) / 100)*.Temperature increases or decreases the yield according to the formula: *IF(L3 >= 0.92, RANDBETWEEN(3,6) / 100, −RANDBETWEEN(1,2) / 100)*.

Relative humidity increases or decreases the yield according to the formula: *IF(M3 >= 0.3, RANDBETWEEN(2,4) / 100, −RANDBETWEEN(2,5) / 100)*. Air quality increases or decreases the yield of sunflower according to the formula: *IF(N3 < 0.92, −RANDBETWEEN(2,4) / 100, RANDBETWEEN(2,4) / 100)*. Wind increases or decreases the yield according to the following formula: IF(O3 >= 0.1, −RANDBETWEEN(3,6) / 100, RANDBETWEEN(1,2) / 100).

The sunflower yield can now be calculated. The yield is displayed at the right side of Figure 21. The general formula is: *1.7 * (1 + SUM(IF(J3 > 0, SUM(AVERAGE(F7,L7), AVERAGE(F10,L10), AVERAGE(F13,L13)), 0), IF(I3 + J3 = 0, SUM(AVERAGE(F8,L8), AVERAGE(F11,L11), AVERAGE(F14,L14)), 0), IF(I3 > 0, SUM(AVERAGE(F9,L9), AVERAGE(F12,L12), AVERAGE(F15,L15)), 0), F18, F20:F21, F23, F25, F27, F29, F31, F33))*. The yield in Figure 21 is calculated as follows:

Yield = 1.7 * **(**1 + SUM(0, SUM(AVERAGE(0.33, 0.3), AVERAGE(-0.11, -0.18), AVERAGE(-0.1, -0.2)), 0, -0.05, -0.08, 0.15, -0.02, 0.03, 0.03, 0.03, -0.06)**)**
= 1.7 * **(**1 + SUM(0, SUM(0.315, -0.145, -0.15), 0, -0.05, -0.08, 0.15, -0.02, 0.03, 0.03, 0.03, -0.06)**)**
= 1.7 * **(**1 + SUM(0, 0.02, 0, -0.05, -0.08, 0.15, -0.02, 0.03, 0.03, 0.03, -0.06)**)**
= 1.7 * (1 + 0.05)
= 1.785 tons per hectare

Similar Monte Carlo models were developed for determining the maize and wheat yields, and can be seen in Figures 22 and 23.

Figure 22: Monte Carlo Simulation for Maize Yield

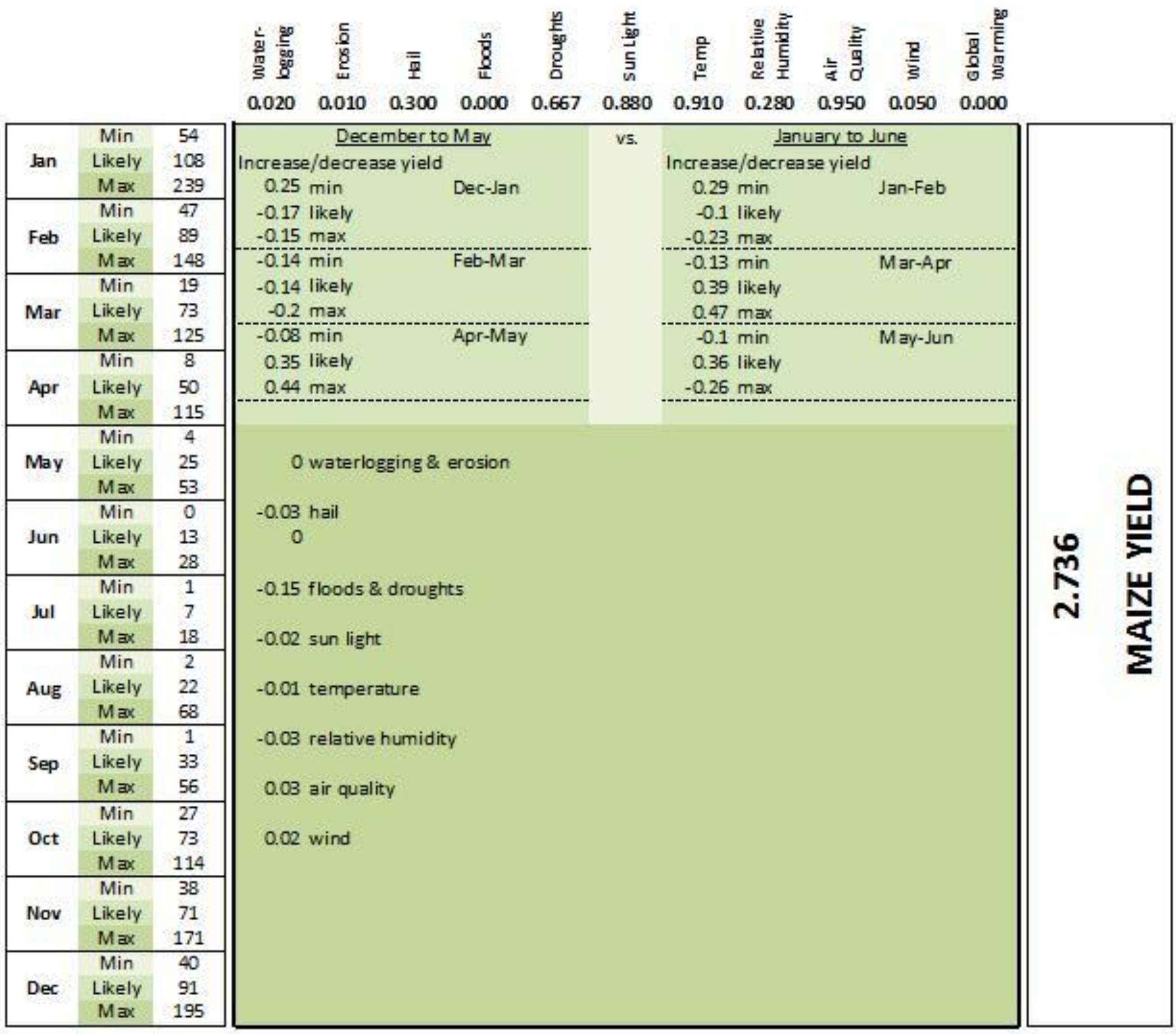


Figure 23: Monte Carlo Simulation for Wheat Yield

Water-logging	Erosion	Hail	Floods	Droughts	Sun Light	Temp	Relative Humidity	Air Quality	Wind	Global Warming
0.04	0.02	0.07	0.00	0.67	0.96	0.91	0.39	0.93	0.08	0.00

Jan	Min	36
	Likely	120
	Max	209
Feb	Min	41
	Likely	78
	Max	144
Mar	Min	15
	Likely	74
	Max	117
Apr	Min	23
	Likely	61
	Max	131
May	Min	2
	Likely	32
	Max	57
Jun	Min	2
	Likely	20
	Max	59
Jul	Min	0
	Likely	9
	Max	20
Aug	Min	4
	Likely	27
	Max	35
Sep	Min	4
	Likely	29
	Max	126
Oct	Min	15
	Likely	99
	Max	114
Nov	Min	6
	Likely	95
	Max	134
Dec	Min	45
	Likely	77
	Max	171

May to October		vs.	June to November	
Increase/decrease yield			Increase/decrease yield	
-0.13 min	May-Jun		0.2 min	Jun-Jul
0.38 likely			0.35 likely	
0.44 max			0.47 max	
0.26 min	Jul-Aug		0.27 min	Aug-Sep
0.31 likely			0.33 likely	
0.35 max			0.45 max	
-0.15 min	Sep-Oct		-0.1 min	Oct-Nov
-0.14 likely			-0.16 likely	
-0.26 max			-0.27 max	

-0.06 waterlogging & erosion

-0.02 hail
0

-0.15 floods & droughts

0.05 sun light

-0.02 temperature

0.02 relative humidity

0.04 air quality

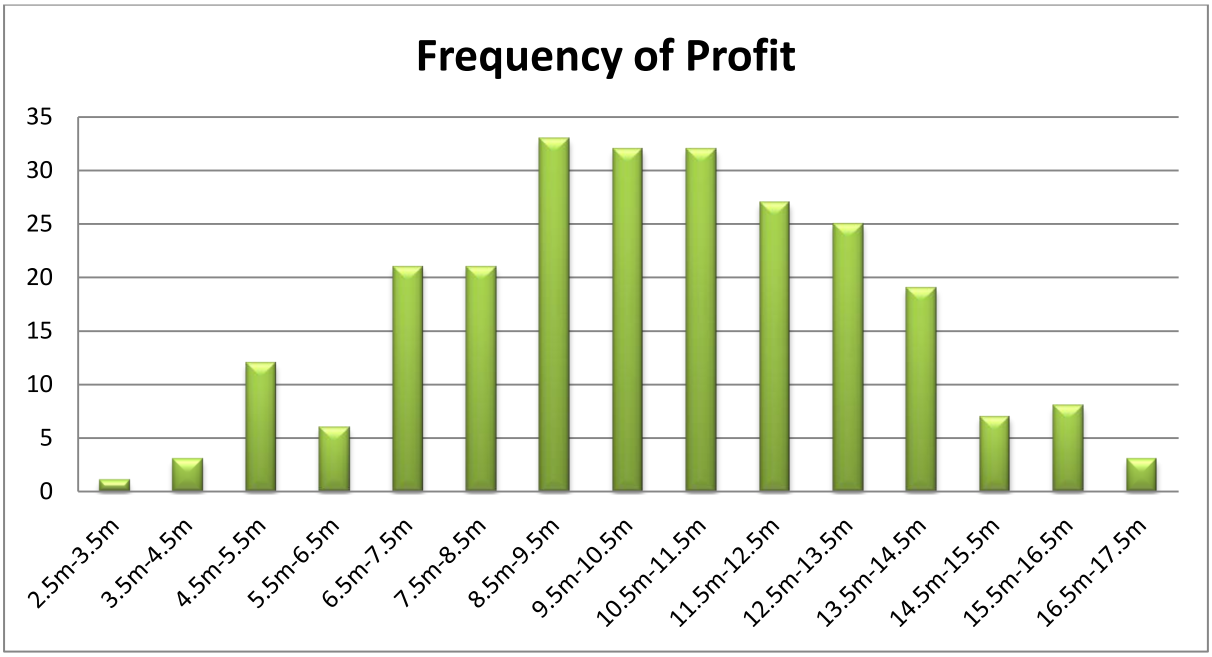
0.01 wind

1.672

WHEAT YIELD

The resulting yields obtained from these Monte Carlo simulations were entered into the Operations Research model to see how it influenced the profit. Two-hundred and fifty iterations were performed and the resulting profits noted. These profits were then grouped into bands with width of one million rand, as can be seen on the x-axis of Figure 24. The y-axis of depicts the number of times the profit fell into a particular group. This can serve as a measure to quantify the risk involved in crop enterprise farming.

Figure 24: Frequency of Profit



The profit obtained from the Operation Research model with yields for sunflower, maize and wheat equal to 1.7, 3.2 and 1.6 tons per hectare respectively, was R8 749 197.00. This profit falls into the group between 8.5 million and 9.5 million rand, which is the group into which most of the iterations fell, as can be seen from Figure 24.

It is clear that 47.2% of the time a profit of between 7.5 million and 11.5 million rand will be realised if the results of the Operations Research model be applied in practise. Alternatively, there is a 17.2% chance to make a profit of less than 7.5 million rand, and a 35.6% chance to make a profit greater than 11.5 million rand.

4.3.2 EOQ Model

The order quantities of the different feed phases for the broiler farming calculated by the inventory control method of economic order quantity (EOQ), was tested against historic data to see whether or not it is feasible to order the calculated quantities. The validation of the EOQ model will now be discussed.

When looking at Table 15, it can be seen that the optimal order quantities are non-integers. In practice however, the order quantities are integer values. For this reason the calculated order quantities have been rounded off to the nearest integer values. The consequences of this are very small; as it only changes the total cost values by a few cents (refer to Table 17).

Table 17: Order Quantities per Cycle Rounded Off

Phase 1		
Q*	=	42
n*	=	9
Supplier 1	=	R 23 776.04
Supplier 3	=	R 75 870.84
Supplier 7	=	R 69 350.84

Phase 2		
Q*	=	60
n*	=	14
Supplier 2	=	R 79 935.03
Supplier 4	=	R 164 708.28
Supplier 8	=	R 68 037.03

Phase 3		
Q*	=	187
n*	=	35
Supplier 2	=	R 749 554.70
Supplier 3	=	R 1 449 588.20
Supplier 5	=	R 932 394.50

Phase 4		
Q*	=	205
n*	=	42
Supplier 6	=	R 1 545 070.25
Supplier 7	=	R 1 580 255.65
Supplier 8	=	R 757 988.15

Phase 5		
Q*	=	169
n*	=	35
Supplier 1	=	R 348 049.18
Supplier 4	=	R 1 273 652.38
Supplier 5	=	R 757 066.78
Supplier 6	=	R 1 048 925.98

The conclusion drawn from this table still is that Supplier 1 should be used to supply feed phases 1 and 5, since it is the least expensive alternative. Similarly Supplier 2 should be used to supply feed phase 3, and Supplier 8 should be used to supply feed phases 2 and 4. This is similar to the results obtained from Table 15. Table 18 shows the revised total annual feed cost.

Table 18: Revised Total Annual Feed Cost

Phase	Total Cost / Phase
1	R 166 432.63
2	R 476 259.31
3	R 5 246 882.95
4	R 5 305 917.11
5	R 2 436 344.51
Total	**R 13 631 836.51**

The following assumptions were made:

- There is no inventory to begin the first cycle with.
- The suppliers are always capable of supplying the ordered quantity of feed.
- The extra feed can be sold back to the supplier at 60% of the purchase price.
- The farm has a storage capacity of 150 tons except for the silos at each broiler house.

Table 19: Division of Storage Space

Phase	Duration (days)	Contribution to Total Duration	Storage Space (kg)
1	3	9%	13 500
2	4	11%	16 500
3	14	40%	60 000
4	8	23%	34 500
5	6	17%	25 500
Total Duration	**35**	**100%**	**150 000**

The first two columns of Table 19 were taken from Table 5. The calculated values in the 'Contribution to Total Duration' column were used to divide the assumed storage space among the different rations. This means that the ration of phase 1 will be allocated 9% of the 150 tons. The same reasoning was followed for the other feed phases.

Table 20 shows an overview of the feed inventory on Groen Goud Landgoed (Pty) Ltd. As mentioned previously there are eight broiler houses on the broiler farm, and each broiler house has two 15 ton silos in which the feed can be stored. This means that there can delivered no more than 240 tons of feed at any one time. The 'Total Phase Demand' column is the sum of the first two columns, and it is also the total phase demand as stated in Table 9. The 'Quantity Ordered' column is calculated by multiplying the optimal order quantity from Table 17 for each phase with a computed integer value. The 'Feed Remaining' column is computed by converting the values of the 'Quantity Ordered' column to kilogram values, and subtracting the values of the 'Total Phase Demand' column.

The amounts under the 'Closing Inventory' column must be smaller or equal to the available storage space allocated to each feed phase, as stated in Table 19. The amounts under the 'Feed Sold Back' column are the difference between the 'Feed Remaining' and 'Closing Inventory' columns.

