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Controlled traffic for grass silage production

- An economic evaluation for dairy farmers

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Abstract

The farm management system controlled traffic farming (CTF) aims to reduce soil compaction by restricting the field traffic from agricultural machinery to permanent traffic lanes. Literature and empirical findings show that soil compaction and field traffic from heavy machinery may affect crop growth negatively, reducing crop yields. If grass-clover leys are subject to heavy field traffic the botanic composition might be altered, providing a lower clover content in the forage. Clover as a silage feed is rich in protein providing good conditions for high yielding dairy cows. Grass-clover silage production is generally associated with intensive field traffic. Controlled traffic farming is a way to confine the field traffic to the least possible area and thereby reducing the negative effects of soil compaction and mechanical plant damage in the grass-clover ley. If controlled traffic farming would provide increased yield and clover content from the grass-clover ley this could reduce the need for grain and expensive protein feed in the dairy cow feed ration. This study examines the possibility of changes in herbage yield and quality in grass-clover ley and the associated economic benefits due to a CTF system.

A mixed integer programming model is developed to evaluate the potential profit of CTF in a dairy farm context. The investment associated with CTF is defined by calculating the machinery cost for random and controlled traffic systems. Existing field trial data is used to calculate the expected yield outcome of CTF. Three alternative potential yield and quality outcomes are examined that alter the dairy cow feed ration providing quantified values for the changes in silage quantity and quality.

The study reveals that CTF is quite profitable if the silage yields increase due to CTF. The most profitable alternative is found when the clover content is increases. When converting to CTF total machinery costs are subject to increase. However, variable machinery costs decrease from the use of CTF. This study concludes that if a yield increase due to CTF is found the system is profitable despite the major investment due to CTF.

Sammanfattning

Controlled traffic farming (CTF), är ett management system som ämnar minska markpackning genom att förlägga all fälttrafik från jordbruksmaskiner till fasta körspår. Forskning och empiriska observationer visar att markpackning och tung fälttrafik från jordbruksmaskiner kan ha en negativ inverkan på grödans tillväxt vilket leder till minskade skördar. Den botaniska sammansättningen i gräs-klöver vallar kan påverkas av tung fälttrafik i from av minskat klöver bestånd. Klöver grödan är rik på protein och tillåter ett högt foderintag, därför ger klöver goda förutsättningar för hög mjölkavkastning. Ensilage skörd medför generellt intensiv fälttrafik på vallarna. Fasta körspår (CTF) är ett alternativt luknings system utvecklat för att minimera den trafikerade fält ytan. Detta för att undvika negativ markpackning och mekaniskskada på vallväxterna. Om användandet av CTF kan öka vallskörden och öka klöver halten skulle detta kunna leda till ett minskat behov av spannmål och protein koncentrat i mjölkkornas foderstat. Den här studien undersöker potentiella skörde- och kvalitetsförändringar i vallfodret, samt de ekonomiska fördelarna, från ett CTF system.

För att utvärdera den potentiella vinsten av CTF i en mjölk gårds kontext har en blandad heltals programmerings modell utvecklats. Investeringen förknippad med CTF är definierad genom beräknade maskinkostnader för system med slumpmässig- (RTF) samt kontrollerad fält trafik (CTF). Med utgångspunkt från fältförsöksdata har en förväntad skördeförändring från CTF beräknats. Från detta används tre potentiella skörde- och kvalitets förändringar i vallfodret för att justera mjölkkornas foderstat. Skördeförändringarna och foderstaterna används som kvantifierade värden i programmerings modellen.

Denna studie har visat att lönsamheten från CTF är påtaglig om vallskörden ökar som en effekt av CTF. Om klöverhalten i vallen ökar utgör detta det mest lönsamma alternativet. Vid en övergång till fasta körspår ökar de totala maskinkostnaderna men de rörliga maskinkostnaderna minskar. Studiens slutsats visar att CTF är lönsamt om en skördeökning kan förväntas från systemet, detta trots de stora investeringarna förknippade med systemet.

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1 Introduction

In every profit-driven company there is a constant ambition to increase profits. Profits represent the difference between revenues and costs (Pindyck and Rubinfeld, 2009). Consequently reducing costs or increasing revenue or sometimes both can increase profits. This applies to agricultural companies as well as any other businesses. The fundamental definition of economics derives from ancient Greek *oikonomia,* which means management of a household. A modern definition from Debertin (2012, p2): "*Economics is defined as the study of how limited resources can best be used to fulfil unlimited human wants".* In this particular case the resource, which we rely on to fulfil our unlimited wants is agricultural land.

Since 1990 prices for agricultural land has more than doubled in Sweden (SJV, 2012). Soils are fundamental for any agricultural production and represent the main asset in the agricultural business. The farm management system controlled traffic farming (CTF) aims to increase the profits from land by avoiding mechanical soil compaction from field traffic and achieving desirable soil conditions. In Tullberg et al. (2003,p1) the system is defined as "*In controlled traffic farming all field traffic is restricted to permanent traffic lanes".*

Since the 1940's post war times the size of agricultural machinery, such as tractors and combines, has increased and from the 1960 with the beginning of the "green revolution" we have experienced an astonishing growth in production capacity and yields (Flygare and Isacson, 2011; Tauger, 2011). Unfortunately this development has stagnated since the mid 1990's and the present situation is often referred to as the yield plateau (Knight et al., 2012). Soil compaction is widely accepted to have an impact on crop growth, and in many cases a negative impact, thereby reducing crop yields. One may argue that the possibility of increasing yields from agricultural land by reducing soil compaction, rather than investing in additional land must be an alternative worth examining. Taking into account forecasted rapid world population growth, the need to increase food production from existing agricultural land becomes even more important (United Nations, 2013)

A recent report form Swedish government, aimed at evaluating the competiveness of Swedish agriculture and horticulture industries reveals weak profitability for Swedish dairy farms. According to this investigation large dairy farms (>100 cows) display a zero profit margin where as medium and small dairy farms operate at -15% and -52% profit margin respectively. Large dairy farms represent 20% of all dairy farms on a national average, constituting 50% of the total milk production. (SOU, 2014). In this thesis; we examine possibility to increase profit margin for dairy farms by introducing the farm management system controlled traffic farming, (CTF). The basis of CTF is simply to increase revenue and decrease costs by a more efficient farming system as a result of reduced soil compaction from agricultural machinery.

This study intends to examine the relationship between field traffic on grass leys for silage production and the possible economic advantages stemming from reducing field traffic by introducing a CTF system. Other studies targeting arable farming has shown that CTF increases farm profits (Kingwell and Fuchsbichler, 2011). It should also be recognized that grass is grown on 45% of the farm land in Sweden (www, SJV, 2014a). Yet statistics show only weak yield increase since the 1960's (www, SJV, 2014b). In the next section of this thesis the academic problem and the background to CTF in dairy farming is described in detail.

1.1 Problem background

Soil compaction and field traffic can alter both yield outcome and botanical composition of grass-clover leys (Hansen, 1996). For ruminants clover is nutritionally superior to grasses with respect to protein and mineral content (McDonald et al., 2011). Therefore, the botanical composition is important in a grass-clover ley. Red clover is particularly sensitive to soil compaction (Frame, 1982). High yielding dairy cows require high feed intake to maintain their yield capacity. Clover in silage increases feed intake capacity (McDonald et al., 2011). To meet the nutritional requirements grain and compound feeds are added to a silage based feed ration. Protein concentrate feed often consists of soy protein and constitutes around 40 % of the total feed cost per kg milk yield (www, Agriwise, 2014a). Reducing compound feed costs without decreased milk yield can be achieved if high quality silage with desired botanical composition can be produced.

1.1.1 Controlled traffic farming – the practical system

To solve the mentioned problem a few farmers are starting to introduce the management system, controlled traffic farming, CTF aimed to reduce the trafficked field area. This is in practical situations adapted by the use of a common machinery width, a CTF module width. Sometimes wider machinery widths divisible in to the same module width are used. Commonly a system can be designed as illustrated in Figure 1, exhibiting a 12-meter module width CTF system, with a 12 meter wide mower and rake, a self-propelled forage harvester and a two module width wide (24 m) slurry spreader. To stay on track a global navigation satellite system (GNSS) based guidance system with an auto steer function is used (Webb et al., 2004). By the use of a module width the field traffic can be confined in to permanent traffic lanes. CTF consequently provides an area of soil that is not compacted in the area in between the traffic lanes. According to previous studies soil compaction, in many cases, reduces yields (Douglas et al., 1992; Håkansson, 2000; Raper, 2005). Therefore, areas of non compacted soil may provide a potential for increasing yields.

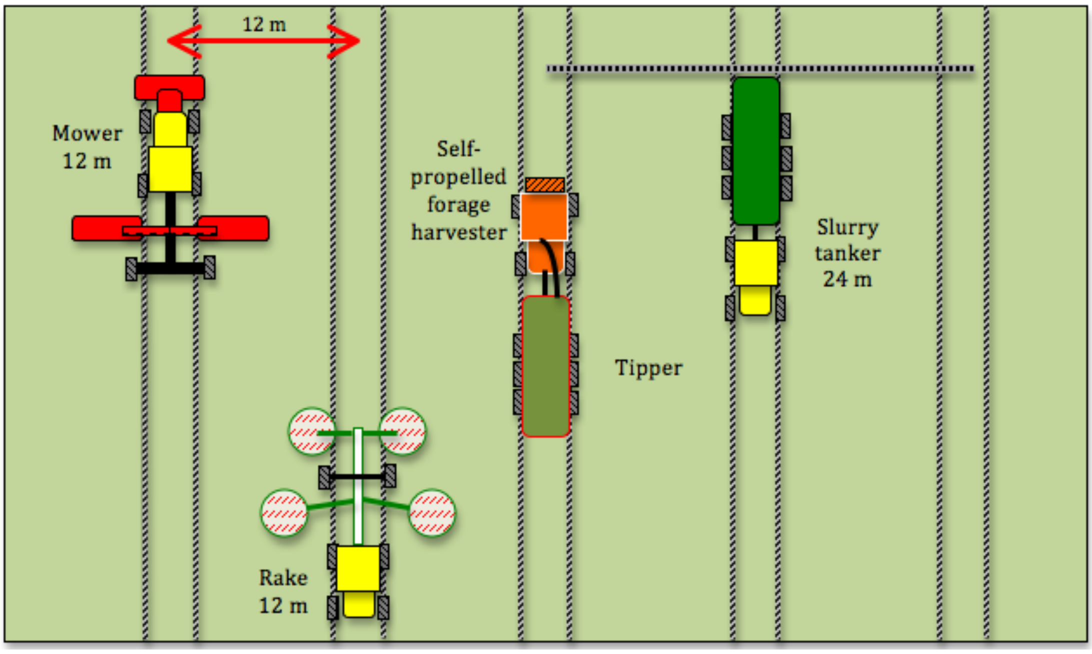


Figure 1: Illustration of CTF system for grass silage for this study

Theoretically any module width can be used when designing a CTF system. However, larger machinery widths provide larger areas of non-compacted soil. In arable farming 6, 8, 9 or 12 meter systems are commonly used. For grass silage production with CTF, 12 meter is the most common module width. The combine harvester in cereal production may increase the cost for converting to CTF. However, for grass silage if a self-propelled forage harvester is used, as illustrated in Figure 1, the introduction of CTF do not induce a larger harvester. The investment cost in wider machinery in a CTF system for grass silage sometimes only pertains to mowers and rake machinery. However the introduction of CTF may require some investments, depending on existing random traffic farming (RTF) system, given the adaption of machinery in to one single module width. According to Chamen (2011) arable farmers do experience lower investment costs for machinery once they are in a CTF system

1.1.2 Soil Compaction and field traffic in agriculture

Soil compaction is a problem in modern agriculture due to increasing farm size and larger machinery (Keller et al., 2003). Agriculture machinery has increased in size during the last 50 years (Kutzbach, 2000; Moitzi and Boxberger, 2007) causing greater impact on the soil. This along with mechanical plant damage stemming from field traffic is the main incentive to introduce CTF for grass silage production.