Table 20: Inventory Control

Cycle 1							
Phase	Beginning Inventory (kg)	Total Phase Requirement (kg)	Total Phase Demand (kg)	Quantity Ordered (ton)	Feed Remaining (kg)	Feed Sold Back to Supplier (ton)	Closing Inventory (kg)
1	0.00	46 436.38	46 436.38	84	37 563.62	24.06	13 500.00
2	0.00	94 400.34	94 400.34	120	25 599.67	9.10	16 500.00
3	0.00	913 245.18	913 245.18	935	21 754.82	0.00	21 754.82
4	0.00	1 092 592.00	1 092 592.00	1 230	137 408.00	102.91	34 500.00
5	0.00	740 520.41	740 520.41	845	104 479.59	78.98	25 500.00

Cycle 2							
Phase	Beginning Inventory (kg)	Phase Demand (kg)	Total Phase Demand (kg)	Quantity Ordered (ton)	Feed Remaining (kg)	Feed Sold Back to Supplier (ton)	Closing Inventory (kg)
1	13 500.00	32 936.38	46 436.38	42	9 063.62	0.00	9 063.62
2	16 500.00	77 900.34	94 400.34	120	42 099.67	25.60	16 500.00
3	21 754.82	891 490.36	913 245.18	935	43 509.64	0.00	43 509.64
4	34 500.00	1 058 092.00	1 092 592.00	1 230	171 908.00	137.41	34 500.00
5	25 500.00	715 020.41	740 520.41	845	129 979.59	104.48	25 500.00

Cycle 3							
Phase	Beginning Inventory (kg)	Phase Demand (kg)	Total Phase Demand (kg)	Quantity Ordered (ton)	Feed Remaining (kg)	Feed Sold Back to Supplier (ton)	Closing Inventory (kg)
1	9 063.62	37 372.76	46 436.38	42	4 627.24	0.00	4 627.24
2	16 500.00	77 900.34	94 400.34	120	42 099.67	25.60	16 500.00
3	43 509.64	869 735.54	913 245.18	935	65 264.46	5.26	60 000.00
4	34 500.00	1 058 092.00	1 092 592.00	1 230	171 908.00	137.41	34 500.00
5	25 500.00	715 020.41	740 520.41	845	129 979.59	104.48	25 500.00

Cycle 4							
Phase	Beginning Inventory (kg)	Phase Demand (kg)	Total Phase Demand (kg)	Quantity Ordered (ton)	Feed Remaining (kg)	Feed Sold Back to Supplier (ton)	Closing Inventory (kg)
1	4 627.24	41 809.14	46 436.38	42	190.86	0.00	190.86
2	16 500.00	77 900.34	94 400.34	120	42 099.67	25.60	16 500.00
3	60 000.00	853 245.18	913 245.18	935	81 754.82	21.75	60 000.00
4	34 500.00	1 058 092.00	1 092 592.00	1 230	171 908.00	137.41	34 500.00
5	25 500.00	715 020.41	740 520.41	845	129 979.59	104.48	25 500.00

Cycle 5							
Phase	Beginning Inventory (kg)	Phase Demand (kg)	Total Phase Demand (kg)	Quantity Ordered (ton)	Feed Remaining (kg)	Feed Sold Back to Supplier (ton)	Closing Inventory (kg)
1	190.86	46 245.52	46 436.38	84	37 754.48	24.25	13 500.00
2	16 500.00	77 900.34	94 400.34	120	42 099.67	25.60	16 500.00
3	60 000.00	853 245.18	913 245.18	935	81 754.82	21.75	60 000.00
4	34 500.00	1 058 092.00	1 092 592.00	1 230	171 908.00	137.41	34 500.00
5	25 500.00	715 020.41	740 520.41	845	129 979.59	104.48	25 500.00

Cycle 6							
Phase	Beginning Inventory (kg)	Phase Demand (kg)	Total Phase Demand (kg)	Quantity Ordered (ton)	Feed Remaining (kg)	Feed Sold Back to Supplier (ton)	Closing Inventory (kg)
1	13 500.00	32 936.38	46 436.38	42	9 063.62	0.00	9 063.62
2	16 500.00	77 900.34	94 400.34	120	42 099.67	25.60	16 500.00
3	60 000.00	853 245.18	913 245.18	935	81 754.82	21.75	60 000.00
4	34 500.00	1 058 092.00	1 092 592.00	1 230	171 908.00	137.41	34 500.00
5	25 500.00	715 020.41	740 520.41	845	129 979.59	104.48	25 500.00

Cycle 7							
Phase	Beginning Inventory (kg)	Phase Demand (kg)	Total Phase Demand (kg)	Quantity Ordered (ton)	Feed Remaining (kg)	Feed Sold Back to Supplier (ton)	Closing Inventory (kg)
1	9 063.62	37 372.76	46 436.38	42	4 627.24	0.00	4 627.24
2	16 500.00	77 900.34	94 400.34	120	42 099.67	25.60	16 500.00
3	60 000.00	853 245.18	913 245.18	935	81 754.82	21.75	60 000.00
4	34 500.00	1 058 092.00	1 092 592.00	1 230	171 908.00	137.41	34 500.00
5	25 500.00	715 020.41	740 520.41	845	129 979.59	104.48	25 500.00

The following table shows the total amount (in tons) of feed sold back to the selected supplier of each specific phase. As mentioned in the assumptions, the selling price is 60% of the purchasing price of the specific suppliers. The last column in Table 21 is simply calculated by multiplying the second and third columns.

Table 21: Annual Income from Feed Sold Back to the Supplier

Phase	Feed Sold Back to Supplier (ton)	Selling Price (R/ton)	Income per Phase
1	48.318	39.12	R 1 890.20
2	162.698	58.50	R 9 517.81
3	92.284	69.30	R 6 395.26
4	927.356	58.50	R 54 250.32
5	705.857	39.12	R 27 613.13
Total			**R 99 666.74**

Groen Goud Landgoed (Pty) Ltd has a lead time of seven days based on historic data. This simply means that it takes seven days for the feed delivery to arrive at the broiler farm on Vaalkoppies, after the order has been placed. The second column in Table 22 shows the number of orders to be made during each phase of the different cycles. The assumption was made that all feed deliveries will arrive the day before it is needed, thereby preventing shortages. The arrival days were calculated by taking into account the 'Cum. Intake' column under the 'In Houses' heading of Table 8, as well as the 'Q*' values listed in Table 17. The days on which the order should be made were simply calculated by subtracting seven days from the arrival days.

Note: The ordering days' values that are less than one are ordered "one minus that day's number" days before the first day of the first cycle; e.g. the first order of feed phase one of the first cycle should be made 1 – (−7) = 1 + 7 = 8 days before day one of the first cycle.

Table 22: Feed Ordering Schedule

Cycle 1 (Day 1 to 52)													
Phase	**Orders**	**1st order**	**1st arrival**	**2nd order**	**2nd arrival**	**3rd order**	**3rd arrival**	**4th order**	**4th arrival**	**5th order**	**5th arrival**	**6th order**	**6th arrival**
1	2	**-7**	0	**-5**	2								
2	2	**-4**	3	**-2**	5								
3	5	**0**	7	**4**	11	**7**	14	**10**	17	**12**	19		
4	6	**14**	21	**15**	22	**17**	24	**18**	25	**20**	27	**21**	28
5	5	**22**	29	**23**	30	**24**	31	**25**	32	**27**	34		

Cycle 2 (Day 53 to 104)													
Phase	**Orders**	**1st order**	**1st arrival**	**2nd order**	**2nd arrival**	**3rd order**	**3rd arrival**	**4th order**	**4th arrival**	**5th order**	**5th arrival**	**6th order**	**6th arrival**
1	1	**45**	52										
2	2	**48**	55	**51**	58								
3	5	**52**	59	**57**	64	**60**	67	**62**	69	**64**	71		
4	6	**66**	73	**68**	75	**69**	76	**71**	78	**72**	79	**73**	80
5	5	**74**	81	**75**	82	**76**	83	**77**	84	**79**	86		

Cycle 3 (Day 105 to 156)													
Phase	**Orders**	**1st order**	**1st arrival**	**2nd order**	**2nd arrival**	**3rd order**	**3rd arrival**	**4th order**	**4th arrival**	**5th order**	**5th arrival**	**6th order**	**6th arrival**
1	1	**97**	104										
2	2	**100**	107	**103**	110								
3	5	**105**	112	**109**	116	**112**	119	**114**	121	**116**	123		
4	6	**118**	125	**120**	127	**121**	128	**123**	130	**124**	131	**125**	132
5	5	**126**	133	**127**	134	**128**	135	**129**	136	**131**	138		

Cycle 4 (Day 157 to 208)													
Phase	**Orders**	**1st order**	**1st arrival**	**2nd order**	**2nd arrival**	**3rd order**	**3rd arrival**	**4th order**	**4th arrival**	**5th order**	**5th arrival**	**6th order**	**6th arrival**
1	1	**149**	156										
2	2	**152**	159	**155**	162								
3	5	**157**	164	**161**	168	**164**	171	**167**	174	**168**	175		
4	6	**170**	177	**172**	179	**173**	180	**175**	182	**176**	183	**177**	184
5	5	**178**	185	**179**	186	**180**	187	**181**	188	**183**	190		

Cycle 5 (Day 209 to 260)													
Phase	**Orders**	**1st order**	**1st arrival**	**2nd order**	**2nd arrival**	**3rd order**	**3rd arrival**	**4th order**	**4th arrival**	**5th order**	**5th arrival**	**6th order**	**6th arrival**
1	2	**201**	208	**203**	210								
2	2	**204**	211	**207**	214								
3	5	**209**	216	**213**	220	**216**	223	**219**	226	**220**	227		
4	6	**222**	229	**224**	231	**225**	232	**227**	234	**228**	235	**229**	236
5	5	**230**	237	**231**	238	**232**	239	**233**	240	**235**	242		

Cycle 6 (Day 261 to 312)													
Phase	**Orders**	**1st order**	**1st arrival**	**2nd order**	**2nd arrival**	**3rd order**	**3rd arrival**	**4th order**	**4th arrival**	**5th order**	**5th arrival**	**6th order**	**6th arrival**
1	1	**253**	260										
2	2	**256**	263	**259**	266								
3	5	**261**	268	**265**	272	**268**	275	**271**	278	**272**	279		
4	6	**274**	281	**276**	283	**277**	284	**279**	286	**280**	287	**281**	288
5	5	**282**	289	**283**	290	**284**	291	**285**	292	**287**	294		

Cycle 7 (Day 313 to 365)														
Phase	**Orders**	**1st order**	**1st arrival**	**2nd order**	**2nd arrival**	**3rd order**	**3rd arrival**	**4th order**	**4th arrival**	**5th order**	**5th arrival**	**6th order**	**6th arrival**
1	1	**305**	312										
2	2	**308**	315	**311**	318								
3	5	**313**	320	**317**	324	**320**	327	**323**	330	**324**	331		
4	6	**326**	333	**328**	335	**329**	336	**331**	338	**332**	339	**333**	340
5	5	**334**	341	**335**	342	**336**	343	**337**	344	**339**	346		

The table below calculates the net annual expenses with regards to the broiler feed. The values in the second column were taken from Table 18, while the values of the third column were taken from the last column of Table 21. To calculate the values in the 'Net Expenses' column, simply subtract the values in the 'Income' column from the 'Expenses' column.

Table 23: Net Annual Expenses

Phase	Expenses	Income	Net Expenses
1	R 166 432.63	R 1 890.20	R 164 542.43
2	R 476 259.31	R 9 517.81	R 466 741.49
3	R 5 246 882.95	R 6 395.26	R 5 240 487.68
4	R 5 305 917.11	R 54 250.32	R 5 251 666.79
5	R 2 436 344.51	R 27 613.13	R 2 408 731.38
Total	**R 13 631 836.51**	**R 99 666.74**	**R 13 532 169.77**

CHAPTER 5

5.1 CONCLUSION

Section 2.3 gives an overview of the general requirements of crop farming in South Africa, while sections 2.4, 2.5 and 2.6 thoroughly discussed the specific requirements, pests and diseases of sunflower, maize and wheat respectively. Section 2.7.1 dealt with the cattle farming, and discussed the breed choice, the breeding method, the breeding cycle, as well as the nutrition and health management of the herd. Section 2.7.2 dealt with the broiler farming, and discussed the heating, lighting, ventilation, water and feed requirements among others.

5.1.1 Crop Enterprise and Cattle Farming

Groen Goud Landgoed (Pty) Ltd comprises of 20 farms, on which there are 144 fields, 29 pastures and 12 planted pastures. The crop enterprise comprises of sunflower, maize and wheat cultivation. The development of the linear programming model has been discussed thoroughly in section 4.1.1. It sets the objective function to maximise the profit made by the crop enterprise and cattle farming.

This model has also been used to determine on which fields each of the crops should be planted, as well as determining how the cattle should be divided amongst the pastures, planted pastures and uncultivated fields to simplify the cattle management.

The Operations Research model's results with regard to the crop enterprise farming have been depicted in Figures 1 to 20 in section 4.2.1, and can be summarised as follows:

- On Beketsrus sunflower is planted on fields 1, 5 and 6, while maize and wheat are planted on fields 2 and 3 respectively. Field 4 is uncultivated.
- On Bullock sunflower is planted on field 7, maize is planted on fields 8 and 10, and wheat is planted on field 9.
- On Danielsfontein sunflower is planted on fields 11, 12 and 13, while wheat is planted on field 14.
- On Erfdeel maize is planted on field 18, while wheat is planted on fields 15, 16, 17, 19, 22 and 24. Fields 20, 21, 23, 25, 26 and 27 are uncultivated.
- On Goodhope wheat is planted on fields 29 and 30, while field 28 is uncultivated.
- On Mike sunflower is planted on fields 31 and 34, while wheat is planted on field 32. Field 33 is uncultivated.
- On Pyrmont wheat is planted on fields 35, 36 and 37.
- On Vaalkoppies sunflower is planted on fields 42 and 51, maize is planted on fields 40, 45 and 52, and wheat is planted on fields 38, 39, 43, 44, 48 and 50. Fields 41, 46, 47, 49, 53 and 54 are uncultivated.
- On Vlakpan maize is planted on field 55, while wheat is planted on field 58. Fields 56 and 57 are uncultivated.
- On Vlakvallei sunflower is planted on field 61, maize is planted on field 59, and wheat is planted on fields 63, 65, 66, 67 and 68. Fields 60, 62 and 64 are uncultivated.

- On Yarima sunflower is planted on fields 70, 75, 82 and 84, maize is planted on fields 71, 74, 77 and 79, and wheat is planted on fields 69, 72, 73, 76, 78, 80 and 81. Field 83 is uncultivated.
- On Dankbaar sunflower is planted on field 85 and maize is planted on field 88. Fields 86 and 87 are uncultivated.
- On Dorpslande maize is planted on fields 89, 90, 92, 94, 95 and 96, while wheat is planted on fields 91 and 93. Fields 97 and 98 are uncultivated.
- On Langverwacht maize is planted on fields 105, 108 and 110, and wheat is planted on fields 109 and 111. Fields 99 to 104, 106 and 107 are uncultivated.
- On Nuldesperandum maize is planted on fields 112 and 113.
- On Olivia maize is planted on fields 115 and 116, while wheat is planted on field 114. Field 117 is uncultivated.
- On Patmos wheat is planted on fields 118 and 119.
- On Rooikraal sunflower is planted on fields 126 and 129, maize is planted on fields 123 and 124, and wheat is planted on fields 120, 122, 125 and 128. Fields 121 and 127 are uncultivated.
- On Vyfhoek maize is planted on fields 130, 132 and 135, while wheat is planted on fields 131, 133 and 137. Fields 134 and 136 are uncultivated.
- On Waverley sunflower is planted on fields 143, maize is planted on fields 138 and 144, and wheat is planted on fields 140 and 142. Fields 139 and 141 are uncultivated.

The fields planted with sunflower covers a total area of 1 049.85 hectares. The fields cultivated with maize covers a total area of 1 296.92 hectares, and the fields planted with wheat covers a total area of 2 176.07 hectares. The uncultivated fields cover a total area of 945.25 hectares.

The cattle were divided into smaller herds to simplify the cattle management. The optimisation model's results with regard to these divisions are summarised in the tables below. Table 24 shows the number of cattle that should graze on each pasture, while Table 25 shows the number of cattle that should graze on each planted pasture. Table 26 shows the number of cattle that should graze on each of the uncultivated fields, which were identified above.

Table 24: Cattle Grazing on Pastures

Cattle Grazing on Pastures			
Pasture	**Number of Cattle Allocated**	**Pasture**	**Number of Cattle Allocated**
1	12	**11**	16
2	5	**12**	3
3	14	**13**	3
4	7	**14**	45
5	2	**15**	14
6	3	**16**	3
7	9	**17**	24
8	2	**18**	17
9	5	**19**	14
10	2	**20**	7

Cattle Grazing on Pastures			
Pasture	**Number of Cattle Allocated**	**Pasture**	**Number of Cattle Allocated**
21	19	**26**	3
22	24	**27**	8
23	31	**28**	10
24	6	**29**	6
25	2		

Table 25: Cattle Grazing on Planted Pastures

Cattle Grazing on Planted Pastures	
Planted Pasture	**Number of Cattle Allocated**
1	7
2	1
3	2
4	5
5	2
6	8
7	11
8	50
9	8
10	8
11	10
12	21

Table 26: Cattle Grazing on Uncultivated Fields

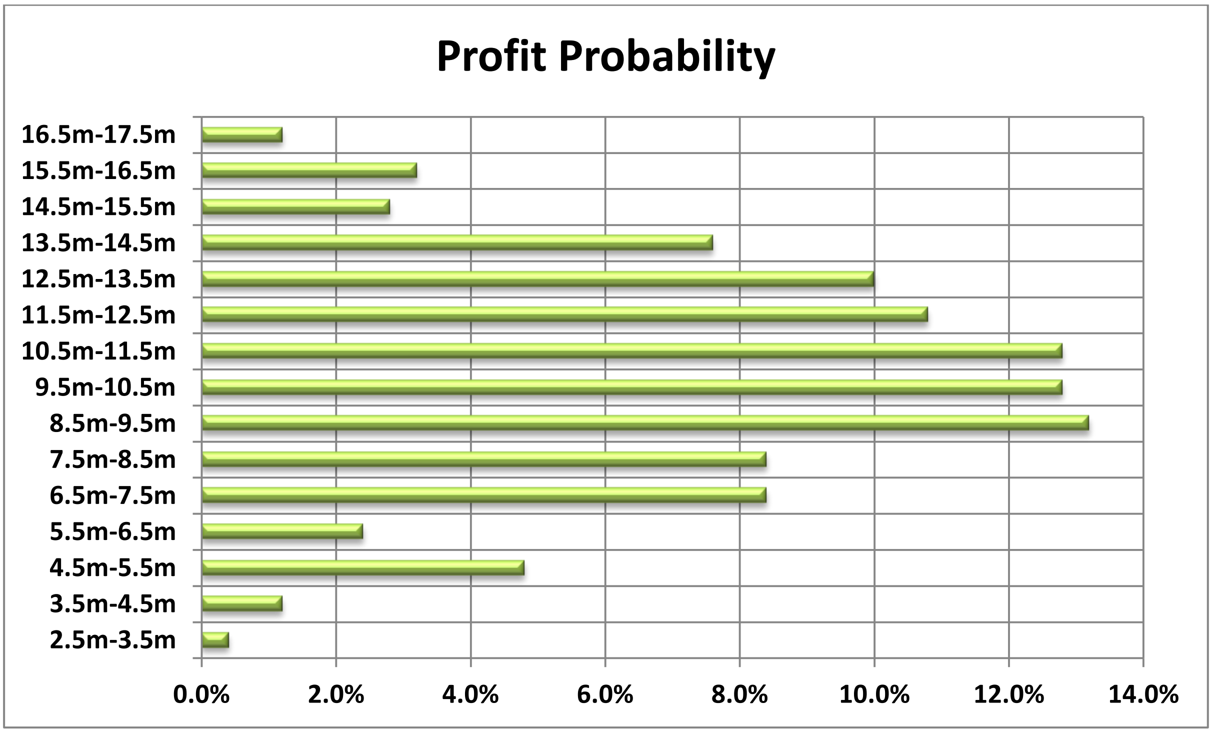
Cattle Grazing on Uncultivated Fields							
Uncultivated Field	**Number of Cattle**	**Uncultivated Field**	**Number of Cattle**	**Uncultivated Field**	**Number of Cattle**	**Uncultivated Field**	**Number of Cattle**
4	2	**46**	2	**83**	3	**104**	5
20	4	**47**	5	**86**	4	**106**	4
21	6	**49**	6	**87**	3	**107**	3
23	4	**53**	3	**97**	2	**117**	2
25	5	**54**	9	**98**	4	**121**	3
26	5	**56**	5	**99**	6	**127**	4
27	3	**57**	5	**100**	5	**134**	2
28	5	**60**	5	**101**	3	**136**	4
33	5	**62**	6	**102**	5	**139**	6
41	4	**64**	5	**103**	3	**141**	3

The current herd consist of 723 cows and 27 registered bulls. The cattle allocated to pastures, planted pastures and uncultivated fields in Tables 24, 25 and 26 respectively, accounts for 82.27% of the whole herd. The optimisation model's results tell one that the remaining 133 cattle should be slaughtered for their meat. It was assumed that all of the cattle to be slaughtered are cows.

Monte Carlo models were developed to analyse how the rainfall and other environmental factors, as discussed in section 2.2, would influence the yields of sunflower, maize and wheat. These models were discussed thoroughly in section 4.3.1. The resulting yields were entered into the Operations Research model to see how it would influence the profit, as calculated by the objective function. Two-hundred and fifty iterations were performed and the yields and results noted.

The resulting profits were grouped into bands with width of one million rand; starting at 2.5 million rand up to 17.5 million rand. From Figure 25 it is clear that there is a 47.2% chance to realise a profit between 7.5 million and 11.5 million rand if the results of the Operations Research model are applied in practise. Alternatively, there is a 17.2% chance to make a profit of less than 7.5 million rand, and a 35.6% chance to make a profit greater than 11.5 million rand.

Figure 25: Profit Probability



The profit obtained from the Operation Research model with yields for sunflower, maize and wheat equal to 1.7, 3.2 and 1.6 tons per hectare respectively, was R8 749 197.00. This profit falls into the group between 8.5 million and 9.5 million rand, which is the group with the greatest probability (13.2%) of realisation. Thus it can be concluded that the Operations Research model's results are feasible.

The annual profit figures in Table 28 for 2007 to 2011 are based on Groen Goud Landgoed (Pty) Ltd's historic data. The profit figures for 2007 to 2011 were calculated by adding the net profit of each crop to the net profit of the cattle farming. Table 27 shows how 2011's profit figure was computed.

Table 27: Calculation of Profit

Sunflower	
Income	R 5 291 412.60
Expenses	R 2 996 444.40
Net Profit	**R 2 294 968.20**
Maize	
Income	R 4 134 682.44
Expenses	R 3 238 346.54
Net Profit	**R 896 335.90**
Wheat	
Income	R 7 418 481.48
Expenses	R 5 350 725.90
Net Profit	**R 2 067 755.58**
Cattle	
Income	R 3 023 547.00
Expenses	R 667 727.00
Net Profit	**R 2 355 820.00**

The annual profit for 2012 with regard to the crop enterprise and cattle farming is R8 749 197.00. This is R2 034 183.92 (or 30.29%) more than the average annual profits from the crop enterprise and cattle farming of the previous five years. Compared to 2011 there has been an increase of approximately 14.90% in the profit from the crop enterprise and cattle farming.

Table 28: Comparison of Annual Profits

Year	Profit
2012	**R 8 749 197.00**
2011	R 7 614 879.68
2010	R 8 197 473.11
2009	R 5 392 634.55
2008	R 5 394 213.26
2007	R 6 975 864.82

5.1.2 Broiler Farming

The developed EOQ model required the annual demand per feed phase to be calculated. These calculations were done in section 4.1.2, and took into account the mortality rate of 0.1443% per day among the broilers. The results are summarised in Table 29. Table 30 summarises the preliminary and final results of the EOQ model.

Table 29: Annual Demand

Phase	Ration Description	Annual Demand (kg)	Annual Demand (ton)
1	Pre-Starter	325 054.660	326
2	Starter	660 802.345	661
3	Grower	6 392 716.260	6 393
4	Finisher	7 648 144.021	7 649
5	Post-Finisher	5 183 642.842	5 184

Table 30: Optimal Order Quantities

Phase	Preliminary EOQ (ton)	Final EOQ (ton)
1	42.268	42
2	60.187	60
3	187.176	187
4	204.739	205
5	168.551	169

The assumption was made that the broiler farm on Vaalkoppies has storage capacity of 150 tons except for the silos at the broiler houses. This storage capacity has been divided among the feed phases, and is summarised in the table below.

Table 31: Extra Storage Space

Phase	Storage Space (kg)
1	13 500
2	16 500
3	60 000
4	34 500
5	25 500
Total	**150 000**

The EOQ model was also used to determine the ordering schedule for each feed phase. The assumption was made that the orders are delivered the day before it is needed in order to avoid shortages. Tables 32 to 36 summarise the ordering schedule as it were tabulated in Table 22 according to feed phase.

Note: The negative ordering days' values are ordered "one minus that day's number" days before the first day of the first cycle; e.g. the first order of feed phase one of the first cycle should be made 1 – (−7) = 1 + 7 = 8 days before day one of the first cycle.

Table 32: Ordering Schedule of Feed Phase 1

Phase 1	
Cycle	Order on Day
1	-7
1	-5
2	45
3	97
4	149
5	201
5	203
6	253
7	305

Table 33: Ordering Schedule of Feed Phase 2

Phase 2			
Cycle	Order on Day	Cycle	Order on Day
1	-4	4	155
1	-2	5	204
2	48	5	207
2	51	6	256
3	100	6	259
3	103	7	308
4	152	7	311

Table 34: Ordering Schedule of Feed Phase 3

Phase 3					
Cycle	Order on Day	Cycle	Order on Day	Cycle	Order on Day
1	0	3	112	5	220
1	4	3	114	6	261
1	7	3	116	6	265
1	10	4	157	6	268
1	12	4	161	6	271
2	52	4	164	6	272
2	57	4	167	7	313
2	60	4	168	7	317
2	62	5	209	7	320
2	64	5	213	7	323
3	105	5	216	7	324
3	109	5	219		

Table 35: Ordering Schedule of Feed Phase 4

Phase 4							
Cycle	**Order on Day**	**Cycle**	**Order on Day**	**Cycle**	**Order on Day**	**Cycle**	**Order on Day**
1	14	2	73	4	176	6	277
1	15	3	118	4	177	6	279
1	17	3	120	5	222	6	280
1	18	3	121	5	224	6	281
1	20	3	123	5	225	7	326
1	21	3	124	5	227	7	328
2	66	3	125	5	228	7	329
2	68	4	170	5	229	7	331
2	69	4	172	6	274	7	332
2	71	4	173	6	276	7	333
2	72	4	175				

Table 36: Ordering Schedule of Feed Phase 5

Phase 5					
Cycle	**Order on Day**	**Cycle**	**Order on Day**	**Cycle**	**Order on Day**
1	22	3	128	5	235
1	23	3	129	6	282
1	24	3	131	6	283
1	25	4	178	6	284
1	27	4	179	6	285
2	74	4	180	6	287
2	75	4	181	7	334
2	76	4	183	7	335
2	77	5	230	7	336
2	79	5	231	7	337
3	126	5	232	7	339
3	127	5	233		

From Table 32 it is clear that there should be made 9 orders of 42 tons each of pre-starter during a one year period. It can be seen from Table 33 that there should be made 14 orders of 60 tons each of starter during a one year period. From Table 34 it is evident that 35 orders of 187 tons each of grower should be made during a one year period. It can be seen from Table 35 that 42 orders of 205 tons each of finisher should be made during a one year period. From Table 36 it is clear that there should be made 35 orders of 169 tons each of post-finisher during a one year period.

From the above findings it is clear that the ration demand in each phase has been met, with no exceptions. Thus, the conclusion can be drawn that the problem with regards to determining what quantity and when to order each ration, as stated in section 1.2, has been solved. After the EOQ model has been developed and validated, the solution was found feasible.

The annual net expenses with regard to the broiler feed is R13 532 169.77. This is R2 222 277.76 (or 14.11%) less than the average feed expenses of the previous four years. A better comparison might be made when one compares the total expenses of the broiler feed when the optimal order quantities are ordered. When this is done, it is found that a saving of R2 122 611.03 (or 13.47%) has realised compared to the average of the previous four years' annual expenses.

Table 37: Comparison of Annual Feed Expenses

Year	Net Expenses	Total Expenses
2012	**R 13 532 169.77**	**R 13 631 836.51**
2011	R 15 378 707.00	R 15 378 707.00
2010	R 16 449 066.00	R 16 449 066.00
2009	R 15 671 822.50	R 15 671 822.50
2008	R 15 518 194.64	R 15 518 194.64

Possible future work may include changing the Operations Research model in such a way that not only the crops' yields are variable, but also the input cost per crop, as well as the selling price of each crop. This can possibly lead to very different results than those obtained from the current model as it was noted in this document.

BIBLIOGRAPHY

'Cropping Decisions'. 2004, April, viewed 20 August 2012, <http://www.agriculture.gov.sk.ca/Default.aspx?DN=71987997-30df-425c-86da-1466e8732faa>.

'Growing sunflower'. 2011, *Farmer's Weekly*, 14 October, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=10701&h=Growing-sunflower>.

'Industrial agriculture'. n.d., viewed 20 August 2012, <http://en.wikipedia.org/wiki/Industrial_agriculture>.

'Industrial Engineering'. n.d., viewed 20 August 2012, <http://www.buzzle.com/articles/types-of-engineers-and-what-they-do.html#IndustrialEngineer>.

'South Africa's Farming Sectors'. 2008, *South African Info*, October, viewed 20 August 2012, <http://www.southafrica.info/business/economy/sectors/542547.htm>.

'South African Agriculture'. 2008, *South African Info*, October, viewed 20 August 2012, <http://www. southafrica.info/business/economy/sectors/agricultural-sector.htm>.

Aviagen Limited. 2002, *Broiler management manual*, Author, Newbridge.

Baldy, C. & Stigter, C.J. n.d., *Agrometeorology of multiple cropping in warm climates*, viewed 27 April 2012, <http://books.google.co.za/books?id=D4Ic1lkQJAMC&pg=PA204&lpg=PA204&dq=climatological+factors+in+agriculture&source=bl&ots=3AmqZW2tYH&sig=3fwLnGaCkOthAnbtBWKuULucCDA&hl=en&sa=X&ei=oW6aT_SAJYWKhQegiJHiDg&sqi=2&ved=0CGsQ6AEwCA#v=onepage&q=climatological%20factors%20in%20agriculture&f=false>.

Bareja, B.G. 2011, *Climatic factors promote or inhibit plant growth and development*, viewed 27 April 2012, <http://www.cropsreview.com/climatic-factors.html>.

Bergh, L. 2008, *Breeding season for beef cattle in South Africa*, viewed 27 April 2012, <http://www.charolais.co.za/files/breedingseason.pdf>.

Botzen, W.J.W., Bouwer, L.M. & van den Bergh, J.C.J.M. 2009, *Climate change and hailstorm damage: empirical and implications for agriculture and insurance*, Vrije Universiteit, Amsterdam.

Boyer, J.S. n.d., *Drought decision-making*, viewed 20 August 2012, <http://jxb.oxfordjournals.org/content/61/13/3493.full>.

Coleman, A. 2011a, 'Precision farming removes guesswork', *Farmer's Weekly*, 10 June, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=6491&h=Precisionfarmingremovesguesswork>.

Coleman, A. 2011b, 'No place for pampered stud animals in beef cattle production', *Farmer's Weekly*, 22 July, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=6835&h=No-place-for-pampered-stud-animals-in-beef-cattle-production>.

Coleman, A. 2011c, 'Work on profit per hectare', *Farmer's Weekly*, 14 October, viewed 28 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=10668&h=Work-on-profit-per-hectare>.

Dessens, J.D. 1995, 'Severe convective weather in the context of nighttime global warming', *Geophysical Research Letters*, vol. 22, no. 10, pp. 1241-1244.

Du Plessis, H. 2012, 'Oordeelkundige beheer van valsstinkbesies op sonneblomme – hierdie besies se skade is nie vals nie!', *SA Graan*, January, p.26-27.

Du Plessis, J. 2003, *Maize production*, Department of Agriculture, Pretoria.

Eagleman, J.R. 1985, *Meteorology: the atmosphere in action*, Wadsworth Publishing Co., Belmont.

Freking, B.M. 2000, *Heifer management*, Beef Progress Report – 1, Kerr Centre for Sustainable Agriculture, South Dakota.

Hoffman, T. & Ashwell, A. n.d., *Provincial fact sheet: land degradation Free State*, Salty Print, Bloemfontein.

Huber, M. n.d. *How to grow wheat in Southern Africa*, viewed 28 April 2012, <http://www.ehow.com/m/how_6537377_grow-wheat-southern-africa.html>.

IPCC (Inter-governmental Panel on Climate Change). 1995, *IPCC second assessment: climate change 1995*, World Meteorological Organization, Geneva.

Joubert, R. 2011a, 'Start early for healthy heifers', *Farmer's Weekly*, 14 October, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=10676&h=Start-early-for-healthy-heifers>.

Joubert, R. 2011b, 'Managing a ley pasture for best returns', *Farmer's Weekly*, 11 November, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=10892&h=Managing-a-ley-pasture-for-best-returns>.

Khula Sizwe. n.d., *Broiler project (South Africa)*, viewed 28 April 2012, <http://www.khula-sizwe.com/?q=broiler>.

Kirtsen, F. n.d., *Riglyne vir die beheer van nagmuise in aangeplante mielie lande*, LNR-NIPB, Pretoria.

Kleyn, R. 2009, *Feeding broiler chickens for profit*, Spesfeed (Pty) Ltd, Johannesburg.

Lovel, H. 2011, 'Are your soils bleeding boron?', *Farmer's Weekly*, 21 October, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=10729&h=Are-your-soils-bleeding-boron>.

Miller, M.A. *et al*. 1990, 'Computers and Electronics in Agriculture', *ScienceDirect*, vol. 5, no. 1, pp. 31–45.

Miller, G.T. Jr. 2001, *Environmental science: working with the earth*, 8th ed., Brooks/Cole, Pacific Grove, CA.

Murray, J.N. n.d., *The damaging effects of hail*, viewed 27 April 2012, <http://ezinearticles.com/?The-Damaging-Effects-of-Hail&id=5323265>.

Oldeman, L.R., Kakkeling, R.T.A. & Sombroek, W.G. 1990, *World map of the status of human-induced soil degradation: an explanatory note*, International Soil Reference Information Centre, Nairobi.

Pannar Seed. n.d., *Wheat production guide*, Author, Greytown.

Pearson, C.H.O. 1968, 'Farm planning as the basis for peak productivity', *Proceedings of the South African Sugar Technologists' Association*, April, pp. 183-185.

Phillips, L. 2011a, 'A strategy for consistently high maize yields', *Farmer's Weekly*, 13 May, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=6303&h=A-strategy-for-consistently-high-maize-yields>.

Phillips, L. 2011b, 'Save time by auctioning your livestock online', *Farmer's Weekly*, 12 August, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=10301&h=Save-time-by-auctioning -your-livestock-online>.

Phillips, L. 2011c, 'Using nature to get the best from cattle', *Farmer's Weekly*, 4 November, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=10837&h=Using-nature-to-get-the-best-from-cattle>.

Phillips, L. 2012, 'Optimal management in big beef enterprises', *Farmer's Weekly*, 2 March, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=15502&h=Optimal-management-in-a-big-beef-enterprise>.

Salomon, L. 2011, 'Om te plant... en hoe om te plant? Dit is die grondboonvraag', *SA Graan*, October, p. 56-59.

Schoeman, A. 2011, 'Kyk uit vir Diplodia kopvrot by mielies', *SA Graan*, December, p. 37.

Sivakumar, M.V.K. n.d, *Impacts of natural disasters in agriculture: an overview*, World Meteorological Organization, Geneva.

Sivakumar, M.V.K. & Valentin, C. 1997, *Agroecological zones and the assessment of crop production potential*, The Royal Society, Great Britain.

South African Poultry Association (SAPA). n.d., *The broiler industry*, Paper no. 9 on Broilers and Eggs, Author, Johannesburg.

Southwood, W. 2011, 'An elite Angus cow for 2011', *Farmer's Weekly*, 23 September, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=10566&h=An-elite-Angus-cow-for-2011>.

Statistics South Africa (StatsSA). 2009, *Agricultural contribution to GDP*, viewed 28 April 2012, <http://www.statssa.gov.za/publications/Bulletin/BulletinSeptember2009.pdf>.