Håkansson (2000) describes soil compaction as a process where the soil porosity decreases as the bulk density increases when affected by external factors, such as agriculture machinery. When pressure is applied to the soil during wet conditions soil compaction increases. Low porosity compacted soils are characterized by lower water infiltration capacity, increasing the top soil water content that subsequently increases the risk for soil compaction during field traffic (Raper, 2005).

Tillage has long been the countermeasure for compacted soils to provide desirable soil structure. Arndt and Rose (1966) state that excessive field traffic needs excessive tillage. Tillage is both energy and time consuming and thus costly. According to prof. S. Blackmore, Harper Adams University, up to 90% of all energy going in to cultivation is used to repair the damage caused by previous machinery passes (www, OFC, 2014). By reducing or confining field traffic to a minor area, soil compaction problems may be avoided for a major part of the field. In annual crops, tillage operations in between growth seasons can repair the soil and reduce the effects of compacted soils. However, for perennial grass leys the opportunities for such tillage operations repairing the soil structure are not available. Therefore, the importance of reducing field traffic during the grass years is accentuated. Prevailing wet conditions during the first harvest may cause soil damage reducing yields for years to come. Soil compaction from heavy machinery often reaches the sub soil layer, which is difficult to reach with normal tillage methods, but still restraining deep root growth (Håkansson, 2000).

Furthermore Håkasson (2000) states that cereal production often results in four machinery passes per growth season. For grass silage harvest Kroulik et al. (2014) states that in one cut 63.8% of the field area is traffic. The traffic intensity is sometimes up to 10 passes over the same area with an average of two passes at 25% of the area. The system used for this study consists of four field operations; mowing, raking, tedding and self-propelled forage harvester with the associated tractors. Subsequently a majority of the field area will be trafficked in a three cuts per year grass ley management system over three to four years of ley resulting in more machinery passes compared to cereal production without the ability to reduced damages through tillage.

The literature reveals a negative correlation between soil compaction and grass yield. Soil compaction or effects of field traffic is found to reduce grass yields (Douglas et al., 1998, 1992; Elonen, 1986; Frame, 1982; Frost, 1988; Håkansson et al., 1990; Hansen, 1996; Jorajuria et al., 1997; Rasmussen and Møller, 1981). Silage forage in Sweden is often based on grass-clover mixtures, both white clover (*Trifolium repens)* and red clover (*Trifolium pratense)* are used. Legume plants such as clover provide valuable protein to the silage. Frame (1982) concludes that red clover is sensitive to field traffic, and that field traffic should me minimized. The growth properties for white clover are more resistant to compacted soil (Hansen, 1996) and more long lasting than red clover (Nilsdotter-Linde, 2001). Clay dominated soils are sensitive to compaction which may induce difficulties in maintaining red clover growth on clay soils. However, white clover establishment may be limited on clay soil. Small size seeds, such as white clover, may cause lack of soil contact if the clay soil develops coarse soil texture (Larsson et al., 2002). Consequently there may be a problem in achieving a desirable botanical composition when establishing perennial grass-clover ley on clay-dominated soils. The interest in a desirable clover-grass ratio for this particular study regards the high crude protein content properties of clover adding to the silage nutritional value. Scarcity of crude protein in silage requires a higher share of protein feed concentrate in the feed ration to maintain constant milk yield. To estimate the value of increased grass yield and changes in crude protein content, the price for different feed rations is included in the study.

1.1.3 Changes in soil structure due to soil compaction

Mineral particles and organic material together with water and air constitute the soils (Eriksson et al., 2011). The previously mentioned problem of soil compaction regards the change in soil structure where the mineral particles, organic matter, water and air ratios are altered. Soil compaction reduces pore space and increases bulk density (Raper, 2005). Desirable soil conditions, where the pores are filled with water and air, provide good conditions for plant growth. A soil with 50% pore space should during desirable conditions provide a distribution of 10-20% air and 30-40% water (Eriksson et al., 2011).

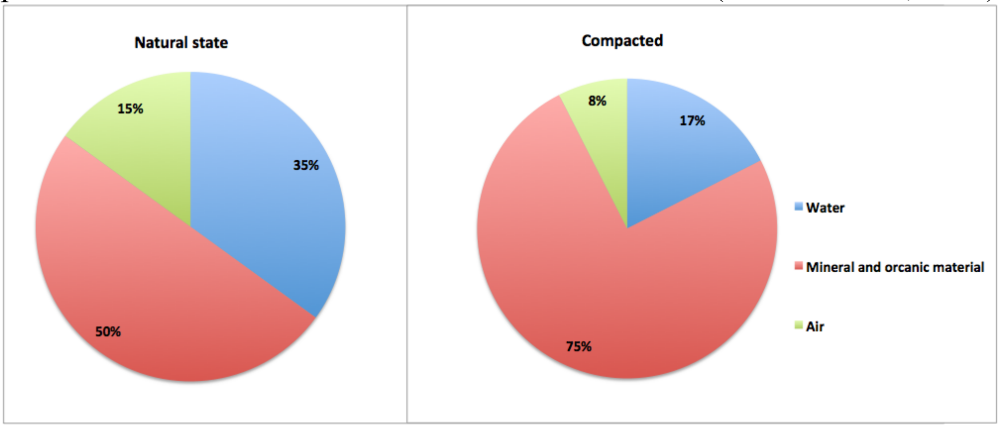


Figure 2: Illustration of changes in soil, water and air contents from soil compaction compared to a natural state

The desirable soil conditions and possible changes due to compaction are presented in Figure 2. Letey (1985) defines four soil physical properties directly affecting plant growth; water, oxygen, temperature and mechanical resistance. All of them are strongly connected with soil compaction. Plants cannot grow without water. Growth is reduced with less available water for the plant. Plant roots growing in compacted soils suffer due to increased mechanical impedance and decreased oxygen availability (Raper, 2005). Restrained root growth decreases both water and nutrients up take (Håkansson, 2000).

1.1.4 Effects of crop nutrients availability due to soil compaction

Plant available nitrogen in compacted soils generally decreases as a result of de-nitrification (Weidow, 2000). Parlak and Parlak (2011) conducted a field trial revealing that soil compaction adversely affects root growth characteristics of forage crops. Macro nutrients of N, Ca and Mg decreased whilst P increased and K revealed an irregularity due to soil compaction. Głąb (2013) examined the correlation between nitrogen fertilizer and soil structure in grass-clover leys, concluding that N fertiliser cannot be utilized by the crop if soil conditions are poor due to insufficient root growth. The economic value of favourable soil physical properties may therefore not only be motivated by increased yields but also due to a more efficient fertilizer use.

1.1.5 Summary of biological and technical background

In general the main problem to be solved when speaking of CTF is soil compaction. For this project, examining grass leys, the benefits from CTF may extent to other issues than soil compaction. In grass leys other benefits from CTF may include; even regrowth after harvest in the non-trafficked areas providing more homogeneous silage quality and a more desirable botanical composition as a result of reduced physical plant damage.

1.2 Problem

The main problem for this thesis is soil compaction or field traffic that influences crop growth, thereby reducing both yield and clover contents in grass ley. To minimise this problem CTF can be used to avoid large trafficked field areas. The potential yield increase from reduced field traffic could result in that the required amount of forage can be produced on a lesser area of grass fields. Thereby a change in crop rotation is facilitated with greater areas of more profitable crops e.g. wheat or oil seed rape (OSR). In addition to this the botanical composition has an impact on feed quality. One of the benefits of reduced field traffic is therefore an expected increase in clover content. Clover provides a higher protein content in the silage. This change in silage quality may enable the replacement of more expensive protein concentrate feeds, hence reducing feed cost.

With regard to the previous section this thesis attempts to investigate the economic potential of a CTF system in a dairy farm context. For this some data, central to the problem, will be collected. Four major aspects, specific to this topic, have been found to need further examination in order to solve this problem:

- What is the yield outcome from trafficked and non-trafficked soils?
- How should the CTF machinery system be designed?
- Which costs are induced by the suggested CTF system?
- What is the value of a change in silage quality from a feed ration perspective?

Applying these data to a representative dairy case farm scenario where the total farming operation is included should enable a comparison of total farm profits between CTF and RTF.

To the best of my knowledge no study has been conducted evaluating the economic benefits of CTF in grass for silage production given the approach to compare the value of different feed rations.

1.3 Aim

This thesis aims to evaluate if CTF is profitable in grass silage production in a dairy farm context. By providing a general picture of the potential economic benefits from implementing CTF in a dairy farm perspective interest in the area might increase, leading to more profitable farms. Economic models are to be developed aimed to be used as a broad, basic knowledgebase applicable to many different farm types, helping farmers and advisors in decision making regarding CTF on dairy farms. The models will, for this particular study, be tested on a fictitious dairy farm case study for generating empirical results. Even if there are many differences in productions methods on dairy farms hopefully this study should provide a generalizable result giving an indication of the potential of CTF. For this study three research questions have been formulated:

1. What is the investment cost for the CTF system in this particular case?
2. What factors are decisive for the profitability of this investment?
3. What are the total differences in farm profit margin between RTF and CTF?

The answer to each specific question should be of relevance for farmers striving to develop their dairy farm business, having CTF in mind. The academic contribution of this study is the economic evaluation of alternative farm management systems. CTF aims to reduce problems of soil compaction but the economic benefits of this system are difficult to generalize. Previous studies focus on the agronomic properties as a result of CTF where physical soil conditions are central. The model developed in this study does not only intend to provide generalizable results for the given conditions but may be used to evaluate the profitability of converting to CTF for other specific situations.

1.4 Delimitations

For this research project some delimitations are made to retain relevance to the study. The use of CTF will only be evaluated for the grass silage production. All other crops are assumed to be cultivated in a conventional tillage system.

The case farm, a 300 hectare farm holding a fixed number of 300 dairy cows, is situated in the western part of the GNS region (Götalands Norra slättbygd). The Västra Götaland region is home to 18% of the Swedish dairy farms (SJV, 2014). The case farm aims to portray a geographically representative large scale dairy farm. The GNS region is dominated by clay soils (Fogelfors, 2001). The western part of the GNS region often experience wet weather (www, SMHI, 2014) enhancing soil compaction from agriculture machinery on the sensitive clay soils. The case farm is entitled to single farm payment, which is included in the total revenue. The amount of single farm payment is determined by the classification of the area, which the farm is situated in, ranging from one to five regions (www, SJVc, 2014). The western part of the GNS region varies from class two to four (www, SJVd, 2014). This study does not intend to measure profitability based on single farm payment. Therefore the study assumes that the case farm is situated in area three, representing a mean for the western part of the GNS region. The use of a mean area for all five classes can also be justified by the announced policy changes in the CAP, directly affecting single farm payment (www, SJVe, 2014)

Moreover all prices in the study are average prices, both for grain and machinery. This study does not intend to measure profits from investing in tractor guidance systems and therefore assumes that the fictitious farm has access to this technology. However for the CTF case an assumption is made that better accuracy is required to maintain permanent traffic lanes. Consequently the use of RTK (real time kinematic) correction signal is assumed. The CTF system used for this thesis is 12-meter system with a 24-meter slurry tanker. The case farm is assumed to use a crop rotation consisting of, home grown grass silage on three to four year grass leys, for the dairy cows, along with a traditional rotation of winter wheat, oats, spring barley and oilseed rape (OSR). However, the crop distribution in the rotation is subject to change in the model. Possible changes to soil nutrient content from previous crops are not regarded when grass areas are in the crop rotation changed.