Total SA. 2006, *A study on a disaster risk management plan for the South African agricultural sector*, Van Schaik, Pretoria.

Van Rooyen, L. 2011, 'A risky business, but it can be done', *Farmer's Weekly*, 2 December, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=10979&h=A-risky-business,-but-it-can-be-done>.

Verdoorn, G.H. 2011, 'Gee nagmuise 'n knou met nuwe denke', *SA Graan*, September, p. 66-69.

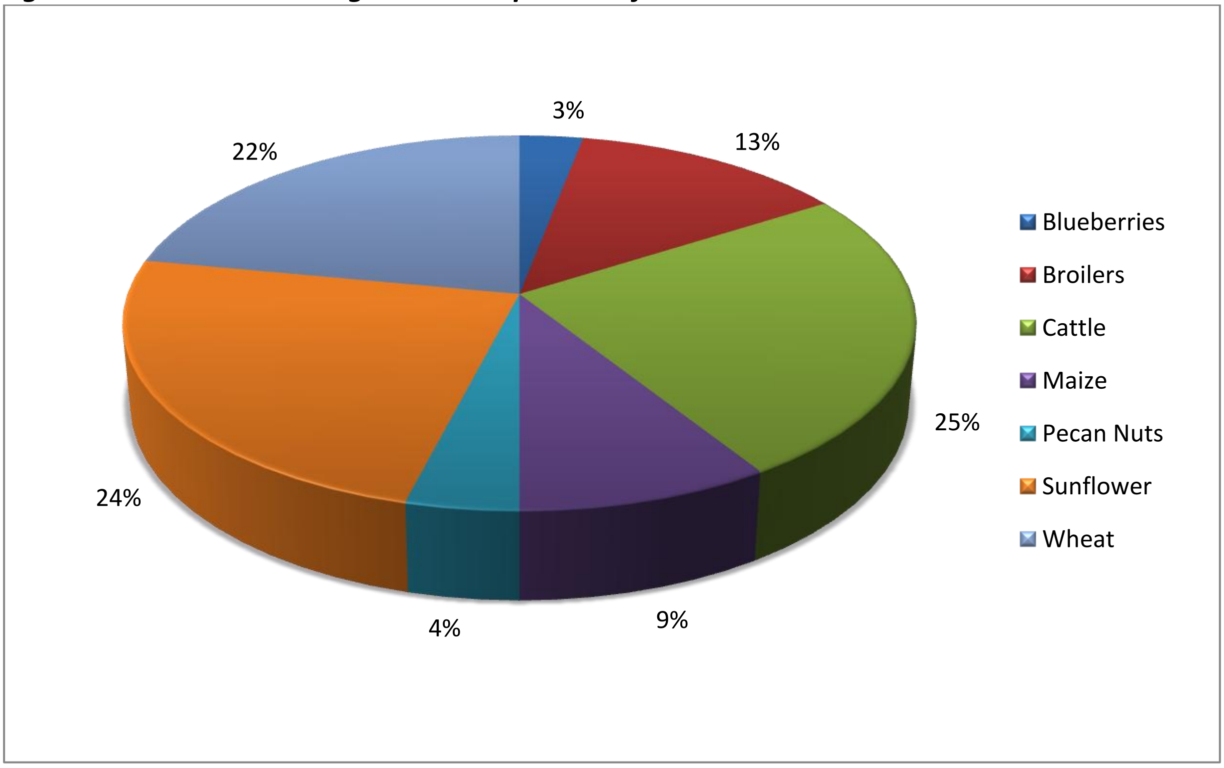
Walne, M. 2002, *Broiler production – get it right from the start*, viewed 27 April 2012, <http://www.sapoultry.co.za/pdf/BROILER%20PRODUCTION%20-%20MIKE%20WALNE.pdf>.

Zietsman, J. 2012, 'High stocking rate on minimum veld', *Farmer's Weekly*, 3 February, viewed 27 April 2012, <http://www.farmersweekly.co.za/article.aspx?id=14648&h=High-Stocking-rate-on-minimum-veld>.

APPENDICES

APPENDIX A

Figure 26: 2011 Gross Margin Incomes per Ramification



APPENDIX B

Map of Beketsrus

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 27: Beketsrus

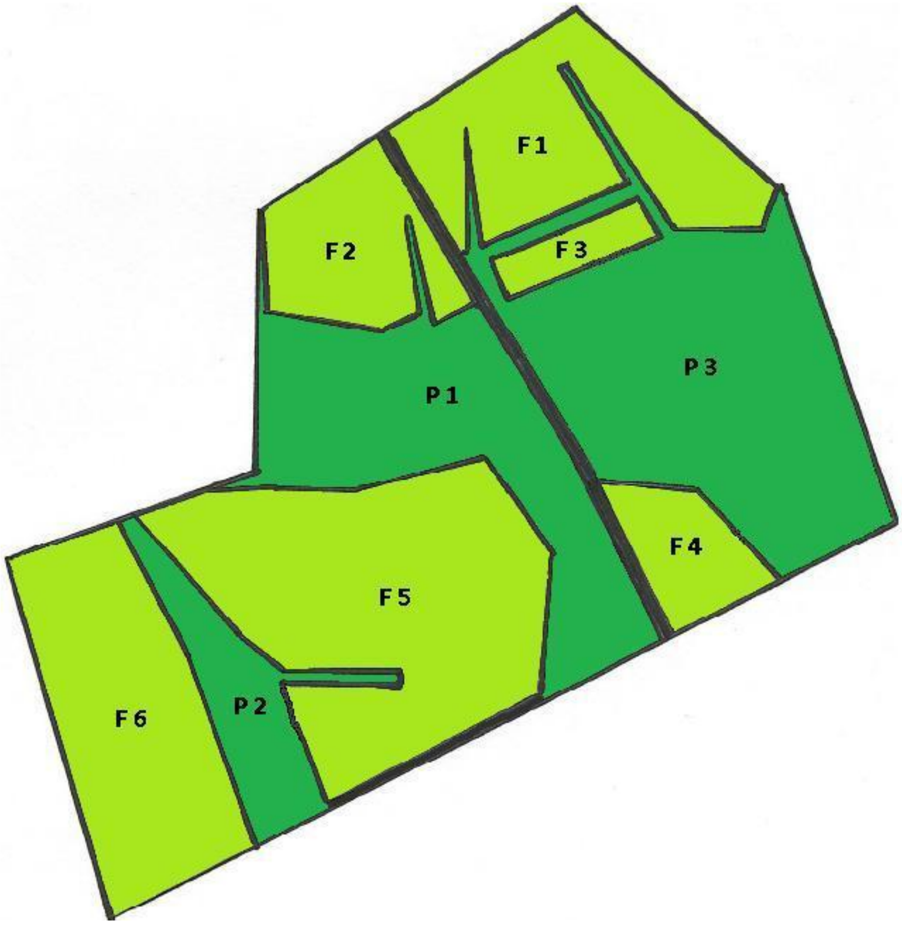


Table 38: Division of Beketsrus' Fields, Pastures and Planted Pastures

Beketsrus	
Field	**Area (ha)**
1	50.65
2	25.33
3	7.52
4	14.34
5	83.00
6	51.70
Pasture	**Area (ha)**
1	63.00
2	26.50
3	74.00

Map of Bullock

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 28: Bullock

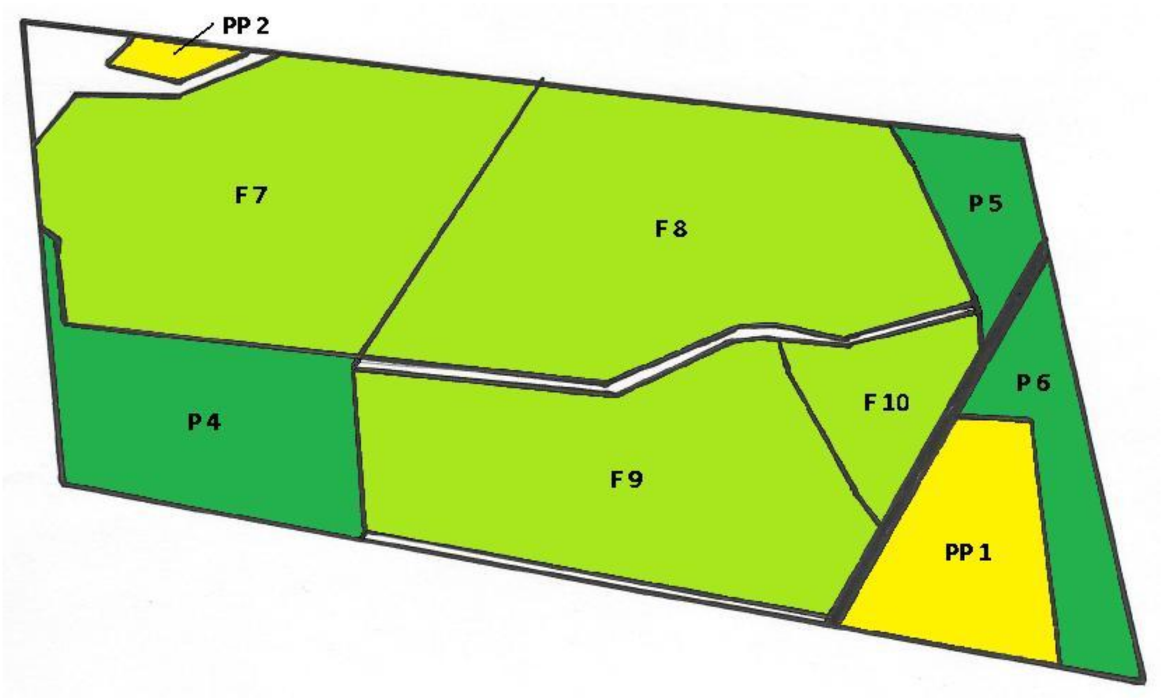


Table 39: Division of Bullock's Fields, Pastures and Planted Pastures

Bullock	
Field	**Area (ha)**
7	65.10
8	74.80
9	60.60
10	12.70
Pasture	**Area (ha)**
4	36.00
5	11.00
6	18.00
Planted Pastures	**Area (ha)**
1	21.80
2	2.25

Map of Danielsfontein

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 29: Danielsfontein

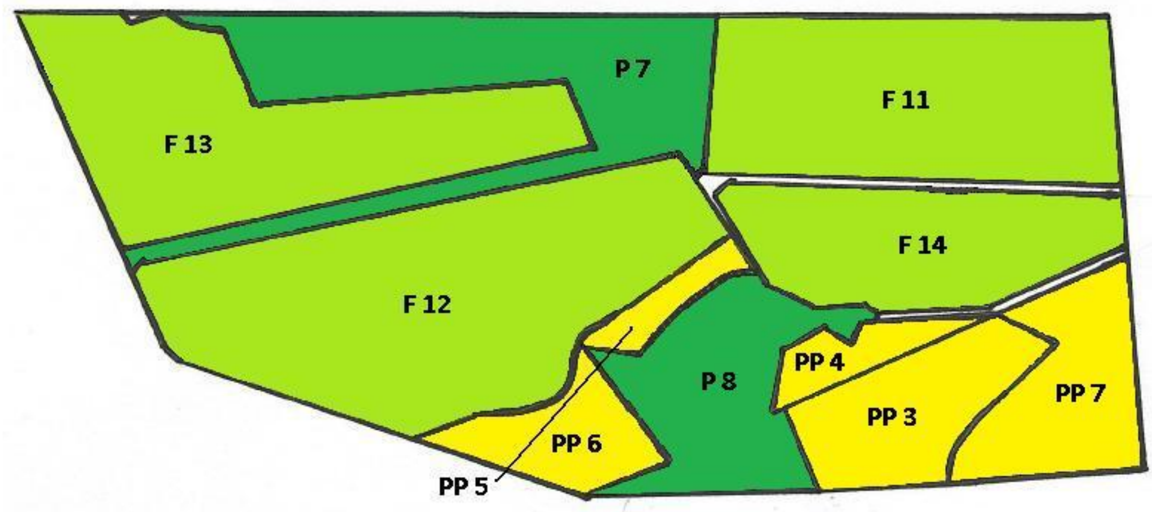


Table 40: Division of Danielsfontein's Fields, Pastures and Planted Pastures

Danielsfontein	
Field	**Area (ha)**
11	67.30
12	81.20
13	69.00
14	42.40
Pasture	**Area (ha)**
7	49.32
8	10.60
Planted Pastures	**Area (ha)**
3	6.48
4	16.94
5	8.60
6	26.70
7	34.11

Map of Erfdeel

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 30: Erfdeel

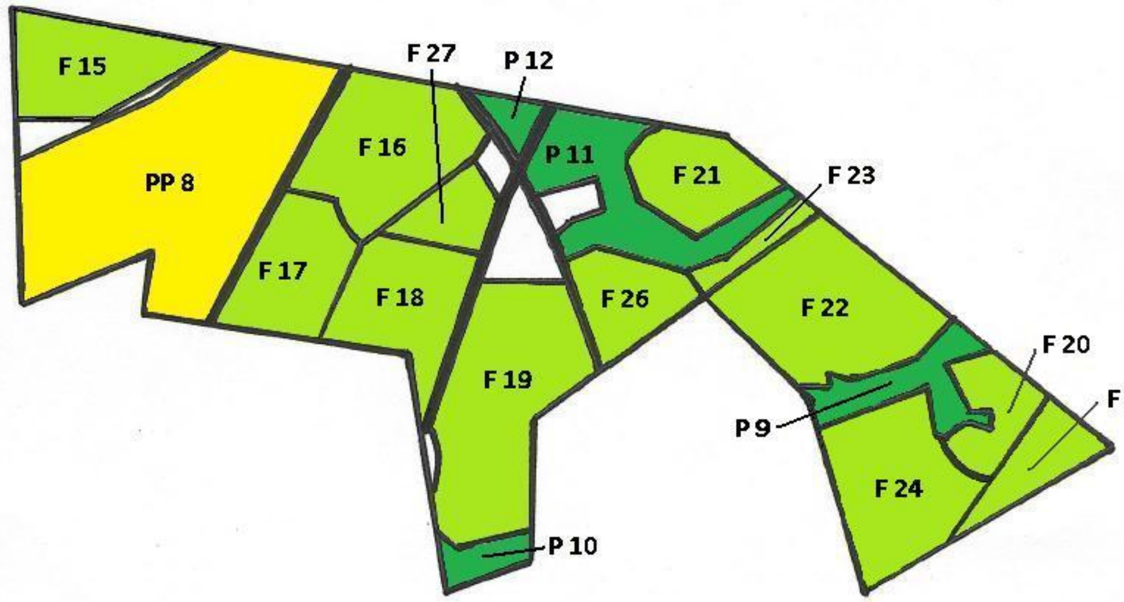


Table 41: Division of Erfdeel's Fields, Pastures and Planted Pastures

Erfdeel	
Field	**Area (ha)**
15	47.20
16	61.90
17	39.70
18	45.50
19	89.10
20	20.75
21	31.60
22	62.50
23	21.80
24	57.95
25	27.70
26	26.00
27	17.60
Pasture	**Area (ha)**
9	29.83
10	12.12
11	81.26
12	18.40
Planted Pastures	**Area (ha)**
8	150.50

Map of Goodhope

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 31: Goodhope

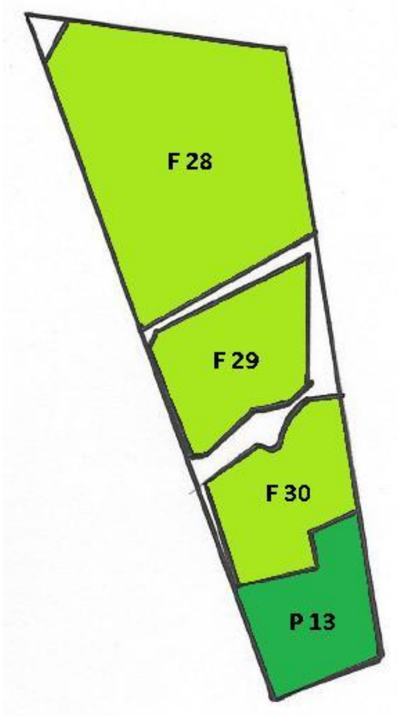


Table 42: Division of Goodhope's Fields, Pastures and Planted Pastures

Goodhope	
Field	**Area (ha)**
28	29.10
29	10.10
30	9.10
Pasture	**Area (ha)**
13	15.50

Map of Mike

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 32: Mike

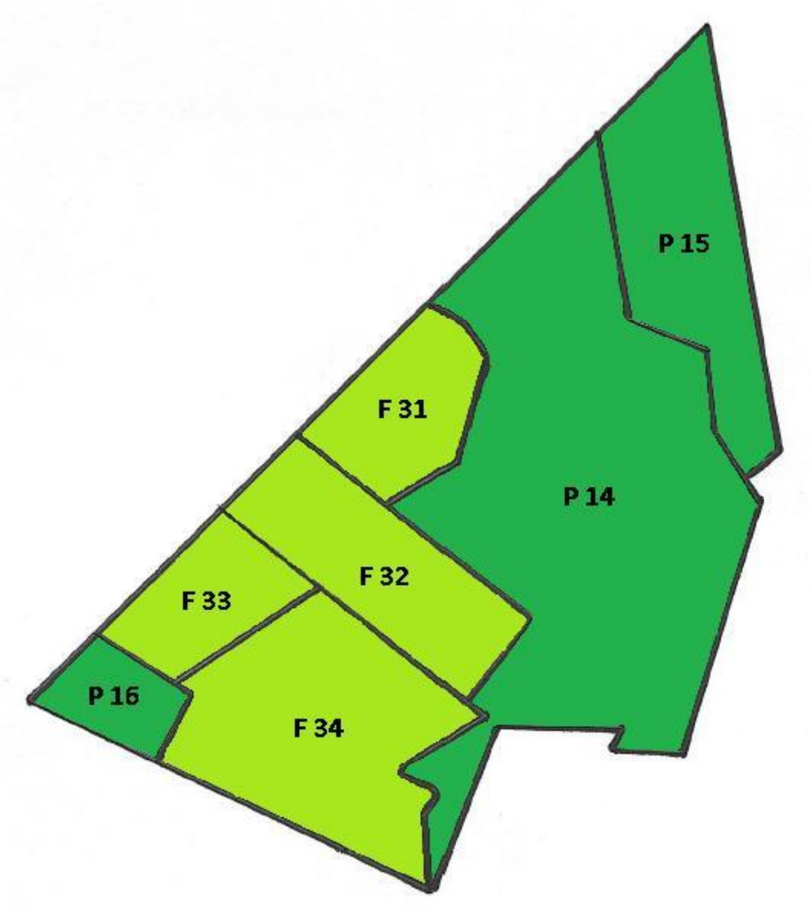


Table 43: Division of Mike's Fields, Pastures and Planted Pastures

Mike	
Field	**Area (ha)**
31	35.20
32	53.80
33	29.80
34	88.60
Pasture	**Area (ha)**
14	226.71
15	71.56
16	18.48

Map of Pyrmont

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 33: Pyrmont

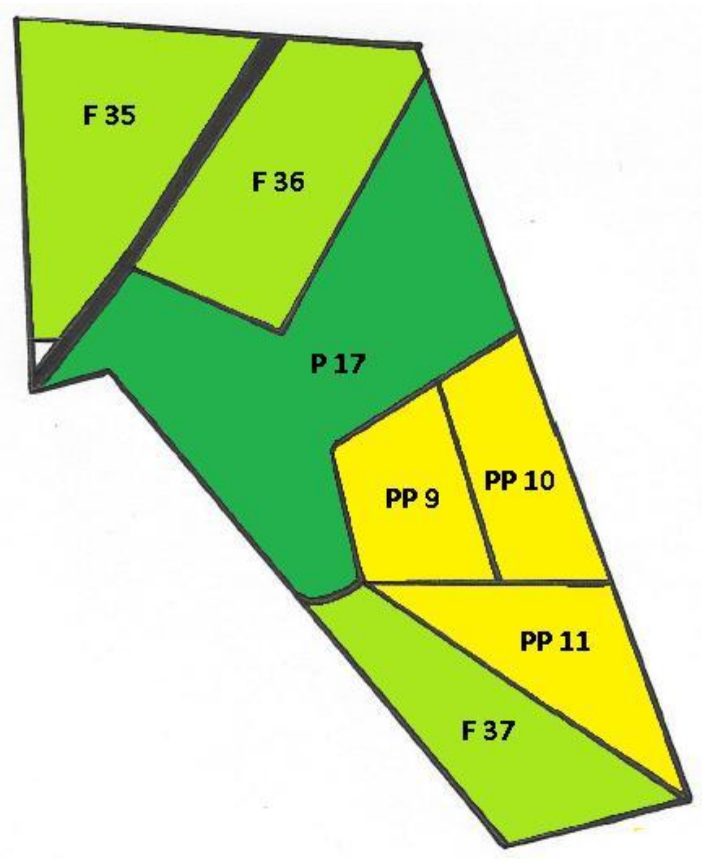


Table 44: Division of Pyrmont's Fields, Pastures and Planted Pastures

Pyrmont	
Field	**Area (ha)**
35	49.88
36	47.88
37	37.95
Pasture	**Area (ha)**
17	121.00
Planted Pastures	**Area (ha)**
9	25.70
10	24.50
11	31.60

Map of Vaalkoppies

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 34: Vaalkoppies

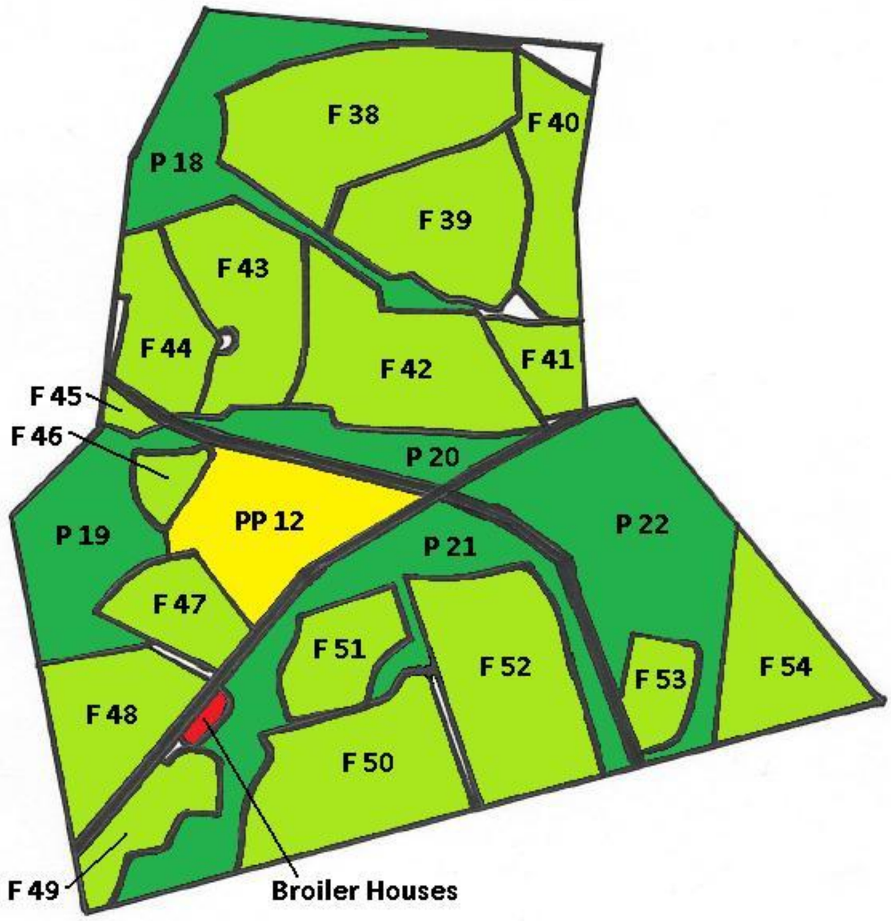


Table 45: Division of Vaalkoppies' Fields, Pastures and Planted Pastures

Vaalkoppies	
Field	**Area (ha)**
38	84.90
39	61.10
40	35.80
41	20.00
42	80.50
43	61.30
44	36.40
45	4.30
46	14.20
47	29.70
48	49.50
49	31.60
50	61.70
51	31.40
52	73.90
53	19.10
54	45.80
Pasture	**Area (ha)**
18	85.00
19	70.04
20	38.10
21	99.00
22	122.86
Planted Pastures	**Area (ha)**
12	65.00

Map of Vlakpan

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 35: Vlakpan

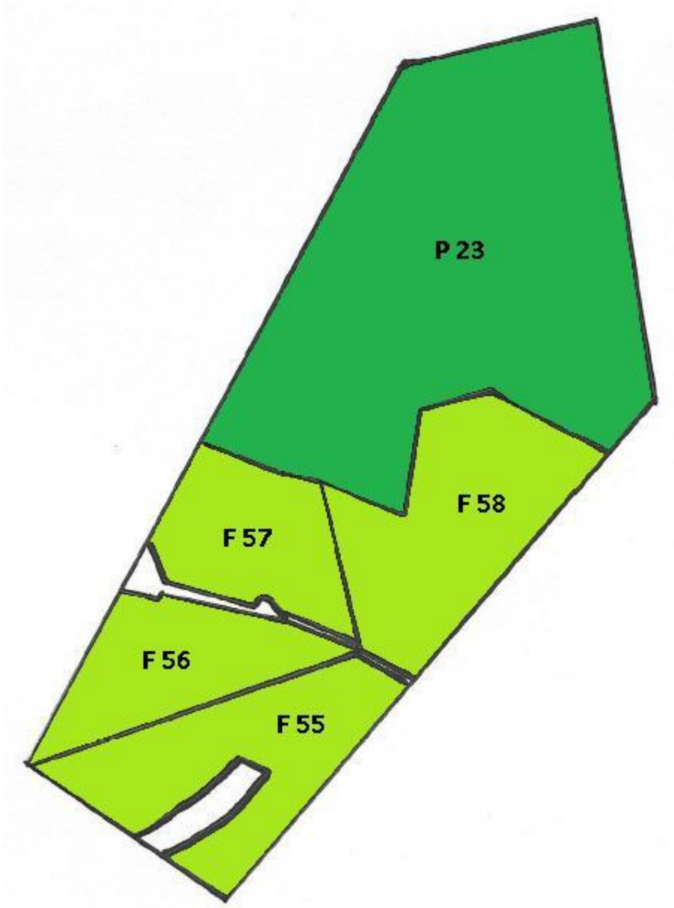


Table 46: Division of Vlakpan's Fields, Pastures and Planted Pastures

Vlakpan	
Field	**Area (ha)**
55	44.42
56	29.10
57	28.13
58	47.37
Pasture	**Area (ha)**
23	155.76

Map of Vlakvallei

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 36: Vlakvallei

Table 47: Division of Vlakvallei's Fields, Pastures and Planted Pastures

Vlakvallei	
Field	**Area (ha)**
59	35.00
60	28.60
61	50.00
62	30.54
63	46.00
64	25.00
65	38.70
66	38.66
67	57.00
68	64.00

Pasture	Area (ha)
24	31.00
25	11.00

Map of Yarima

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 37: Yarima

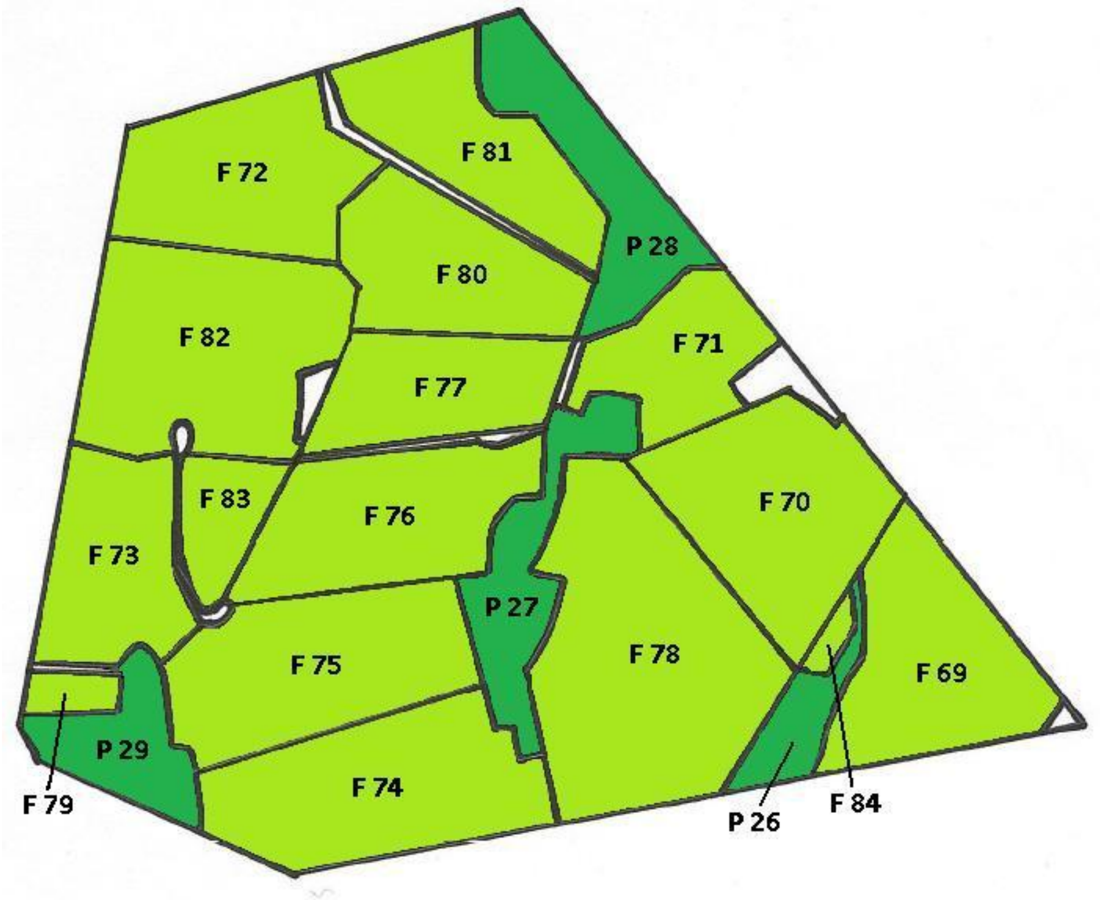


Table 48: Division of Yarima's Fields, Pastures and Planted Pastures

Yarima	
Field	**Area (ha)**
69	58.50
70	68.00
71	34.90
72	46.00
73	43.00
74	74.50
75	67.30
76	60.30
77	45.00
78	106.10
79	7.60
80	61.40
81	52.30
82	79.30
83	16.70
84	5.20
Pasture	**Area (ha)**
26	16.00
27	43.60
28	50.65
29	30.00

Map of Dankbaar

F – Field (light green)

P – Pasture (dark green)

PP – Planted pasture (yellow)

Figure 38: Dankbaar

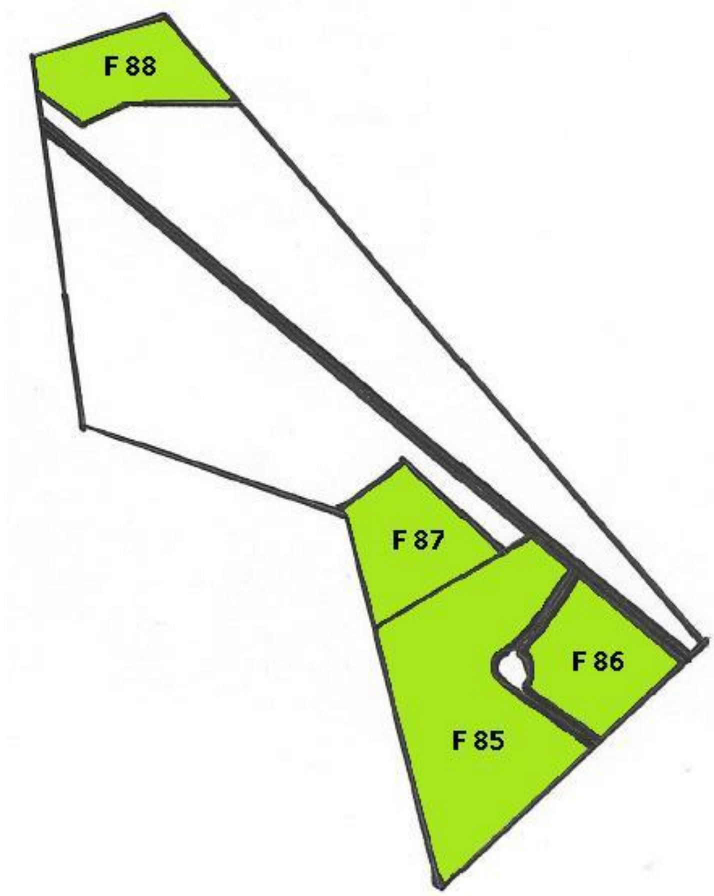


Table 49: Division of Dankbaar's Fields, Pastures and Planted Pastures

Dankbaar	
Field	**Area (ha)**
85	54.39
86	20.04
87	18.38
88	15.19

Map of Dorpslande

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 39: Dorpslande

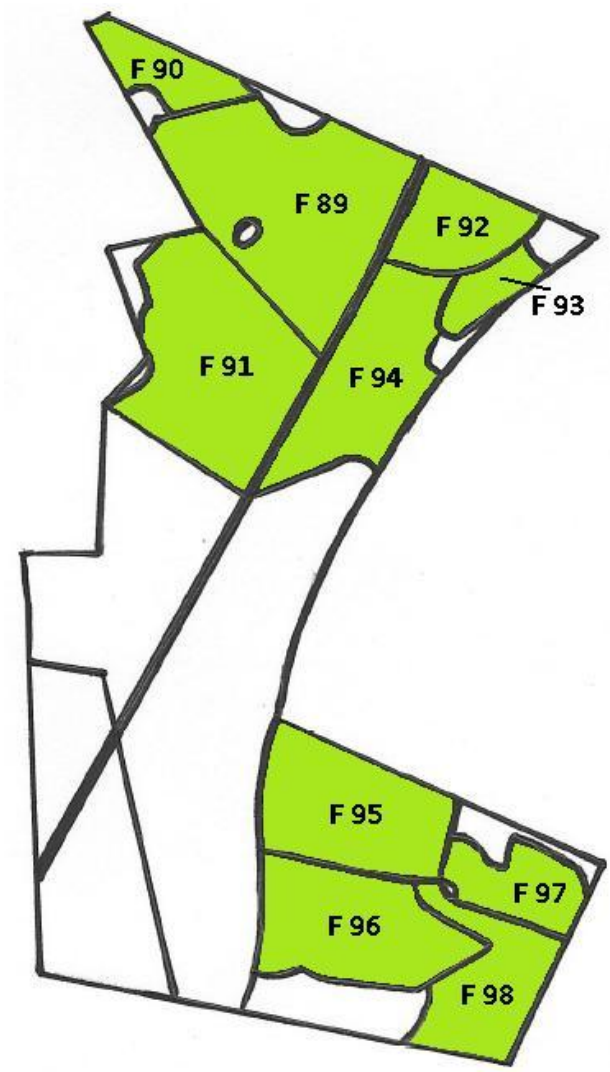


Table 50: Division of Dorpslande's Fields, Pastures and Planted Pastures

Dorpslande	
Field	**Area (ha)**
89	62.09
90	11.53
91	52.96
92	16.70
93	7.48
94	33.46
95	32.83
96	35.26
97	14.55
98	23.76