1.5 Outline

The thesis is based on an academic layout illustrated in Figure 3. Background information presented in the introduction chapter aims to give the reader a basic understanding of the agronomic issues fundamental to this specific economic problem. Chapter 2 presents the theoretical perspective, the theory used to develop a model for comparisons in this study. Chapter 2 is strongly connected to forthcoming methods chapter where the work process of this study is described in detail. Chapter 4 presents the empirical background facts necessary for the study. Detailed figures for the calculations are presented giving the reader an opportunity to comprehend the general context of this study and compare it to studies, thereby enhancing generalizability of the results presented in chapter 5.

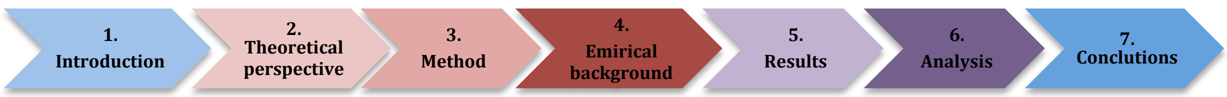


Figure 3: Illustration of thesis outline.

The analysis includes questions raised about possible factors affecting the results of this study together with a detailed comparison of the results. Chapter 7, conclusions, summarizes the study by returning to the research questions formulated in 1.3. The research questions are answered based on new knowledge found from the results of this study.

2 Theoretical framework and model

Chapter 2 provides a theoretical background where relevant theories for this particular research project are described to give a better understanding of the empirical model.

2.1 Theoretical approach

The theoretical basis for this thesis is built upon fundamental micro economic theory (Gravelle and Rees, 1992). Micro level profits, in this case farm profits are maximised. By comparing two different grass silage production systems and four feed ration alternatives. The comparison can be executed using an optimization model that aims to calculate the maximized revenues from RTF and CTF for the case farm. In this model gross margin calculations are used to define the profits from different enterprises in the farming system. However, machinery costs are separated from each enterprise and are presented as first, a fixed capital cost, and second, a variable cost. These gross margins and associated machinery costs constitute the alternatives in the optimization model. The result from the model provides the optimized farm revenue for RTF and CTF.

The problem of this thesis could also be approached with a simulation model. A simulation model, compared to the analytical model previously described, is based upon the outcome of several given conditions. A prerequisite for the use of an analytical model is a realistic simplification of the real world problem. However, this prerequisite is difficult to fulfil since real world problems are often very complex. (Edlund et al., 2007). Suitable simulation models for this study are Agriwise, farm plan program (www, Agriwise, 2014c) or a more advanced model using Monte Carlo simulation. The use of a farm plan would provide comparable revenues for both RTF and CTF. However, this revenues would representcertain given conditions and therefore not necessary an optimal solution. The use of these revenues may affect the generalizability of the result. Simulation models are not limited by mathematical relations, this resulting in more realistic models. This means that the input values of parameters may a follow a stochastic pattern (Edlund et al., 2007). If the exogenous variables for this problem are defined the problem could be solved using a Monte Carlo simulation. However, the use of an analytical model does not only provide the optimized revenues for the case farms but allows for other analytical tools such as a sensitivity analysis of the optimal solution.

2.1.1 Sensitivity analysis

To broaden the extent and use of the study a sensitivity analysis is presented where some alternatives for possible scenarios are analysed when converting from random to controlled traffic. A sensitivity analysis tests the outcome due to changes in some separate factors, which are likely to substantially affect the profits. However, the sensitivity analysis only allows for one value to be changed at the time. The conclusions from the analysis of these factors may be applied as support for an investment decision situation. If there are any particularly uncertain variables, these are useful subject in a sensitivity analysis. (Bergknut et al., 1993). The sensitivity analysis may even provide a break-even point where the investment is viable.

2.2 Applied optimization

Applied optimization is a tool developed within decision theory and management science where mathematical programming is used to find “the best possible solution” for a problem defined in an objective function. The possibility to use an optimization model requires identification of control variables. The problem is defined by an objective function as a maximization or minimization problem, with constraints and non-negative variables. The value of the control variables may be limited by constraints in the model. Lundgren et al. (2001) describes the optimization process in five steps (Figure 4) where the actual problem is defined and simplified to an objective function.

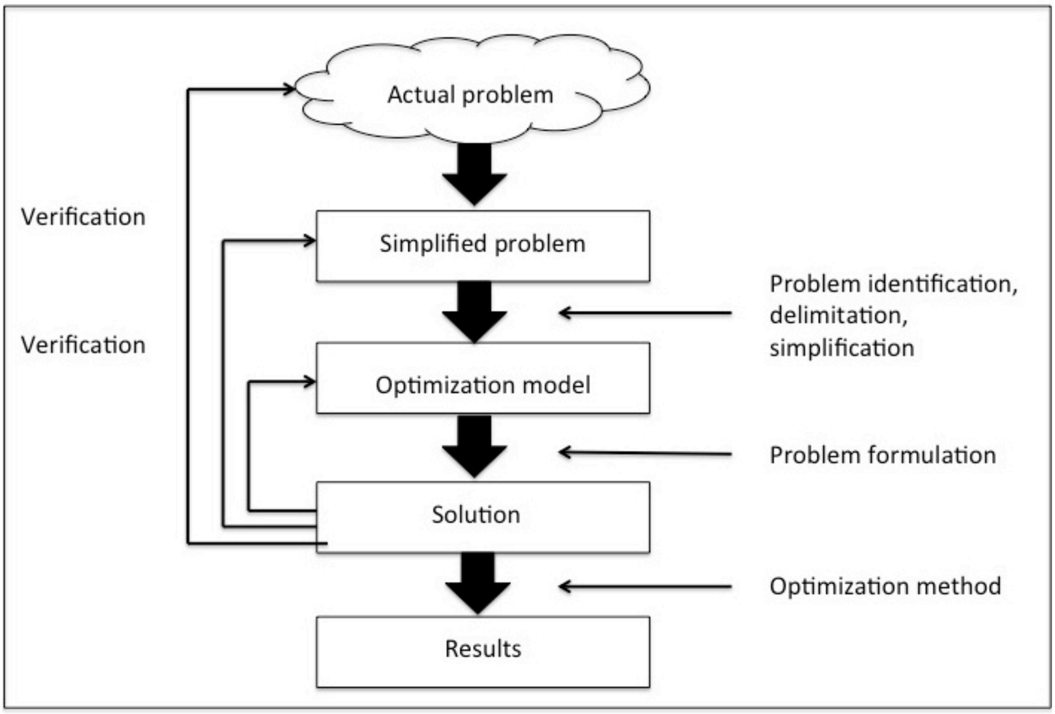


Figure 4: The five steps of the optimization process (Lundgren et al., 2001)

Moreover to find a solution for the actual problem with the optimization model, parameters for the actual problem need the ability to be quantified. In the work process described by Lundgren et al. (Figure 4) the first step is to identify an actual problem, this together with the next step, to simplify the problem, is a rather complex process where the relevant and neglectable factors have to be separated without affecting the relevance of the results. After identifying the core problem and distinctively defining the delimitations the problem can be quantified and described as an optimization model in terms of an objective function, problem constraints and non-negative variables.

Optimization models can be based on both linear and non-linear relations (Lundgren et al., 2001). Linear programming has a broad application in agricultural economics since most of the marginal analysis depend on non-linear relationships (Debertin, 2012). Non-linear problems consist of at least one non-linear function (Lundgren et al., 2001). The model developed for the problem in this study is based on linear relationships where mixed integer programming is used. The model aims to maximize the farm revenue depending on the distribution of crops, machinery system and feed rations for livestock. The optimization model for this thesis uses Excel, details from the spread sheet are presented in appendix 7.

2.2.2 The optimization model

The optimization model developed in this study forms the basis for answering several questions, as described in chapter 1 section 3. There are a number of ways to evaluate these questions. The questions can be divided in two parts. First: CTF or RTF, what is most profitable? Second: based on the outcome of CTF or RTF, what use of the produced silage will maximize the farm level profits?

To solve the problem with regard to the prerequisites presented in chapter 1.4 an optimization model is designed. The optimisation model is based on a maximization problem, formulated as an objective function. In the model silage quantity and quality for RTF is constant, S_{RTF} . For CTF the silage quantity and quality parameters are variable, S_{CTF_f} for index *f,* forage. Three different possible outcomes of CTF, with regard to silage quantity and quality are evaluated, $\forall f = 1 \ldots 3$. Changing the silage parameters in the model enables three different outcomes. When comparing silage from RTF and CTF an alternative feed ration adjusted for one specific silage quality is used. Consequently this model presents four different feed ration alternatives. The first feed ration; FR_{RTF} is based on the silage quantity and quality expected from the RTF system. This feed ration is compared to three alternative feed rations, FR_{CTF_f} associated with potential silage yield quantity and quality form the CTF system. When solving the optimization problem for the three different outcomes of CTF, $\forall f = 1 \ldots 3$ the silage quantity and quality parameters along with the alternative feed ration parameters are changed and compared to RTF.

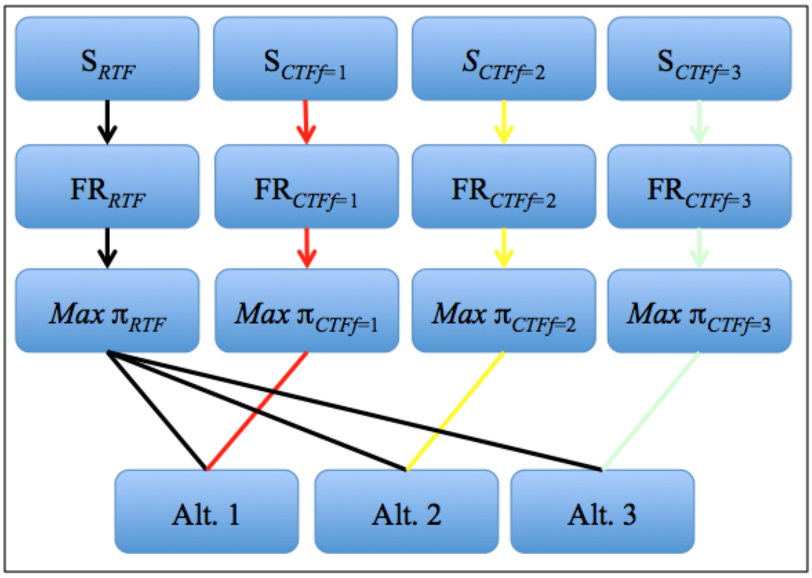


Figure 5: Comparison of RTF and CTF using the optimization model

Figure 5 illustrates the comparison of the optimized revenues from four simulations, RTF and the three possible outcomes of CTF. For each simulation the maximized revenue form the RTF silage, S_{RTF} along with the standard RTF feed ration, FR_{RTF} is compared to; the revenue for each separate simulation, where one of the CTF silage outcomes, S_{CTF_f} for, $\forall f = 1 \ldots 3$ along with an adjusted feed ration, FR_{CTF_f} . The three feed rations are specifically adjusted to each of the different CTF silage qualities, $\forall f = 1 \ldots 3$. The comparison of the optimized revenues from RTF and the three simulations of CTF constitute alternatives one, two and three in the results (chapter 5).

2.2.3 Objective function and constraints

In this section the objective function (1) and constrains (7-17) for the optimization problem are presented. The objective function constitutes the variables subject to change in the optimization model to calculate the maximized total farm revenue. Each of these variables are presented individually in this section.

$$Max\pi = IRTF \cdot C_{RTF} + ICTF \cdot C_{CTF} + \sum_{j=1}^{J} Gm_j \cdot x_j - S_{RTF} \cdot c_{RTF} - \sum_{f=1}^{F} S_{CTF_f} \cdot c_{CTF_f} + \sum_{i=1}^{I} L_i (Gm_i - FR_i)$$

$$IRTF.,ICTF.,x_j.,S_{RTF}.,S_{CTF_f}.,L_i.,FR_i. \qquad (1)$$

The control variables are designed to represent all activities that result in income and costs in the model. The objective function can be divided in to four major parts; fixed machinery costs, arable farming, silage production and livestock production. The control variables included in the objective function are presented in detail in this section (equation 2-6). The first control variable, Equation (2), determines the fixed machinery cost for each system. The binary control variables, $IRTF$ and $ICTF$ determines that the two machinery systems cannot be used simultaneously. These are multiplied by the fixed capital cost for each system, C_{RTF} and C_{CTF} with respect to CTF alternative one, two and three $\forall f = 1 \ldots 3$.

$$IRTF \cdot C_{RTF} + ICTF \cdot C_{CTF} \qquad (2)$$

Furthermore the arable farming revenue is defined as the gross margins for each crop, Gm_j multiplied by the quantity of all arable crop, x_j. The gross margins and quantity of crops in Equation (3) are measured per hectare.

$$\sum_{j=1}^{J} Gm_j \cdot x_j \qquad (3)$$

The RTF grass silage production cost is described in Equation (4) where the quantity of RTF silage measured in number of hectares cultivated, S_{RTF} is multiplied by the sum of the production cost for one hectare of RTF grass silage, c_{RTF}. The production cost includes necessary inputs along with the variable machinery cost for RTF.

$$S_{RTF} \cdot c_{RTF} \qquad (4)$$

Equation (5) defines the CTF system grass silage production cost as the CTF silage production, quantity of hectares, S_{CTF_f}, multiplied by the sum of production cost for one hectare of CTF grass silage, $c_{CTF_f +}$ for any of the three CTF silage alternatives, $\forall f = 1 \ldots 3$. The production cost includes necessary inputs along with the variable machinery cost for CTF

$$\sum_{f=1}^{F} S_{CTF_f} \cdot c_{CTF_f} \qquad (5)$$

The revenues from the dairy cows are defined by Equation (6). Where, L_i is the number of cows, and, FR_i is the feed cost for one unit of cows and, Gm_i is the gross margin for of unit cows where, i defines the feed ration alternatives. The variables for Equation (1-6) are found in Figure 6.

$$\sum_{i=1}^{I} L_i (Gm_i - FR_i) \qquad (6)$$

To solve the optimization model all 13 constraint, Equation (7 to 17) must be satisfied. The constraints stem from the delimitations of this thesis and are related to practical situations for the case farm.

$$\sum_{j=1}^{J} x_j + S_{RTF} + \sum_{f=1}^{F} S_{CTF_f} \leq A \qquad (7)$$

The area constraint (7) restrains the total area for arable crops x_j, RTF grass, S_{RTF} and CTF grass, S_{CTF_f} in the model to the available land area (A) for the case farm.

$$L_i = 300 \qquad (8)$$

Constraint (8) regulates the number dairy cows (L_i) to 300.

$$FR_{RTF} + FR_{CTF_f} - \sum_{i=1}^{I} L_i \geq 0 \qquad \forall f = 1 \ldots 3 \qquad (9)$$

$$YRTF \cdot RTF_{MJ} + YCTF_f \cdot CTF_{MJ_f} - \sum_{i=1}^{I} L_i \cdot FR_{MJ_f} \geq 0 \qquad \forall f = 1 \ldots 3 \qquad (10)$$

$$YRTF \cdot RTF_{AAT} + YCTF_f \cdot CTF_{AAT_f} - \sum_{i=1}^{I} L_i \cdot FR_{AAT_f} \geq 0 \qquad \forall f = 1 \ldots 3 \qquad (11)$$

The feeding system is modelled by the constraints (9), (10 and (11). Equation (9) determines the total feed consumption, where the sum of all feed rations, FR_{RTF} and FR_{CTF_f}, measured in units of feed ration per cow must exceed or be equal to the total number of cows L_i. Thereby for each unit of cow one unit of feed ration must be produced. The nutritional requirements for each cow must be met by all feed rations. This is ensured by the two constraints (10) and (11). The energy and protein requirements for each feed ration is defined by the nutrient requirements in relation to expected milk yield. The feed rations are adjusted to the four different silage production systems. The expected silage quality determines the silage fraction in the different feed ration alternatives. The silage energy, RTF_{MJ} and CTF_{MJ_f} and protein, RTF_{AAT} plus CTF_{AAT_f} is defined as a share of the dry matter yield. The energy and protein share is multiplied by the total yield for each system, *YRTF* and, *YCTF* to find the total energy and protein production. The total energy and protein content from the silage has to exceed or be equal to the energy, FR_{MJ_f} and protein, FR_{AAT_f} requirements for silage in one unit of feed ration multiplied by the total number of cows, L_i. In the model the CTF silage, S_{CTF_f} and feed ration, FR_{CTF_f} parameters are adjusted to three potential outcomes from CTF $\forall f = 1 \ldots 3$. These three silage qualities and feed rations are individually compared to the RTF silage, S_{RTF} and the standard feed ration, FR_{RTF} using the maximized revenue from the objective function to calculate the difference in profits from each case. However the model does not constrain the use of CTF silage production system to any specific feed ration. Consequently the standard feed ration is available for any silage production system and may be used, if the energy and protein constraints (10, 11) are met, in a optimal solution.

$$x_{j3} \leq 35 \qquad (12)$$

$$x_{Oats} + x_{Barley} \geq 0,33 \cdot RTF + 0,25 \cdot CTF_f \qquad \forall f = 1 \ldots 3 \qquad (13)$$

$$x_{j1} = x_{j2} \qquad (14)$$

The constraints (12), (13) and (14) constitute the crop rotation. Constraint (12) determines the allowable area for oil seed rape in the crop rotation to a maximum of 35 hectares. The grass ley is established in a nurse crop. In this case any spring cereal crops of oats or barley may be applicable. Equation (13) determines the required nurse crop area for re-seeding the grass ley. In this study it is assumed that the RTF grass ley is re-established every third year and the CTF ley is re-established every fourth year. Consequently for the RTF system one third of the grass area is re-established every year, which requires one third of the grass area to be cultivated with oats or spring barley. The same applies to the CTF system. However, the re-establishment frequency is assumed to be every fourth year due to better regrowth when the majority of grass is not trafficked. To comply with the desired crop rotation, constraint (14) requires the oats and spring barley areas to be equal, thereby diversifying the cereal crops in the rotation.

$$ICTF + IRTF = 1 \qquad (15)$$

$$S_{RTF} \leq IRTF \cdot 300 \qquad (16)$$

$$S_{CTF_f} \leq ICTF \cdot 300 \qquad \forall f = 1 \ldots 3 \qquad (17)$$

When changing silage production system the machinery costs are subject to change. The objective function (1) determines that the total revenue is affected by both fixed and variable machinery costs. Constraints (15, 16, 17) determine the fixed machinery costs. Equation (15) states that the sum of IRTF and ICTF systems is equal to one. This ensures that the two production systems cannot be used simultaneously. The binary control variables IRTF and ICTF in the objective function (1) represent the fixed machinery cost for each silage production system. To connect the fixed machinery cost with the operational production system, constraints (16) and (17) regulates the cultivated area of RTF, S_{RTF} and CTF grass, S_{CTF_f} must not exceed the binary control variable IRTF or ICTF each multiplied by 300 (A). The variables for Equations are found in (1-17) in Figure 6

x_j	Quantity hectares of crop *j*
Gm_j	Gross margin for one hectare of crop *j*
S_{RTF}	Quantity, hectares of RTF silage
S_{CTF_f}	Quantity, hectares of CTF silage for CTF silage *f* for ∀ *f*=1…3
c_{RTF}	Production cost for one hectare of RTF grass ley
c_{CTF_f}	Production cost for one hectare of CTF grass ley *f* for ∀ *f*=1…3
L_i	Quantity of Livestock (dairy cows) *i,* where *i* defines feed ration *i=f*
Gm_i	Gross margin from one unit of L_i
FR_{RTF}	Standard feed ration based on RTF silage production
FR_{CTF_f}	Alternative feed rations based on CTF silage production ∀ *f*=1…3
FR_i	Feed cost for grain and feed concentrate for one unit of L_i 1=RTF and 2-4=CTF
IRTF	Binary control variable for RTF machinery system
ICTF	Binary control variable for CTF machinery system
C_{RTF}	Total capital cost for RTF machinery system
C_{CTF}	Total capital cost for CTF machinery system
RTF_{MJ}	Energy content of one kg DM of RTF silage
CTF_{MJ_f}	Energy content of one kg DM of CTF silage ∀*f*= 1…3
FR_{MJ_f}	Energy content in feed ration from silage *f*
RTF_{AAT}	Protein content of one kg DM of RTF silage
CTF_{AAT_f}	Protein content of one kg DM of CTF silage ∀*f*= 1…3
FR_{AAT_f}	Protein content in feed ration from silage *f*
A	Total area of tillable land
YRTF	Herbage yield (kg DM/ha) RTF
$YCTF_f$	Herbage yield (kg DM/ha) CTF *f* ∀*f*=1…. 3
x_{j1}	Quantity, hectares of Oats
x_{j2}	Quantity, hectares of Barley
x_{j3}	Quantity, hectares of Oil seed rape

Figure 6: List of variables for Equations (1-17)

2.3 Model for machinery cost calculations

In this section theory related to calculations used to set up the alternatives for the mixed integer optimization is presented.

2.3.1 Machinery Costs

The Machinery cost for both CTF and RTF systems are calculated based on Equations (19, 20 and 21) presented further in this section. The machinery systems for both RTF and CTF have been discussed with Christer Johansson, agricultural technical advisor, LRF Konsult to validate that the choice of system represent typical systems (pers. Comm, Johansson, C., 2014) There are three major parts that define the annual machinery costs, cost of capital, maintenance cost and fuel consumption. All three are calculated with respect to annual use in both systems and are adjusted according to the crop rotation. The process is broken down in to six steps presented below:

I. Replacement value

One of the factors for calculating the capital cost is the replacement value. The replacement value is defined as the price of a new machinery with similar functionality. This value is used to calculate an average annual cost where the machinery is replaced during the period. The replacement value is based on average prices, from several manufacturers collected and published in a machinery costs booklet (Maskinkostnader, 2014) In addition some price data for specific machinery has be obtained a from machinery distributor (pers, Comm, Larsson, H.,2014)

II. Annuity factor

The annuity factor represents the cost of capital that is determined by the interest rate and instalments as an average during the period. The use of an annuity factor provides a fixed annual cost during the period (Brealey et al., 2008). The real interest rate, r is calculated by the Fisher Equation (18) based on the nominal interest rate, i and the inflation rate, π (Fisher, 1930). The period, t is determined by the economic life-span of the machinery, which is defined at three intervals, in Maskinkostnader, (2014) based on annual use. The depreciation periods are adjusted to the annual use and are adjusted to changes in the cereals/grass ley ratio. The annuity factor for each machine is defined in Equation (19). The variables for Equation (18) and (19) are found in Figure 7.

$$r = \frac{1+i}{1+\pi} - 1 \qquad (18)$$

$$AF = \frac{r}{1-(1+r)^{-t}} \qquad (19)$$

r = real interest rate
i = nominal interest rate
π = inflation rate
AF = annuity factor
t = period of t years

Figure 7: List of variables for Equation (18) and (19)

III. Present value

The present value is used in investment situations where future payments are to be valued today (Brealey et al., 2008).The present values are discounted by dividing the value with a discount factor based on the discount rate during the period. The real interest rate, *r* defined in equation (18) is used for the present value to resemble an investment with similar risk. As for the machinery costs the salvage value, SV of machinery is of subject to present value calculations. The salvage value at the end of the economic lifetime, *t* is estimated to 25 % of the replacement value (www, Agriwise, 2014a). When calculating the capital cost, the present value of the salvage value after the economic life-time is subtracted from the replacement value and multiplied by the annuity factor (19). The variables for Equation (20) are found in Figure 8.

$$PV = (\frac{SV}{1+r})^t \qquad (20)$$

PV= present value of future payment
SV= salvage value of machinery at the end of economic lifetime
r = real discount rate
t = period of *t* years

Figure 8: Variables for present value Equation (20)

IV. Annual use

Machinery working capacity is based on figures from (Maskinkostnader, 2014). These are calculated based on a theoretical capacity where the working width and speed is multiplied. The factor from the theoretical machinery capacity is then adjusted for headland turns, which yields a value of hectares per hour (pers. Comm, Johansson, C., 2014). The working capacity is then taken into account along with desired field operations e.g. number of spraying operations, grass cuts, years before re-establishing grass ley or number of passes with the harrow to determine the annual machinery use. Annual use is calculated for each machine as well as for the tractor required in each specific operation. These figures constitute the basis for calculating the machinery economic lifetime and the maintenance and labour costs.