Map of Langverwacht

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 40: Langverwacht

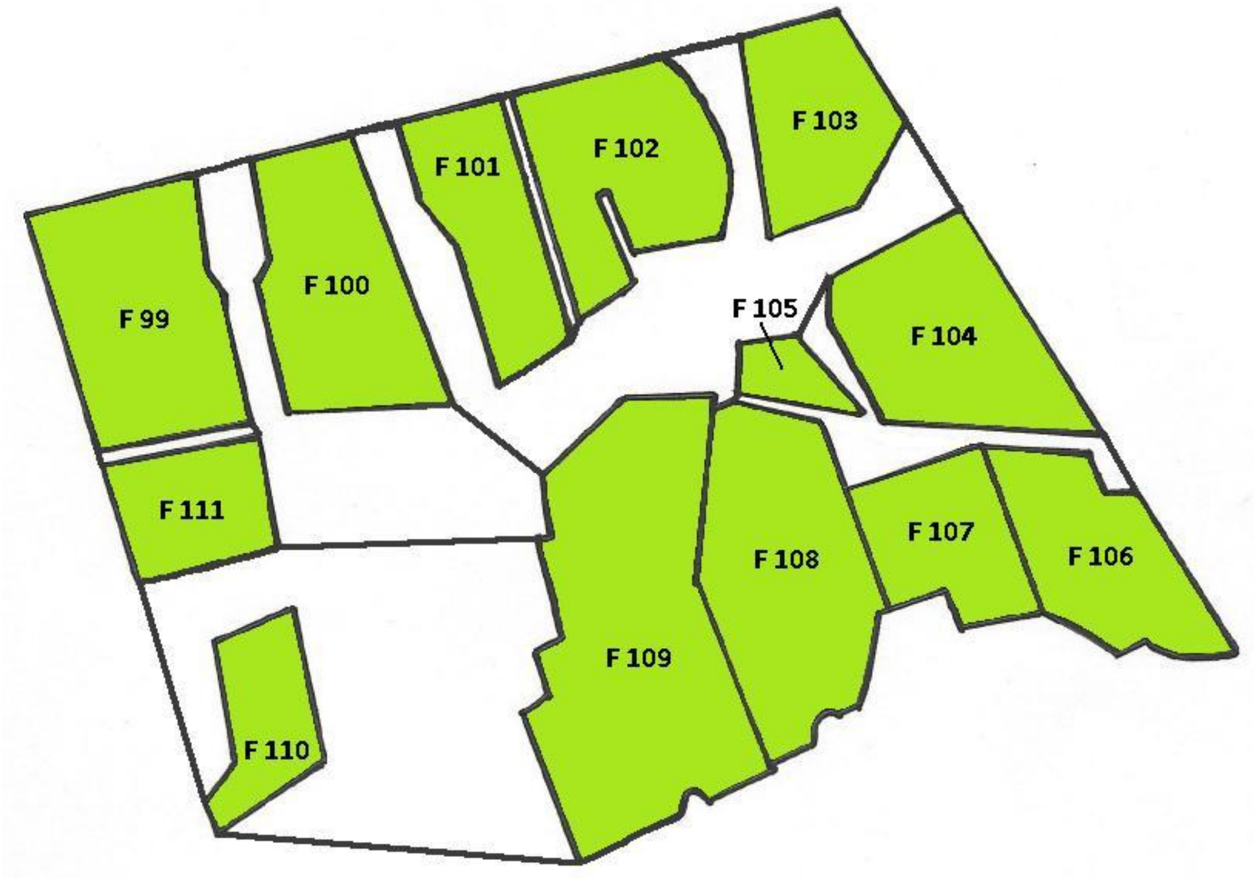


Table 51: Division of Langverwacht's Fields, Pastures and Planted Pastures

Langverwacht	
Field	**Area (ha)**
99	30.40
100	27.50
101	18.80
102	27.00
103	18.80
104	27.50
105	6.20
106	22.50
107	19.40
108	35.00
109	54.50
110	11.90
111	14.00

Map of Nuldesperandum

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 41: Nuldesperandum

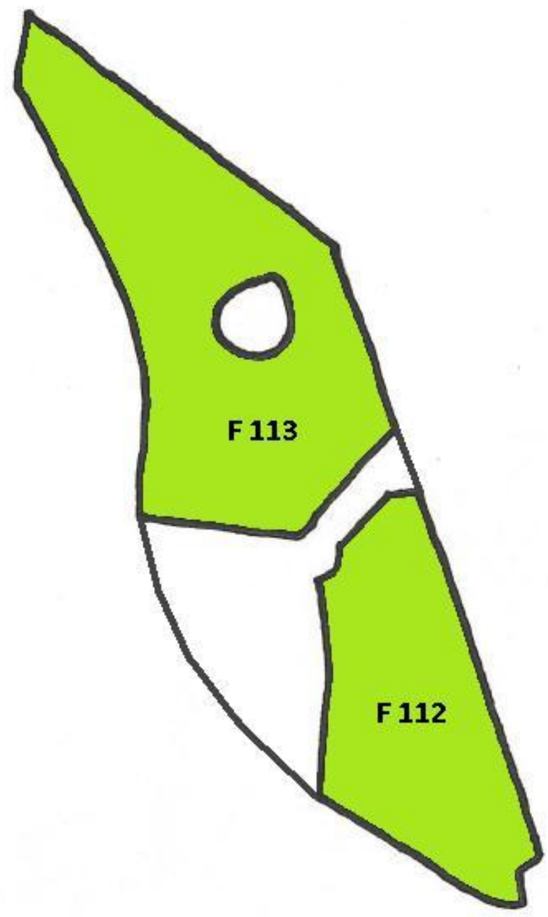


Table 52: Division of Nuldesperandum's Fields, Pastures and Planted Pastures

Nuldesperandum	
Field	**Area (ha)**
112	44.67
113	76.00

Map of Olivia

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 42: Olivia

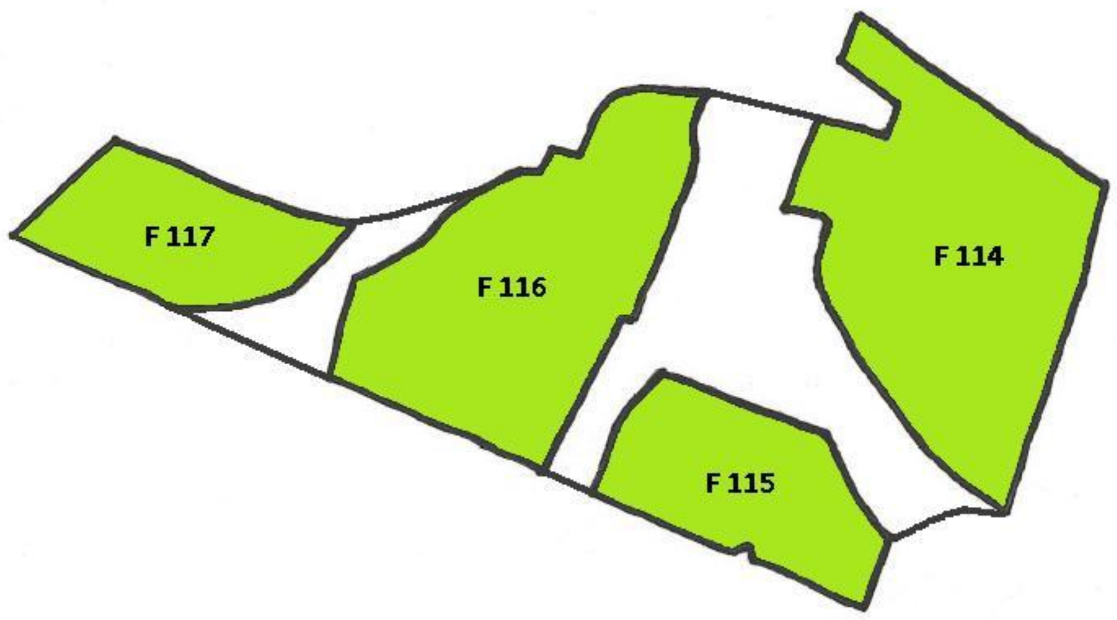


Table 53: Division of Olivia's Fields, Pastures and Planted Pastures

Olivia	
Field	**Area (ha)**
114	39.80
115	17.42
116	34.70
117	14.91

Map of Patmos

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 43: Patmos

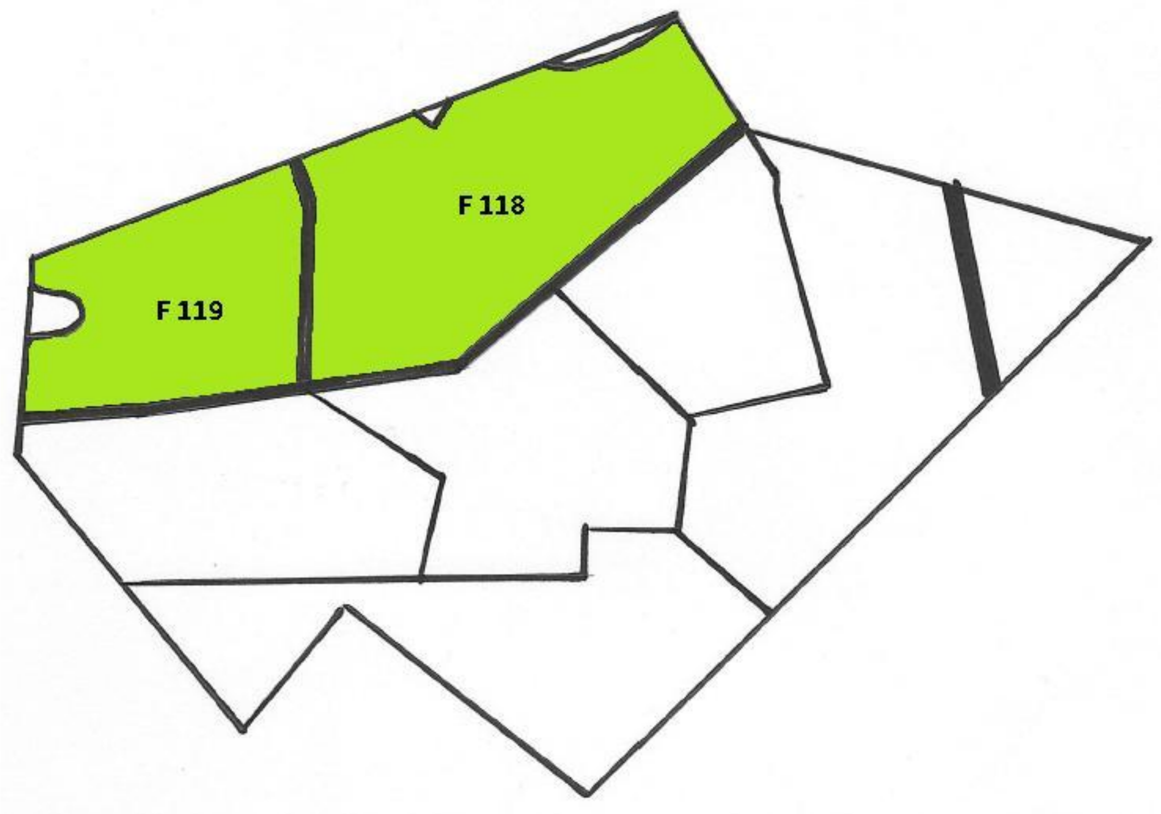


Table 54: Division of Patmos' Fields, Pastures and Planted Pastures

Patmos	
Field	**Area (ha)**
118	72.50
119	42.00

Map of Rooikraal

F – Field (light green)   P – Pasture (dark green)   PP – Planted pasture (yellow)

Figure 44: Rooikraal

Table 55: Division of Rooikraal's Fields, Pastures and Planted Pastures

Rooikraal	
Field	**Area (ha)**
120	11.60
121	18.87
122	56.72
123	16.04
124	76.31
125	5.60
126	70.19
127	20.70
128	7.48
129	3.52

Map of Vyfhoek

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 45: Vyfhoek

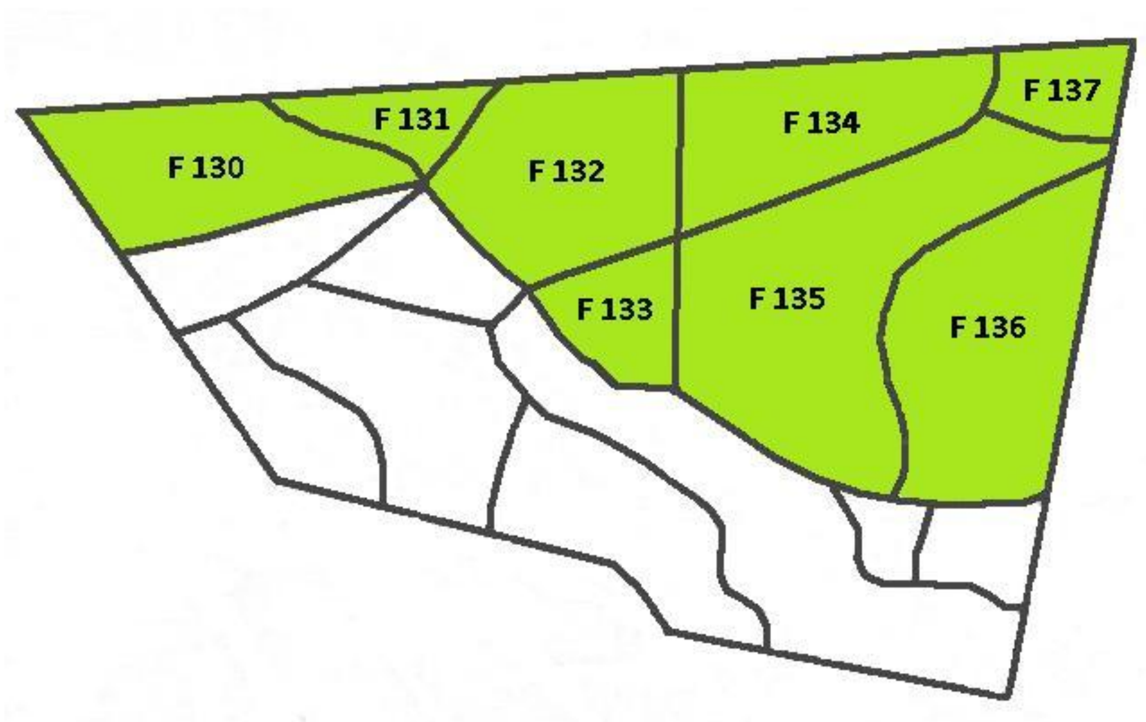


Table 56: Division of Vyfhoek's Fields, Pastures and Planted Pastures

Vyfhoek	
Field	**Area (ha)**
130	17.40
131	5.23
132	17.18
133	5.40
134	14.24
135	33.26
136	23.51
137	4.34

Map of Waverley

F – Field (light green) P – Pasture (dark green) PP – Planted pasture (yellow)

Figure 46: Waverley

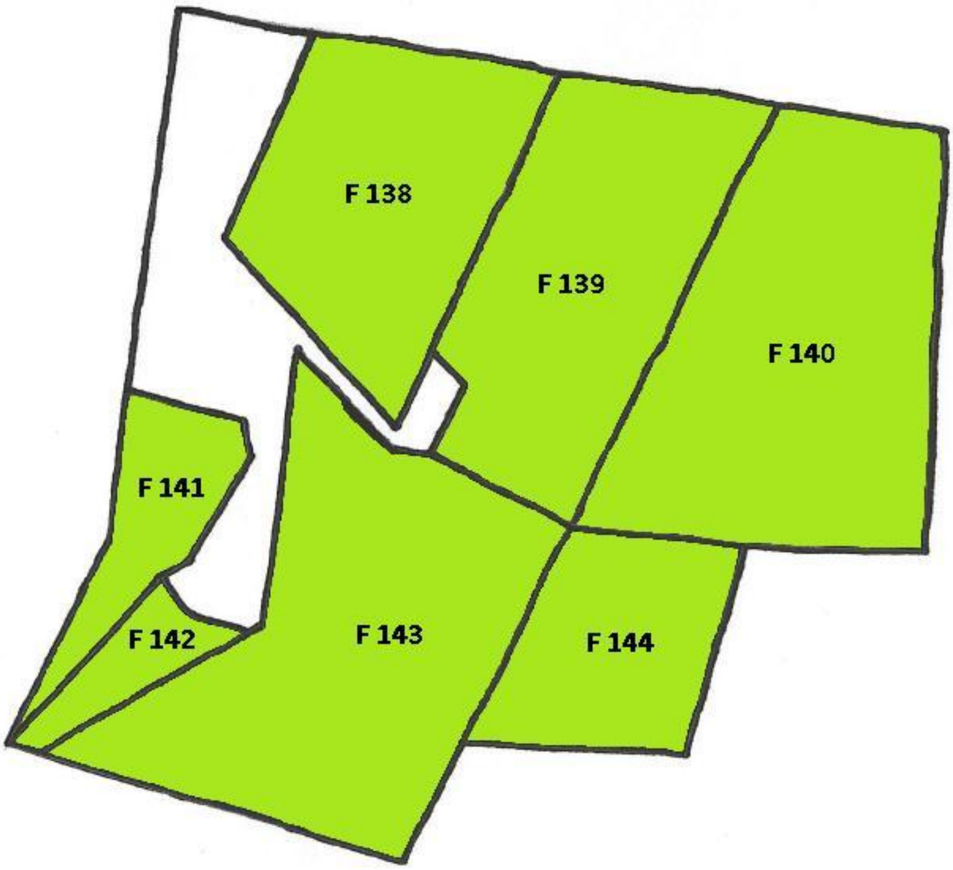


Table 57: Division of Waverley's Fields, Pastures and Planted Pastures

Waverley	
Field	**Area (ha)**
138	32.70
139	30.21
140	40.67
141	17.02
142	3.98
143	72.10
144	33.53