V. Maintenance cost

The maintenance costs are calculated as described in Equation (21) based on two repair factors from ASABE Standards (2011), the technical lifetime and replacement value of the machine. Even though ASABE Standards provide a figure of expected lifetime in hours this calculation is conducted assuming an upper limit of 25 years in line with Agriwise (2014a) maximum machinery lifetime. In some cases the annual use is rather low and the lifetime of some machinery according to ASABE Standards would be above 40 years and would therefore not comply with the expected salvage value of 25 %. The variables in Equation (21) are presented in Figure 9

$$C_{Mt} = \frac{RF1 \cdot RV \left(\frac{h \cdot TL}{1000} \right)^{RF2}}{TL} \qquad (21)$$

C_{Mt} = *annual maintenance cost*
RF1 = *repair factor 1*
RF2 =*repair factor 2*
RV =*replacement value*
TL =*technical lifetime*
H =*annual usage*

Figure 9: List of variables for Equation (21)

VI. Fuel cost

The fuel consumption for each field operation is estimated by using data from Agriwise (2014a) and Maskinkostnader (2014). This provides an interval of consumption for different tractor sizes from heavy to light use. This estimation is conducted for each different field operation. The fuel cost from Maskinkostnader (2014) is calculated on the basis of a diesel price of 10 SEK/litre, which is an estimate of farmers price excluding VAT and after refund of CO_2 emissions tax.

In the objective function (1) Equation (19) and (20) constitute the fixed capital cost for each system, C_{RTF} and, C_{CTF}. The maintenance cost (21) along with the fuel and labour costs constitute the variable machinery cost accounted for in the cereals gross margin, Gm_j and the silage production cost, c_{RTF} and, c_{CTF_f}.

2.4 Yield outcome from controlled traffic

The literature review reveals no field trials results regarding yield outcome from CTF in grass ley but only comparisons of conventionally trafficked and zero trafficked grass ley. To find useful figures for this project a theoretical approached is used. The theoretical approach to estimate the yield potential in a CTF system has to be made utilizing greek geometry. By calculating the tracked area and simply detain yields for trafficked and non-trafficked area respectively. The potential yield response from converting to controlled traffic stems from the tracked area. By comparing the tracked areas in RTF and CTF to yield responses from tracked and non-tracked areas in field trials the potential yield response in a CTF system is calculated, Equation (22). The field trials and tracked area in both systems are presented in chapter 4.

$$X_Y = \frac{Y_{RTF}}{A_T \cdot Y_D + A_{NT}} \tag{21}$$

$$Y_{CTF} = X_Y \cdot (A_T \cdot Y_D + A_{NT}) \tag{22}$$

Y_{RT}	= Yield random traffic
Y_{CTF}	= Yield controlled traffic
X_Y	= Zero traffic theoretical yield
Y_D	= Yield depression from field traffic
A_T	= Trafficked area
A_{NT}	= Non-trafficked area

Figure 10: List of variables for Equation (21) and (22)

Using knowledge about yield depression from a non-trafficked to a 100 % trafficked area we use Equation (21) to calculate the potential yield in a no traffic scenario starting from a normal yield, Y_{RTF} and the RTF system trafficked area, A_T. Using the no traffic theoretical yield and the tracked area in a CTF scenario in Equation (22) gives the new yield in a CTF system. The variables for Equation (21) and (22) are found in Figure 10. The trafficked areas used in this study are presented in Figure 12 and 13. Based on the theoretical framework presented in chapter 2 this study will be conducted with the method presented in chapter 3.

3 Method

In this chapter the fundamental steps for conducting the project are presented. This includes choice of method and other considerations with regard to the methodological framework.

3.1 Research design and strategy

Traditionally when choosing research design there are two choices, quantitative and qualitative methods. Robson (2011) describes these two approaches as fixed or flexible design. The fixed design signifies a predefined method for data collection. However in a flexible design there is only a preliminary outline for the collection of data, which might change during the course of work. These two fundamental research approaches are not to be considered as opposites but in contrast the combination of the two and different kinds of data can be highly synergistic (Eisenhardt, 1989; Robson, 2011). Robson (2011) describes a multi-strategy approach, sometimes labelled mixed methods, as a mix of the two traditional quantitative-qualitative approaches that emerged in the 1990s and are able to combine these in a variety of ways. The objective of this study is to find generalizable and comparable results for two different silage production systems given differences in machinery system. Starting from existing research data regarding machinery and yield outcome these data are compared with data obtained from farmers practicing the alternative production system, this represents a choice of a mixed method approach.

Robson (2011) suggests choosing a suitable research design with regard to the research questions and the purpose of the study. Regarding the research questions in this study there is a possibility to use a qualitative approach in the context of a case study comparison of farm profits on several farms with different grass silage production systems. However since the objective of this study is to find a generalizable result that can be used in several situations and furthermore to develop a model for evaluating farm profits when choosing machinery system for grass silage production the quantitative approach is more suitable to the objectives. Gummesson (2006) on the other hand emphasizes that certain characteristics in a subject requires the use of a qualitative approach to accomplish a genuine relevance. Even though this study is be conducted with a quantitative approach some qualitative elements such as interviews are used to validate the empirical data.

3.1.1 Work process

The work process for this study is illustrated in Figure 11.The figure relates to the use and interpretation of data. Starting from the problem statement, a theoretical approach to the problem is determined. The theoretical approach provides a tool box to interpret data from previous studies. The literature review reveals that data exists from previous studies relating to several parts of this research project. Some of the data are contradictory. In order to resolve some questions regarding this problem, interviews are conducted in order to find useful practical experiences and data that are not available in the literature. Thereby, useful data is established for this study. This data is then analysed with regard to the context of this thesis taking in to account delimitations, practical issues and generalizability.

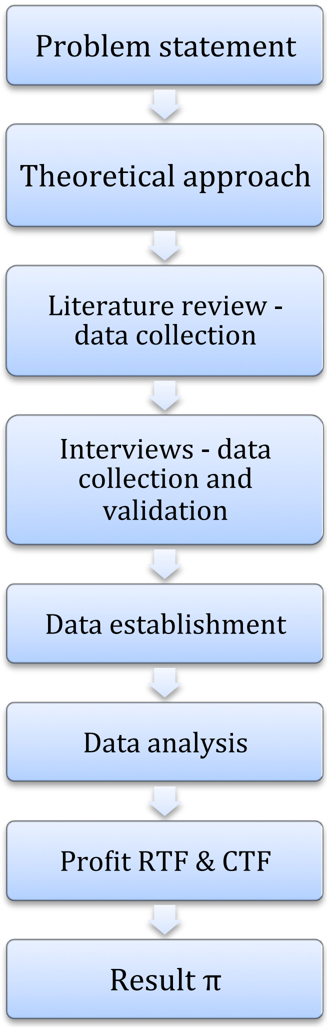


Figure 11: Illustration of thesis work process

The data represents parameters in the mixed integer programming model, Equation (1) – (17), which provide the optimal choice of RTF or CTF system. The difference in profits is compared and constitutes the final result of this study.

3.2 Methods for literature review and data collection

Both Eisenhardt (1989) and Yin (2009) note the importance of the choice of research question and unit of analysis for the development of problem understanding. Hence an early start with a literature review and theory development in this study is important for developing a more refined understanding of the problem.

The study is based on a deductive approach where well-established theory is used to provide a general description of the problem as well as existing methods used to examine similar problems. Moreover this is to some extent combined with an inductive approach where persons who possess a certain expertise are interviewed to connect the assumptions to reality in order to validate the final results.

As illustrated in Figure 11, the process of this research project starts with the collection of data from a literature review where articles on different field trials are examined to find if there is a common relation between soil compaction or field traffic and yield outcome. Ten different studies are compared and even though the majority of them show similar results only one study is relevant to the problem presented in chapter 1.4.

3.2.1 Data collection

Robson (2011) stresses the advantage of using computer in handling data in a quantitative approach. For this particular research project Excel has been used to organize and present the data, but also to solve the programming problem (Equation (1) The most uncertain variable in this study is the yield response associated with to changing field traffic system. To solve this problem, data collection triangulation is used, which increases the validity and thus the data quality.

Robson (2011) refers to four types of triangulation:

- *Data triangulation.* The use of more than one method of data collection.
- *Observer triangulation.* Using more than one observer in the study
- *Methodological triangulation.* Combining quantitative and qualitative approaches.
- *Theory triangulation.* Using multiple theories or perspectives.

For this study the first three types of triangulation are used. The critical data collection regarding yield response is triangulated using several field trial studies and interviews with farmers using CTF in grass production. This also extends to the second type, *observer triangulation,* since all data observations in this study stem from more than one source with in the same observation method. As described in Robson (2011) the third triangulation type, mixed method, is a typical way of triangulating. Triangulation is a way of increasing validity. However, it should be noted that the use of different contradicting sources might open up possibilities for discrepancies between different sources. Moreover Robson (2011) raises the argument introduced by Bloor (1997, pp. 38-41) that even though the use of triangulation is relevant for validity, it raises both logical and practical issues when comparing findings collected by different methods. These difficulties are found when collecting data regarding yield response in this particular study. In the final calculation only one out of 10 studies are used.

3.3 Interviews

The qualitative part of the study consists of interviews, which provides a link between theory and the real world. During different stages in the research process farmers, advisors, researchers and representatives for machinery manufacturers have been interviewed.

There are two purposes for conduction interviews in this study. First; to validate assumptions made on the basis of previous research and second; to gather technical information required for the calculations. Additionally, information regarding practical observations, difficulties and possible solutions from farmers that use CTF are found rewarding and might increase the practical connection and thereby the generalizability and quality of the results.

Table 1: Presentation of interviews conducted in this study

Organisation	Interviewee	Position	Location	Interview date
SLU	Bodil Farnkow-Lindberg	Professor Agricultural Cropping Systems	Uppsala	2014-05-27
LRF Konsult	Christer Johansson	Agricultural technical advisor	Linköping	2014-07-04
SLU	Rolf Spörndly	Research Group Leader, Feed Science Division	Uppsala	2014-06-16 & 2014-08-19
Knepperhedegård	Jørgen Sønderby	Organic Dariy Farmer	Bjerringbro, Denmark	2014-06-20
Poul Sørensen	Poul Sørensen	Dairy Farmer	Fjerritslev, Denmark	2014-06-21

The interview questions differ for the persons introduced in table 1 based on the information required from the individual interview object. The method used for interviews is a semi-structured interview. The interviewer has a guide for the interview with a default wording and order of questions but still allows a flexibility modifying the interview based on how the interview progresses. The semi-structured interview method often leads to unplanned questions to follow up the answers. This type of interview is widely used in multi-strategy research designs, such as this particular project, where the researcher is also the interviewer (Robson, 2011). The farmers interviewed in this project are asked some generic questions regarding their farm operations, farm size, machinery systems etc. but are then encouraged to tell the story about the conversion to CTF with pros and cons. The other interviews are more structured where the interview objects often provide specific knowledge or data that is crucial for the results of this study. This method of data collection might be a weak link causing errors in the results. However, given the interview objects and their specific expertise in the given area this approach is used. All interview are transcribed and presented in appendix 1 to 5.

3.4 Calculations and data analysis

The traditional quantitative part that represents the major part of this project is associated not only to data collection but also to data analysis using mixed integer programing. The parameter values in the objective function and constraint functions are for example technical coefficients for the inputs used, both in terms of machinery and seeds, fertilizer, crop protection and preservatives for silage conservation. These are used when calculating the gross margins in the mixed integer programming model. The gross margin calculations are conducted using data from Agriwise (www, Agriwise, 2014b). Adjustments are made for manure use, average grain and fertilizer prices. To compare values of the two different silage production systems (RTF and CTF) four different feed rations are defined (pers. Comm, Spörndly, R., 2014). Using a fixed milk ECM yield the subject of change are inputs of forage, grain and protein feed concentrate. Silage price is implicitly accounted for by machinery costs and associated input costs as production costs in the mixed integer programming model.

However the grain and compound feed cost is expressed as the feed ration cost. The feed ration cost changes as the silage volume and quality is adjusted with respect to the three different possible outcomes of CTF, $\forall f = 1 \ldots 3$. By defining the objective function with one standard (RTF) and one alternative (CTF) feed rations the model is used to examine if RTF or CTF is profitable for three specific alternative outcomes. Details regarding the feed rations are presented in section 4.5. The profit for the three alternative outcomes is expressed as the differences between two maximised solutions of the objective function (23).

$$Max\pi_{CTF}^{f} - Max\pi_{RTF} \qquad \forall f = 1 \ldots 3 \qquad (23)$$

4 Data for the empirical study

The following chapter provides an introduction to the empirical data, which are necessary for executing this study and to present the empirical results.

4.1 Field trial data

There are several studies conducted comparing yield outcome in grass ley from trafficked and non-trafficked areas. In Table 2, ten different field trial studies are presented providing a general picture of yield decrease from field traffic. In order to obtain parameter values for the calculations regarding potential yield outcome in a CTF operated system the conditions, methods and results from different studies are compared. The comparison is conducted with respect to dry matter yield changes from soil compaction or field traffic and changes in the botanical composition for grass-clover leys.

Table 2: Presentation of field trial studies found in the literature review where changes due to soil compaction is expressed as yield decrease in the trafficked area

Yield response				
Study	**Yield decrease**	**Grass crop**	**Soil type**	**Location**
Douglas & Crawford, 1991	32%	Ryegrass	Clay loam	Scotland
Douglas et al., 1992	13%	Ryegrass	Clay loam	Scotland
Elonen, 1986	8-68%	-	Clay loam	Finland
Frame, 1982	11-36 %	Red clover	-	Scotland
Frost, 1988	9-13%	Ryegrass	Clay loam - sandy clay loam	Northern Ireland
Hansen, 1996	27%	Grass/clover	Sandy loam	Norway
Håkansson et al., 1990	9%	Grass/clover	Various	Sweden
Jorajuria et al,. 1997	74%	Grass/Clover	Silty loam	Argentina
Jørgensen et al., 2009	4,6-23%	Grass/Clover	-	Denmark
Rasmussen & Møller, 1981	21-54%	Ryegrass & Grass/clover	Sandy loam & Silty loam	Denmark

The studies presented in table 2 mainly compare 100% trafficked area to a zero traffic reference area. As described in chapter 2, Equation (22) is used to calculate the yield change in a CTF system with respect to trafficked and non-trafficked area. Reviewing these field trial results with consideration to methods used should provide realistic figures for a CTF scenario. Selecting studies conducted over a three to four year period should give a generalizable average herbage yield. Douglas et al. (1992) reveal substantial differences in second to fourth year but only marginal changes in the first year. In chapter 1.4 the delimitations for this study states the assumption of three and four year grass leys for RTF and CTF respectively. This leaves only Douglas et al. (1992) and Hansen (1996) that conducted studies over a period of three to four years together with Håkansson et al. (1990) who conducted a study of 24 trial sites with a variety of years in ley and cuts per year. Other studies presented in table 2 (Douglas and Crawford, 1991; Elonen, 1986; Frame, 1982; Frost, 1988; Jorajuria et al., 1997; Jørgensen et al., 2009; Rasmussen and Møller, 1981) which are conducted in one or two years. Some of them only review yield responses for one cut. Håkansson et al. (1990) argues that herbage yields tend to decrease in relation to the number of cuts. Consequently, the relevance of studies conducted of only one cut is of less significance for this study although of interest to this subject.

For this specific study the value of increased clover content in silage is a part of the problem statement. This leaves only Hansen (1996) including grass-clover silage as a basis for the yield change estimation. Hansen (1996) presents several fertilizer and manure treatment alternatives. However for this study, the alternative most reasonable for contemporary silage production is chosen, 177kg N/ha/year. This treatment resulted in an average yield reduction from soil compaction of 18.4%. In addition to this the botanical composition changed. In the third year, clover share amounted to 2% more in the non-compacted ley compared to compacted ley. This is mainly due to the continued growth of red clover, which has proved to be quite sensitive to intensive field traffic, not mainly as an effect on soil compaction but as a result of wheel traffic. Frame (1982) and Rasmussen & Møller (1981) also conclude that the reduction of red clover content is not only a result due to soil compaction but mainly a result from mechanical plant damage. Alsike clover used in Hansen (1996) is rarely used in grass-clover seed mixes today, (pers. Comm, Frankow-Lindberg, B., 2014), this might affect the interpretation of the results. The botanical composition also changes with regard to weeds where the percentage of monocotyledon weeds in the ley changed from 5 to 12% on average from uncompacted to compacted soil (Hansen, 1996).

4.2 Yield change

The yield used to calculate the results in this study is based on figures presented in table 3 where machinery system for both RTF and CTF is taken into account for the potential yield outcome of CTF.

Table 3: CTF theoretical yield response

Theoretical yield response CTF based on Hansen, 1996			
Normal yield kg DM/ha RTF	Traffic reduction	Tracked area RTF	Tracked area CTF
8000	18%	74%	20%
Theoretical no traffic yield	9261	Yield CTF kgDM/ha	8960
increase %	**12%**		

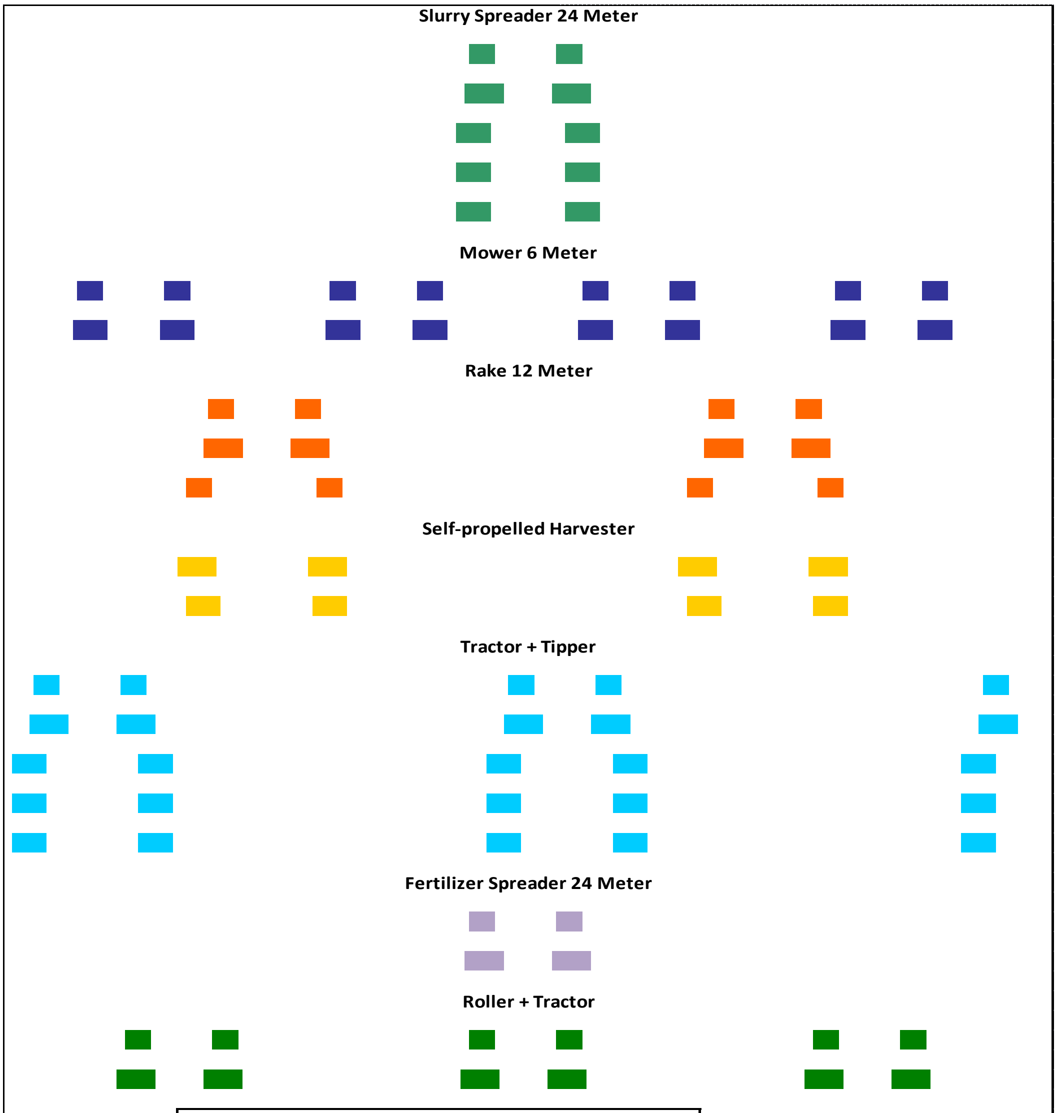
By using Equation 22 (chapter 2) and yield responses from Hansen (1996) the theoretical yield response from a CFT system covering 20 per cent area with tracks is calculated, and presented in table 3. The normal grass yields in this study are collected from a recent study by Henriksson et al. (2012) that collected yield data from statistics and agricultural advisor for different regions in Sweden, which is in line with the delimitations in chapter 1.4 .The region West in Henriksson et al. best suits the GNS region to which this study applies.

4.3 Description of machinery systems

The machinery system used on the case farm is altered to fit a CTF system by replacing the mower, rake and roller. These changes imply the replacement of both tractors due to increased power requirements from both mower and rake. However the new 12,30 meter mower is available in three alternatives. One model without conditioner which only requires 145 kW. The middle alternative which enables conditioning, and the third and most versatile one allows both conditioning and collection from the full working width in to a single swath of grass. The third alternative requires a 220 kW tractor and the available grass treatment, conditioner and collector, is equal to the 6 meter mower used in the random traffic system. The possibility to build a CTF 12 meter grass harvest system on the first or second alternative would definitely reduce the need for machinery investments and should be regarded as an alternative when converting to CTF. However, given the limitations of this study the changes in forage quality from soil contamination due to raking and prolonged drying from no conditioning cannot be taken into account. Therefore this study presents a similar forage harvest system as in RTF. In the analysis machinery costs for an alternative system is presented.