APPENDIX C

LINGO 13.0 Source Code

```
MODEL:

SETS:
	crops/1,2,3/:input_cost;
	field/1..144/:field_area, field_empty, cattle_on_empty;
	cultivate(crops,field):cult, f;
	pasture/1..29/:pasture_area, cattle_on_pasture;
	planted_pasture/1..12/:planted_area, cattle_on_planted;
ENDSETS

DATA:
	input_cost = 2628.47, 3171.74, 2340.65;
	! What-if analysis: replace yield-values if '?';
	yield_sunflower = 1.70;
	yield_maize = 3.20;
	yield_wheat = 1.60;
	field_area = 50.65, 25.33, 7.52, 14.34, 83.00, 51.70, 65.10, 74.80,
60.60, 12.70, 67.30, 81.20, 69.00, 42.40, 47.20, 61.90, 39.70, 45.50,
89.10, 20.75, 31.60, 62.50, 21.80, 57.95, 27.70, 26.00, 17.60, 29.10,
10.10, 9.10, 35.20, 53.80, 29.80, 88.60, 49.88, 47.88, 37.95, 84.90, 61.10,
35.80, 20.00, 80.50, 61.30, 36.40, 4.30, 14.20, 29.70, 49.50, 31.60, 61.70,
31.40, 73.90, 19.10, 45.80, 44.42, 29.10, 28.13, 47.37, 35.00, 28.60,
50.00, 30.54, 46.00, 25.00, 38.70, 38.66, 57.00, 64.00, 58.50, 68.00,
34.90, 46.00, 43.00, 74.50, 67.30, 60.30, 45.00, 106.10, 7.60, 61.40,
52.30, 79.30, 16.70, 5.20, 54.39, 20.04, 18.38, 15.19, 62.09, 11.53, 52.96,
16.70, 7.48, 33.46, 32.83, 35.26, 14.55, 23.76, 30.40, 27.50, 18.80, 27.00,
18.80, 27.50, 6.20, 22.50, 19.40, 35.00, 54.50, 11.90, 14.00, 44.67, 76.00,
39.80, 17.42, 34.70, 14.91, 72.50, 42.00, 11.60, 18.87, 56.72, 16.04,
76.31, 5.60, 70.19, 20.70, 7.48, 3.52, 17.40, 5.23, 17.18, 5.40, 14.24,
33.26, 23.51, 4.34, 32.70, 30.21, 40.67, 17.02, 3.98, 72.10, 33.53;
	pasture_area = 63.00, 26.50, 74.00, 36.00, 11.00, 18.00, 49.32,
10.60, 29.83, 12.12, 81.26, 18.40, 15.50, 226.71, 71.56, 18.48, 121.00,
85.00, 70.04, 38.10, 99.00, 122.86, 155.76, 31.00, 11.00, 16.00, 43.60,
50.65, 30.01;
	planted_area = 21.80, 3.25, 6.48, 16.94, 8.60, 26.70, 34.11, 150.50,
25.70, 24.50, 31.60, 65.00;
ENDDATA
```

```
! Objective function;

Max = ((yield_sunflower*3407.22) - 2628.46)*(sunflower_planted) + ((yield_maize*1361.43) - 3171.74)*(maize_planted) + ((yield_wheat*2324.09) - 2340.65)*(wheat_planted) + (613*0.52*23)*(cattle_sold) - 1137.52*(cattle_pasture + cattle_field) - 1198.12*(cattle_planted);


! Constraints for Crops;

13000000 >= @SUM(crops(i):@SUM(field(j):input_cost(i)*cult(i,j)));

sunflower_planted = @SUM(field(j):f(1,j));

maize_planted = @SUM(field(j):f(2,j));

wheat_planted = @SUM(field(j):f(3,j));

@FOR(cultivate(i,j):f(i,j) = field_area(j)*cult(i,j));

@FOR(field(j):cult(1,j) + cult(2,j) + cult(3,j) <= 1);

@FOR(field(j): field_empty(j) = field_area(j) - f(1,j) - f(2,j) - f(3,j));

unplanted = @SUM(field(j):field_area(j)) - sunflower_planted - maize_planted - wheat_planted;

unplanted >= 945.25;

1049.86 >= @SUM(field(j):f(1,j));

1088.07 <= @SUM(field(j):f(2,j));

2176.14 >= @SUM(field(j):f(3,j));

@FOR(cultivate(i,j):@BIN(cult(i,j)));

@FOR(cultivate(i,j):f(i,j) >= 0);


! Constraints for Cattle;

@FOR(pasture(p):cattle_on_pasture(p) <= (pasture_area(p))/5);

@FOR(planted_pasture(q):cattle_on_planted(q) <= (planted_area(q))/3);

@FOR(field(j):cattle_on_empty(j) <= (field_empty(j))/5);

cattle_pasture = @SUM(pasture(p):cattle_on_pasture(p));

cattle_planted = @SUM(planted_pasture(q):cattle_on_planted(q));

cattle_field = @SUM(field(j):cattle_on_empty(j));

617 = cattle_pasture + cattle_planted + cattle_field;

cattle_sold = 750 - (cattle_pasture + cattle_planted + cattle_field);
```

```
@FOR(pasture(p):@GIN(cattle_on_pasture(p)));

@FOR(planted_pasture(q):@GIN(cattle_on_planted(q)));

@FOR(field(j):@GIN(cattle_on_empty(j)));

END
```