4.3.1 Random traffic machinery system

The machinery systems tracked area, Figure (12 and 13) are calculated using a program developed by Pedersen and Novak (2013), which gives an overview of the track patterns of the machinery. The random traffic machinery system uses the machinery presented in Figure 10. The tractors and harvester uses GPS guidance system with 15 cm accuracy, which is considered by a 5% overlap when the tracked area is calculated.



Data	Tracked	Uncropped
Percentage	74%	0%

Figure 12: Illustration of RTF machinery system traffic pattern (model from Pedersen and Novak, 2013)

Figure 12 illustrates a 24 wide area and the traffic pattern expected from a RTF machinery system, based on actual machinery measurements (per. Comm, Larsson, H, 2014). The 24-meter slurry spreader makes one pass in this illustration. The 6-meter mower passes the 24-meter span 4. The self-propelled forage harvester working at a width of 12 meter as a result of 12-meter rake both passing the 24-meter span two times. The tractor and tipper wagon that follows the self-propelled forage harvester drives alongside the harvester thereby increasing the trafficked area.

4.3.2 Controlled traffic machinery system

The CTF system uses an overall 12-meter module width, with exception for a slurry tanker and the fertilizer spreader working at 24-meter. The GPS guidance system uses a RTK (real time kinematic) correction signal enabling 2.5 centimetre accuracy auto steering with the possibility to return to the same tracks year after year. The tracked area is calculated using actual machinery measurements (per. Comm, Larsson, H, 2014).

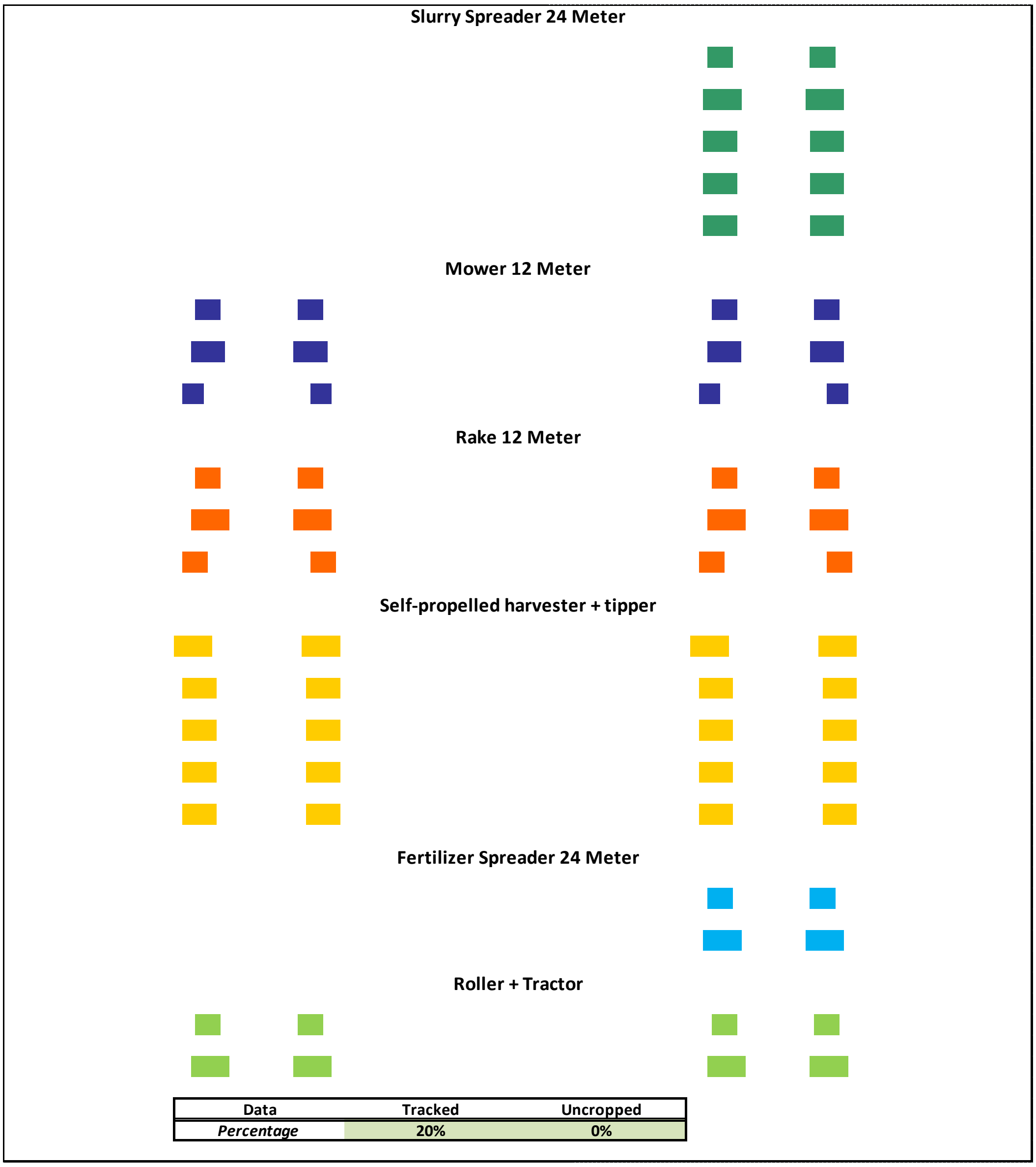


Figure 13: Illustration of CTF machinery system traffic pattern (model from Pedersen and Novak, 2013)

The 24-meter slurry spreader operates at every second permanent field track. All other machinery work at 12-meter and use the same tracks reducing the trafficked area from 74% in RTF to 20% with CTF, as Illustrated in Figure 13. For this system the tipper wagon is assumed to be pulled by the self-propelled forage harvester and to be changed at the headland.

4.4 Machinery costs

The machinery costs used in the mixed integer programming model to compare the two systems are calculated as presented in chapter 2.3.2. In the programming model the costs are separated into two fractions, fixed and variable costs. The fixed costs originate from the capital cost and the variable cost stems from maintenance, fuel and labour cost.

Table 4: Summary of changes in fixed, variable and total machinery costs from RTF and CTF

Machinery cost summary			
	Fixed cost	Total variable cost	Total annual cost
Random traffic	1 042 677 SEK	999 799 SEK	2 042 476 SEK
SEK/ha	3 476 SEK	3 333 SEK	6 808 SEK
Controlled traffic	1 161 985 SEK	945 378 SEK	2 107 363 SEK
SEK/ha	3 873 SEK	3 151 SEK	7 025 SEK

In table 4 a comparison of machinery costs from both the RTF and CTF systems are presented. The introduction of a CTF system increases fixed machinery costs induced by machinery investments. However the variable costs are likely to decrease, depending on the crop rotation determined by the objective function (1) and constraints presented in chapter 2. The values in table 4 are based on the crop rotation for the solution of alternative 1, presented in detail in chapter 5.1. The total annual cost for machinery increases by 64 877 SEK when using CTF in this example. A detailed presentation of the machinery cost calculation are found in Appendix 6.

4.5 Feed rations

To quantify the value of a machinery system allowing less field traffic in grass silage production, the change in feed quantity and quality has to be considered. The yield response due to decreased field traffic is well established in the literature (4.1). However, regarding changes in energy (MJ/kgDM) and crude protein (cp g/kgDM) content for a grass-clover ley there are no accurate data. Nevertheless both previous research (Frame, 1982; Hansen, 1996) and field observations indicates a reduced growth of clover on heavily trafficked soils (pers, Comm, Sørensen, P., 2014)

Table 5: Summary of the feed rations nutritional and price data.

Feed rations nutritional content								
Feed rations	Silage Price=0 (production cost)			Grain (barley) price=1.29 SEK/kg		Protein concentrate price= 3.6 SEK/kg		Price/cow
	MJ/kgDM	cp as g/kgDM	Feed intake (relative)	MJ/kgDM	cp as g/kgDM	MJ/kgDM	cp as g/kgDM	
FR 1	10,5	120	100	13,1	123	13,6	305	7 525 SEK
FR 2	10,5	120	110	13,1	123	13,6	305	7 126 SEK
FR 3	10,4	150	110	13,1	123	13,6	305	6 933 SEK
FR 4	11,2	150	120	13,1	123	13,6	305	6 307 SEK

Together with Rolf Spörndly (Feed science division, Department of Animal nutrition and Management, SLU) four different feed rations are designed (table 5). The four feed rations are based on two alternative scenarios. The first (FR 1) is intended to used with the RTF system. The second ration (FR 2) uses more silage of the same quality as FR1 and is therefore an alternative if CTF produces a higher quantity of silage but with the same quality.

In this case, FR2 is based on a 12% (Equation 22) yield increase. However, this alternative is also available for the RTF system but it uses more land. The third alternative (FR 3) assumes not only a 12 per cent yield increase but also a 10 per cent increase in clover content providing a higher crude protein content. Alternative 4 (FR 4) assumes a similar dry matter yield as FR 1 but due to improved regrowth from reduced field traffic the grass is cut earlier providing a higher quality silage with increased MJ/kgDM and crude protein as g/kgDM content allowing a higher feed intake. The prices presented in table 5 are based on the amount of grain and protein concentrate feed. The silage price is set to zero and implicitly taken into account through the production cost (machinery, establishment and conservation costs) in the model. Hence the decreasing feed ration price as the silage fraction increases for FR 2-4. The feed rations are presented in detail in appendix 8 to 11.

4.6 Summary of gross margins

Table 6 present the gross margins used to calculate the revenues for both RTF and CTF. Using the objective function gross margins for all arable crops are summarized along with the dairy production gross margin and feed costs.

Table 6: Summary of gross margin values and production costs in the objective function

Background data					
Arable	W-Wheat	S-Barley	OSR	Oats	Single farm payment
Yield kg/ha	7300 kg	5600 kg	3800 kg	5500 kg	
Grain price SEK/kg	1.49 SEK	1.29 Sek	3.35 SEK	1.13 SEK	
Gross margin SEK/ha	3 362 SEK	586 SEK	4 825 SEK	346 SEK	1700 SEK
Grass	RTF	CTF		**Dairy cows**	
Yield	8000 kgDM/ha	8960 kgDM/ha		Milk yield kg ECM	9150
Storage and respration losses	20%	20%		Milk price SEK/kg	3.5 SEK
Cost SEK/ha	4 691 SEK	5 049 SEK		Labour h/cow/year	23 h
No. of cuts per year	3	3		Gross margin	12756 SEK
No. of years in ley	3	4			

Moreover both the fixed and variable machinery costs and the direct income payments are added to constitute the final revenue. In line with the delimitations presented in 1.4 the direct income payment for classification area three is assumed. Given the figures provided by the Swedish Board of Agriculture regarding the amount of direct income payment entitled for one hectare is 182.81 € (www, SJVe, 2014). The SEK/€ exchange rate used is 9.2. When comparing the two systems the optimized value of the objective function (Equation 1) for both RTF and CTF is used. This is done by changing the grass yield parameter for each system to an unfavourable value. This is forces the model to find an optimized value for each system. One of these revenues is then compared to the new revenue found when setting the accurate parameters for the optimization model finding the most profitable alternative.

5 Results

This chapter presents the results from the empirical study where total farm profits are compared for the case farm. The result is the outcome from three different tests using the mixed integer programming model (chapter 2.2.2) to compare one standard feed ration (FR 1) and three alternative feed rations (FR 2-4) based on three different possible outcomes of reduced field traffic. The comparison, illustrated in Figure 14, provides three different alternative results with regard to expected changes in silage yield and quality from CTF.