APPENDIX D

Figure 47: January's Rainfall Distribution

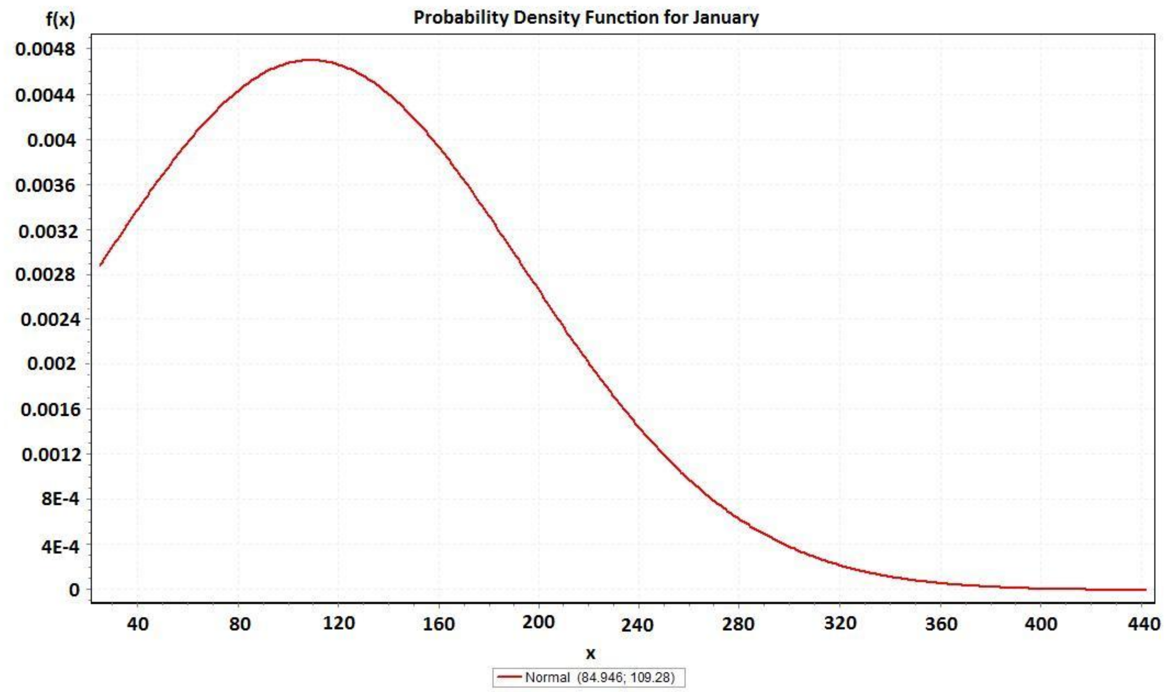


Figure 48: February's Rainfall Distribution

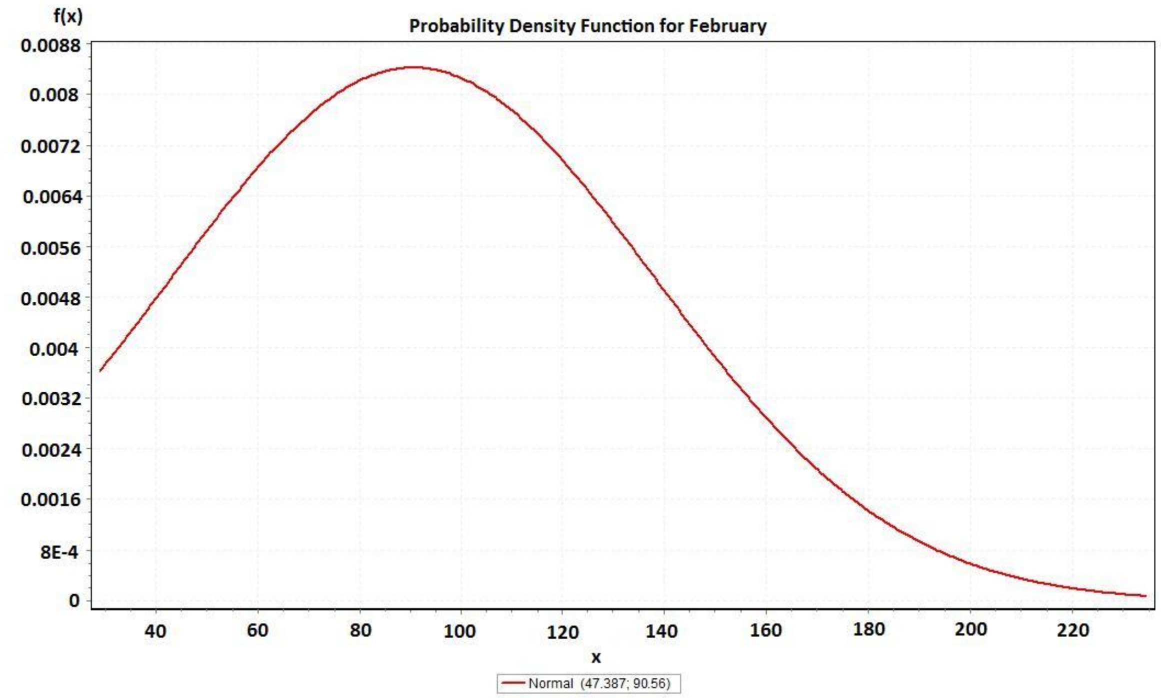


Figure 49: March's Rainfall Distribution

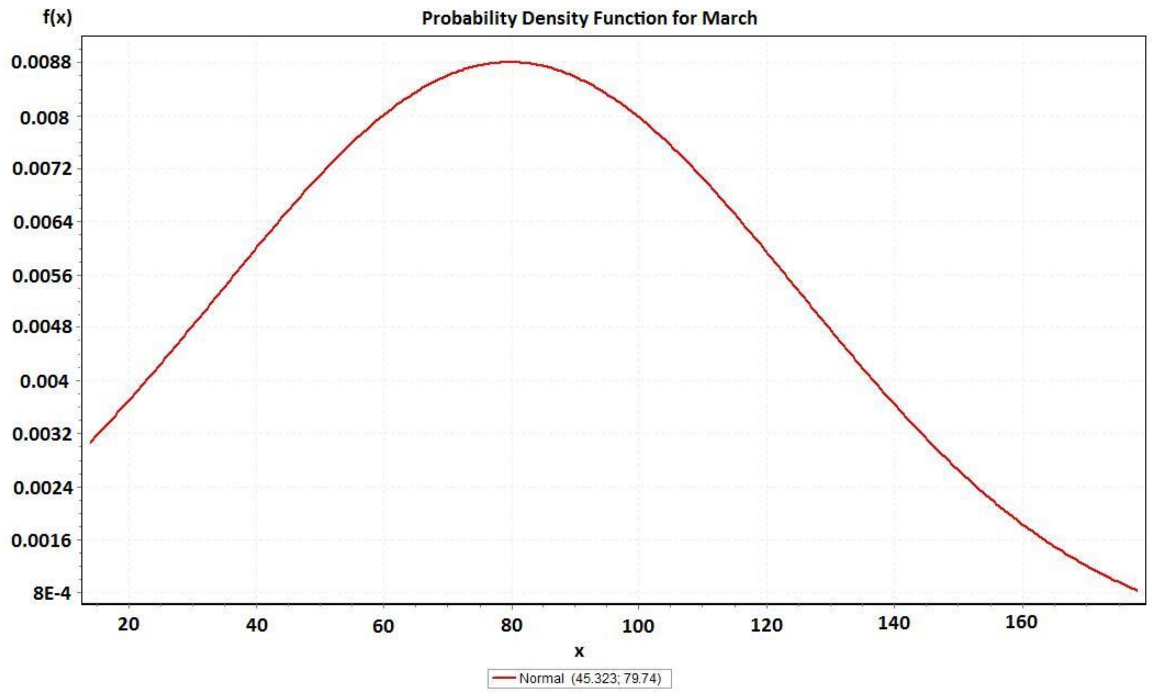


Figure 50: April's Rainfall Distribution

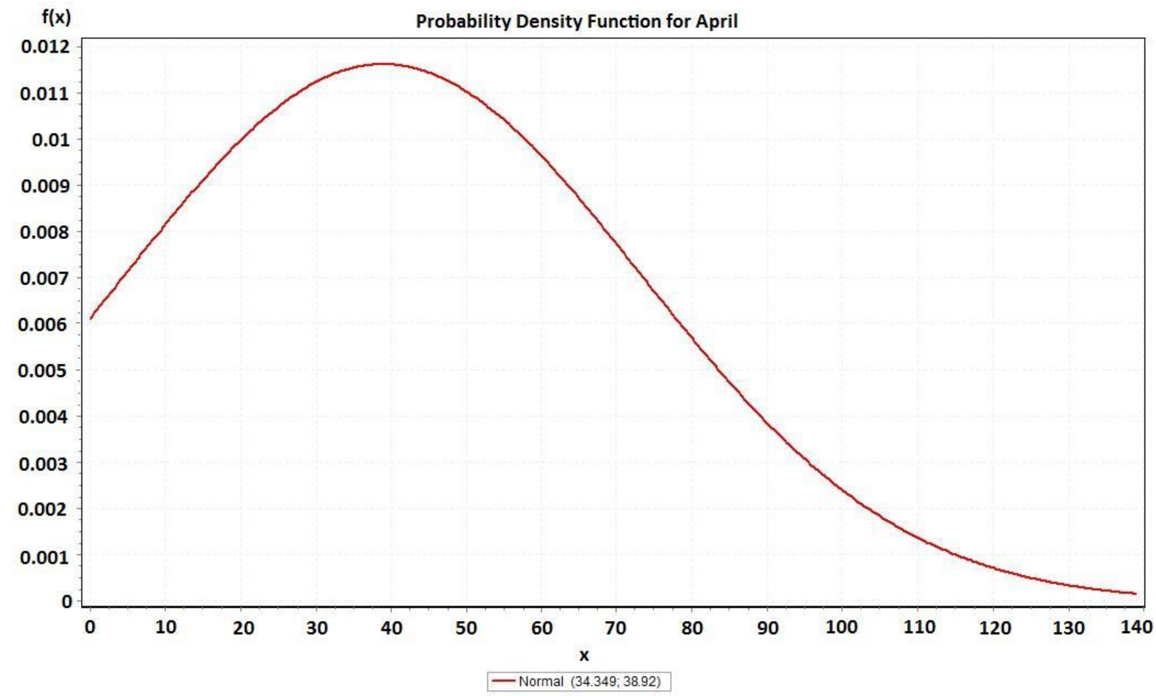


Figure 51: May's Rainfall Distribution

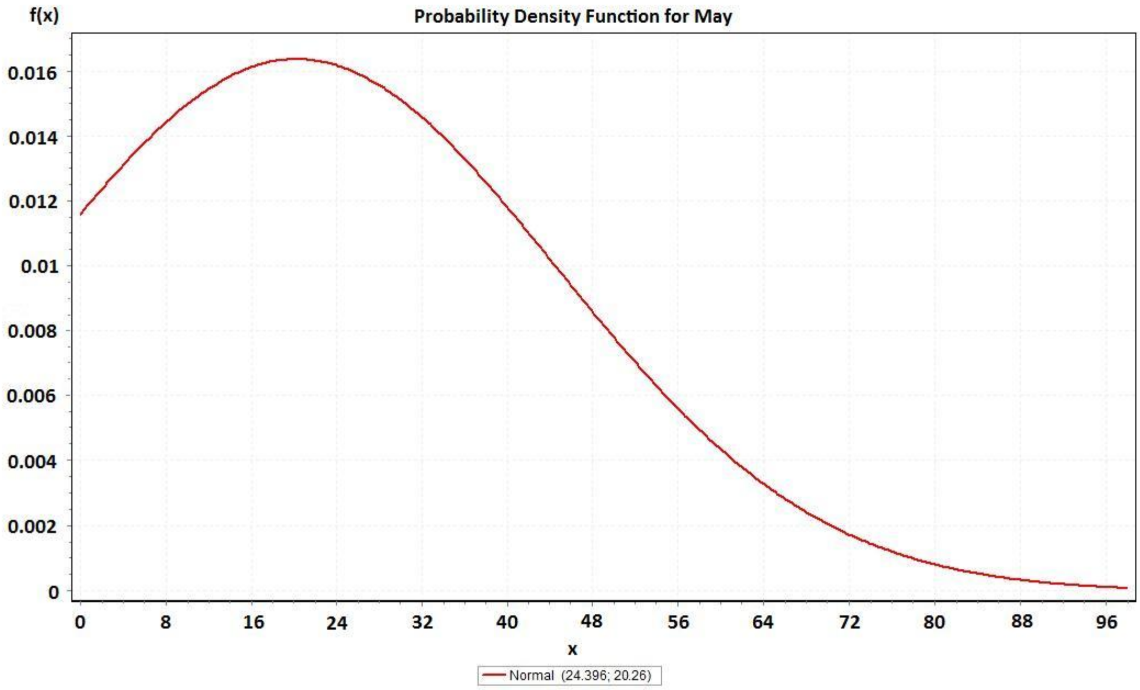


Figure 52: June's Rainfall Distribution

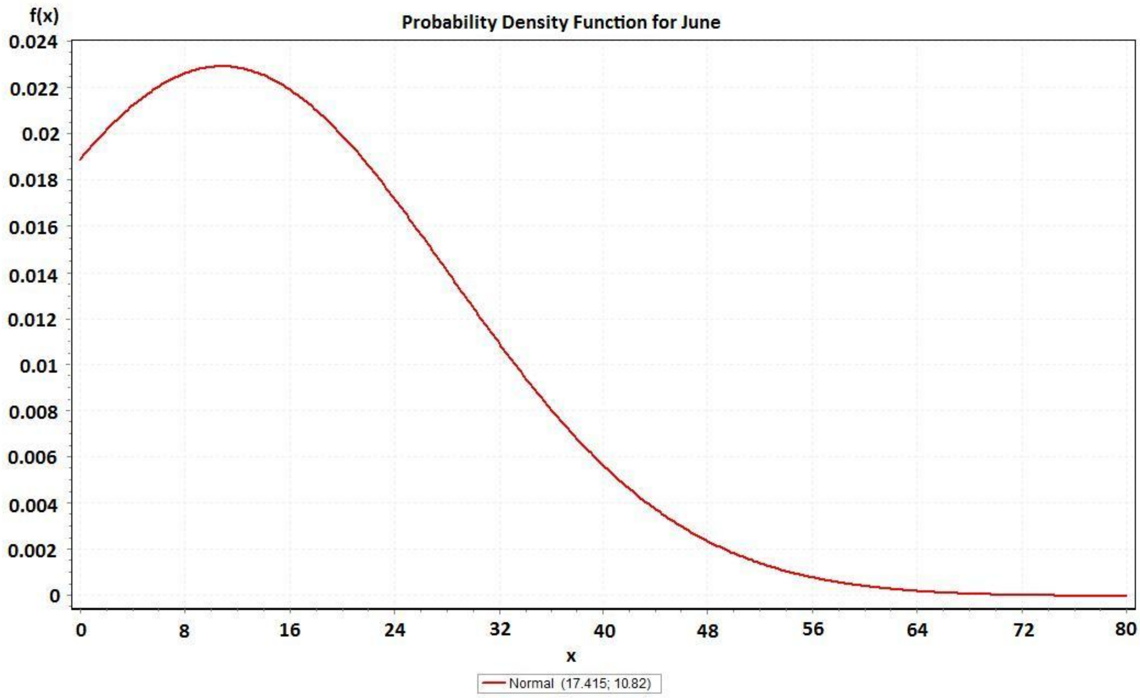


Figure 53: July's Rainfall Distribution

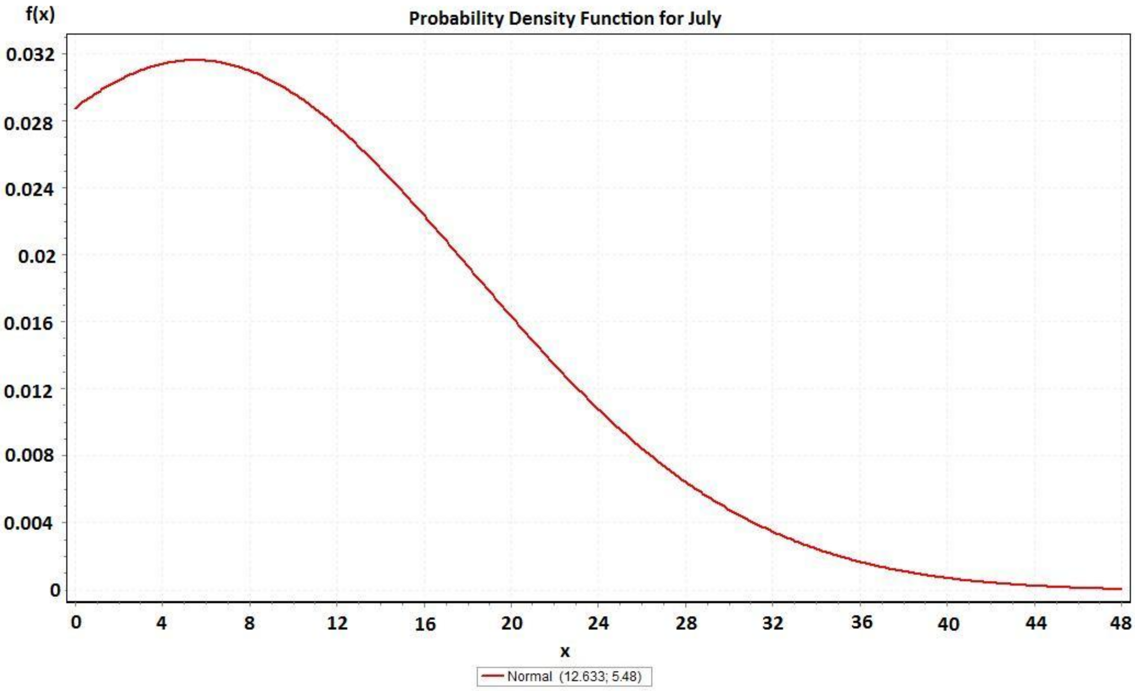


Figure 54: Augusts' Rainfall Distribution

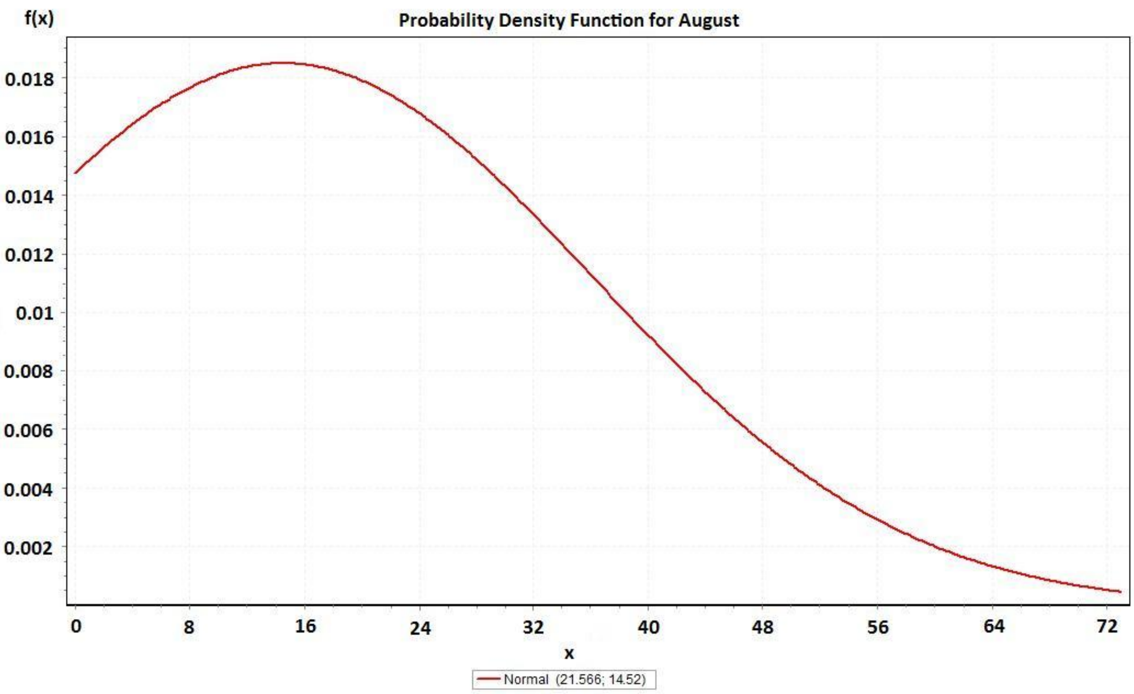


Figure 55: September's Rainfall Distribution

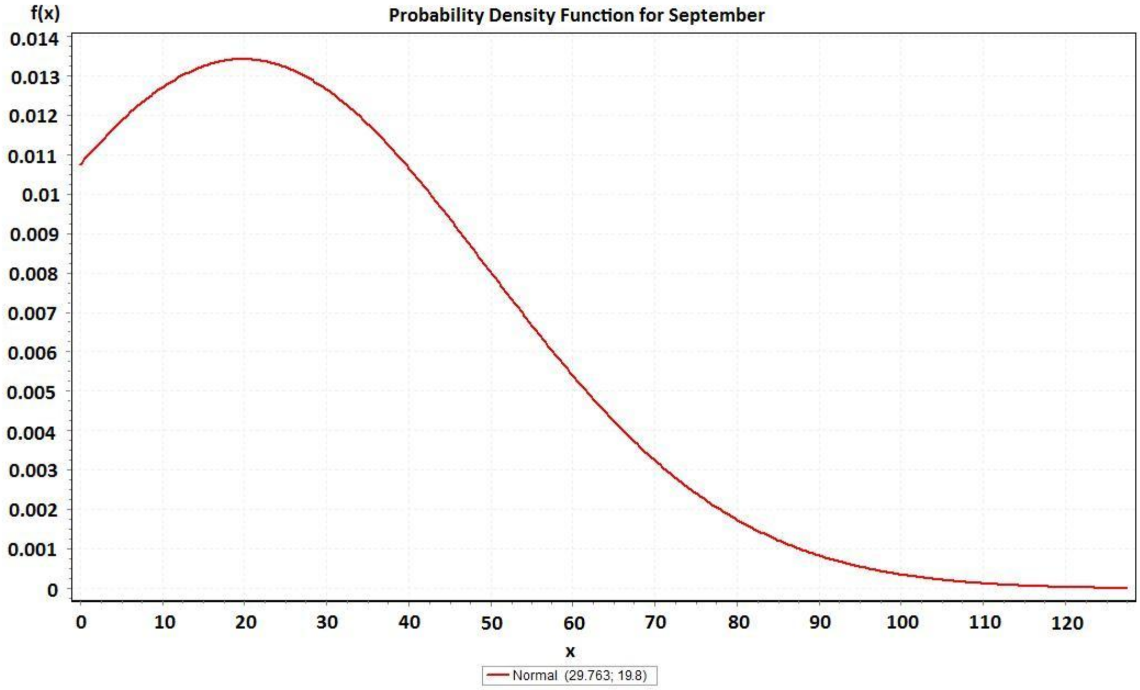


Figure 56: October's Rainfall Distribution

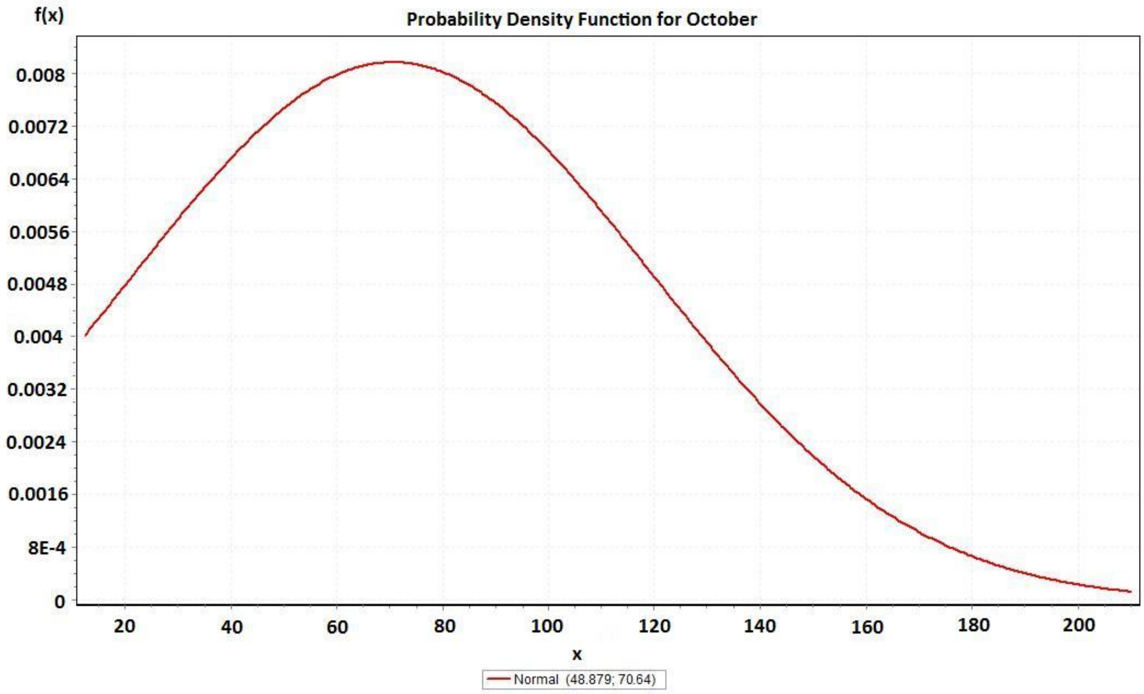


Figure 57: November's Rainfall Distribution

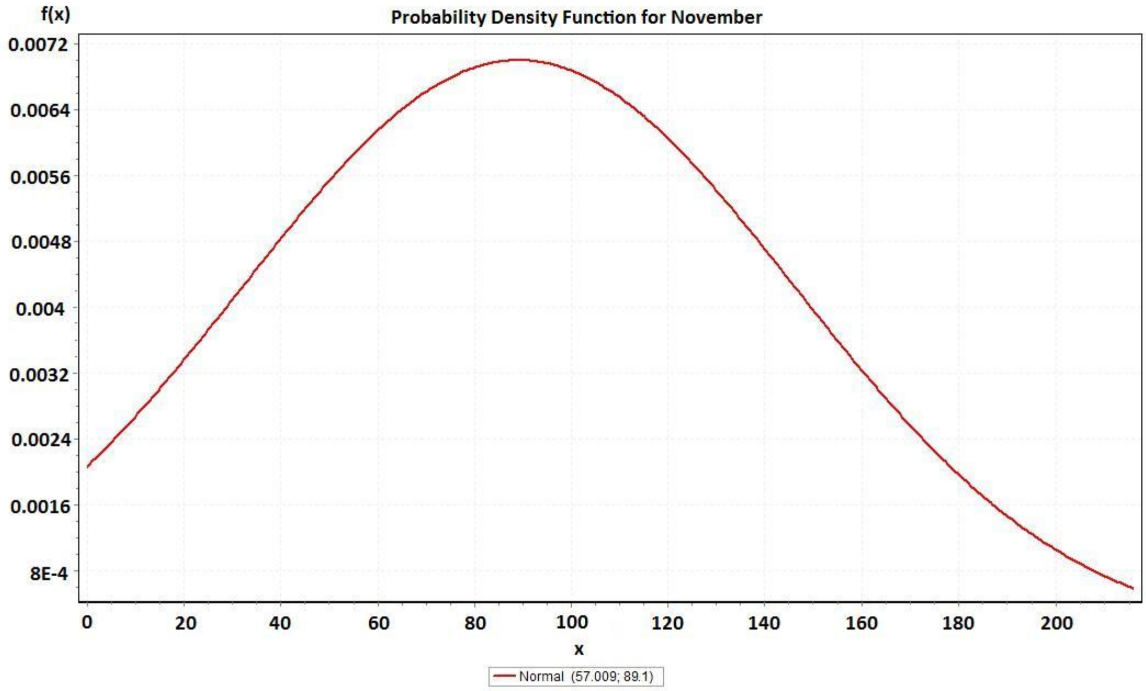


Figure 58: December's Rainfall Distribution