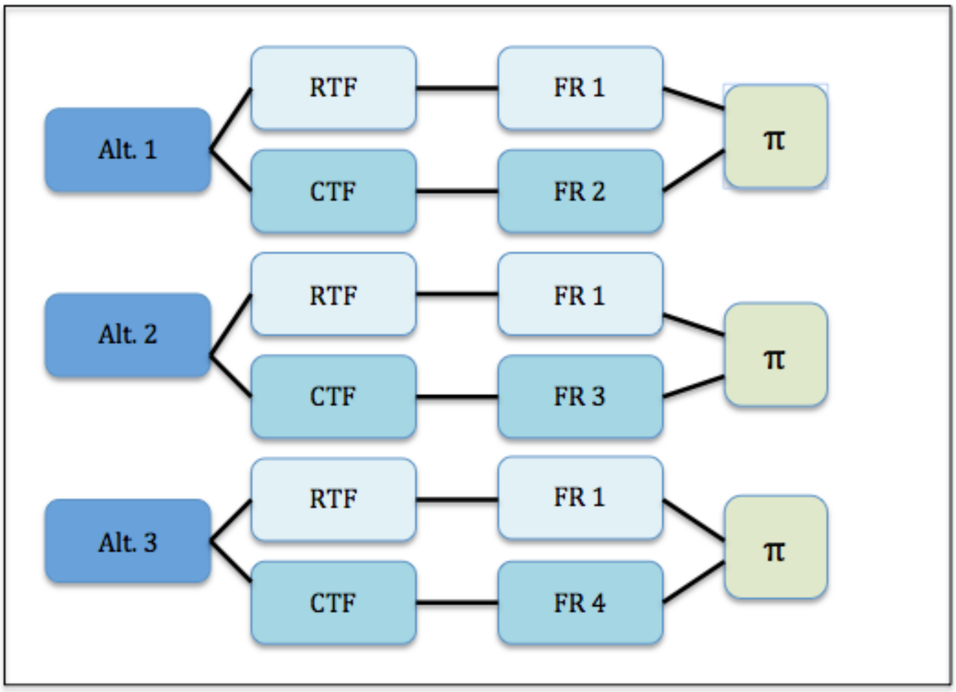


Figure 14: Illustration of the three comparison alternatives presented in chapter 5

The results compared in alternative one, two and three (Figure 14) is expressed as the difference between the optimized revenue for RTF and one of the three CTF scenarios (Equation 23). The three alternatives compare the value of different silage qualities expected from RTF and CTF. The nutritional value of these different silage qualities relates to the total feed ration cost where a more favourable silage quality substitutes costly protein feed concentrates and grain. The optimization model, used for the comparison, allows an alternative feed ration in the CTF scenario. However the standard feed ration (FR 1) is optional with CTF, if it is found to be more profitable. Alternative one (Alt. 1) compares the RTF system associated with the standard feed ration (FR 1) with the CTF system and feed ration two (FR 2) assuming a 12 per cent increased silage yield. Thereby, a higher silage content in the feed ration (FR 2) providing a lower feed cost. Alternative two (Alt. 2) compares RTF and feed ration one (FR 1) with CTF and the alternative feed ration three (FR 3) assuming not only a 12 % yield increase for silage from CTF but 10 % increase of silage clover content resulting in an increase of crude protein content by 25%. Alternative three (Alt. 3) compares RTF and feed ration one (FR 1) with CTF and the alternative feed ration (FR 4). Feed ration four is adjusted to the assumed better regrowth from CTF and therefore earlier silage harvest providing higher quality silage. However in this assumption yields are constant due to shorter period of regrowth. The results and detailed information regarding the three alternatives are presented further in chapter 5.1-3.

5.1 Comparison alternative 1

Alterative one compares revenues from the RTF system with revenues from the CTF system. For both the RTF and CTF system feed ration one and two (FR 1 & 2) are available as alternatives to utilise the assumed energy and crude protein contents of the silage in the most profitable way. Silage energy and crude protein contents is assumed to be equal for both RTF and CTF. However, for CTF silage yield an increase of 12 % is assumed.

Table 7: Summary of crop rotation, revenues, grass yield, feed ration and machinery cost from the optimal values in the model: alternative 1

Results from Comparison Alternative: 1					
RTF	Grass	W-Wheat	S-Barley	OSR	Oats
Crop distribution hectare	161,6	49,2	27,2	35,0	27,2
Total farm revenue	56 780 SEK				
Feed ration	FR 1				
Grass yield	8000 kgDM/ha				
Variable machinery cost SEK/ha	3 591 SEK				
CTF	Grass	W-Wheat	S-Barley	OSR	Oats
Crop distribution hectare	144,3	83,7	18,5	35	18,5
Total farm revenue	201 508 SEK				
Feed ration	FR 1				
Grass yield	8960 kgDM/ha				
Variable machinery cost SEK/ha	3 146 SEK				
Profit *(MaxπCTF-MaxπRTF)*	**144 728 SEK**				

In Table 7 detailed results from the first alternative are presented. The crop rotation induced by converting to CTF enables larger areas for winter wheat and a reduction of the grass area. The silage yield per hectare excludes storage and respiration losses. The increased yield for CTF is calculated using Equation (22) in chapter 2. Both the optimized values for RTF and CTF include feed ration 1 (FR1). This is explained by the non-increased feed intake potential in the second feed ration (Table 5), which despite the lower cost is worth less than the alternative value of producing extra units of wheat. The constraint regarding nurse crops for grass emancipates the oats and barely area in favour for wheat due to the assumption of four instead of three productive years in the grass ley for CTF. Machinery costs for silage production for these two particular crop rotations is 3591 SEK/ha and 3146 SEK/ha for RTF and CTF respectively. The maximised revenue amounts to 201 508 SEK from using a CTF machinery system for silage production. The profit from introducing CTF is measured as the difference between the optimized revenue between RTF and CTF. In this first case the increase in profits amount to 144 728 SEK.

5.2 Comparison alternative 2

Alterative two compares revenues from RTF and CTF with regard to feed ration one and three (FR 1 & 3). Both feed rations are available for RTF and CTF however FR 3 is calculated to utilise the energy and crude protein contents of the CTF system therefore it should be more beneficial in a CTF system. For CTF in this alternative, not only the grass yield is assumed to be increased by 12 % but the grass-clover ley botanical composition is also assumed to be altered providing 10% higher clover content assumed to increase silage crude protein contents by 25 %.

Table 8: Summary of crop rotation, revenues, grass yield, feed ration and machinery cost from the optimal values in the model: alternative 2

Results from Comparison Alternative: 2					
RTF	Grass	W-Wheat	S-Barley	OSR	Oats
Crop distribution hectare	161,6	49,2	27,2	35,0	27,2
Total farm revenue	56 780 SEK				
Feed ration	FR 1				
Grass yield	8000 kgDM/ha				
Variable machinery cost SEK/ha	3 591 SEK				
CTF	Grass	W-Wheat	S-Barley	OSR	Oats
Crop distribution hectare	157	67,8	20,1	35	20,1
Total farm revenue	234 095 SEK				
Feed ration	Fr 3				
Grass yield	8960 kgDM/ha				
Variable machinery cost SEK/ha	3 076 SEK				
Profit *(MaxπCTF-MaxπRTF)*	**177 315 SEK**				

Table 8 summarize the results from the second optimization analysis. In this case there is only a small decrease in grass area, 4.1 ha. However due to the assumption of four instead of three years with high production in a CTF grass ley compared to a RTF grass ley wheat area increases by 18.6 ha in favour of a reduction of less profitable spring crops, such as, barley and oats. The constraint for oil seed rape is binding in both scenarios at 35 ha. As aforementioned the two grass yields are calculated using Equation (22). The variable machinery costs for silage amount to 3591 SEK/ha and 3076 SEK/ha for RTF and CTF respectively. The lower variable silage machinery cost for CTF in this alternative compared to CTF in alternative 1 is explained by changes to the crop rotation. Cultivating lager areas of grass in this case, enables a greater area to distribute the costs. In this case the alternative feed ration (FR3) is used in the optimized solution. As explained in section 4.5, feed ration 3 assumes not only higher DM yield but also an increase in clover content by 10 %, which increases the feed intake capacity. Consequently, the higher nutritional value of the silage decrease the required share of grain and protein concentrate in the feed ration, providing a lower feed ration cost. The total revenue found is 234 095 SEK, which is the maximised revenue using a CTF system for silage production. The difference between the optimized RTF revenue and CTF revenue represents the profit originating from introducing CTF. This profit amount to 177 315 SEK

5.3 Comparison alternative 3

Alternative three follow a similar pattern as alternative one and two where revenues from RTF and CTF are compared to find the most profitable alternative. For this alternative (3) feed ration one and four (FR 1 & 4) are used, both available for RTF and CTF to find the maximised revenue with respect to energy and crude protein contents of silage from RTF and CTF. Feed ration four (FR 4) assumes a stronger and more uniform grass regrowth after harvest allowing earlier cuts thereby increasing silage energy contents in the CTF system. The botanical composition is also assumed to be altered from CTF, increasing clover content by 10 %. The total silage dry matter yield in this CTF scenario is assumed to be similar as RTF due to earlier cuts.

Table 9: Summary of crop rotation, revenues, grass yield, feed ration and machinery cost from the optimal values in the model: alternative 3

Results from Comparison Alternative: 3					
RTF	Grass	W-Wheat	S-Barley	OSR	Oats
Crop distribution hectare	161,6	49,2	27,2	35,0	27,2
Total farm revenue	56 780 SEK				
Feed ration	FR 1				
Grass yield	8000 kgDM/ha				
Variable machinery cost SEK/ha	3 591 SEK				
CTF	Grass	W-Wheat	S-Barley	OSR	Oats
Crop distribution hectare	161,5	62	20,7	35	20,7
Total farm revenue	61 064 SEK				
Feed ration	FR 1				
Grass yield	8000 kgDM/ha				
Variable machinery cost SEK/ha	3 057 SEK				
Profit *(MaxπCTF-MaxπRTF)*	**4 284 SEK**				

The third alternative that is summarized in Table 9 reveals a slightly different result compared to alternative 1 and 2. Even though CTF yields the highest revenue in this case as well, it is by a much smaller margin. This is mainly due to the assumption of an extended period of high yielding grass ley, by one year. This assumption changes the crop rotation allowing more wheat in favour for the less profitable nurse crops, barley and oats. However, this only results in a change in the crop rotation by the increase of wheat from 49.2 to 62 ha. Barley and oats decrease by 6.5 hectares each from 27.2 to 20.7. The variable machinery cost for the RTF grass machinery system is 3591 SEK/ha and 3057 SEK/ha for CTF. Feed ration alternative 4 (FR4) is not part of the optimized solution despite high, MJ/kgDM and cp as g/kgDM values due to the early harvest assumption. Presumably the result is due to the prerequisite of unaltered grass yields in the early harvest assumption. The cost reduction of 16 % for FR 4 compared to FR 1 does not compensate the benefits of increased wheat area. Therefore, the less grass consuming feed ration 1 is used in both RTF and CTF optimized solutions. The revenue for RTF silage production system amounts to 56 780 SEK compared to 61 064 SEK for the CTF system. The optimized solution reveals that CTF is the most profitable silage production system in this case delivering a total farm profit of 4284 SEK by using CTF instead of RTF.

5.4 Sensitivity analysis

There may exist possible weaknesses and irregularities in the data used in this study. Hence, a sensitivity analysis simulating two possible changes in external factors is conducted.

5.4.1 Changes in grain price

This section of the sensitivity analysis examines the outcome from the three scenarios (Table 10) with regard to either a 10 % decrease or increase in grain prices. The grain prices affect not only the gross margin of the crops, and thereby the value of land but also the effective price of silage, λ i.e. the implicit price of silage estimated by the Lagrangian multiplier for constraint (10) and (11), as well as the feed price. In this test prices for wheat, barley, oilseeds and oats are adjusted in the gross margin calculation. Moreover the price for barley in the feed ration is also adjusted.

Table 10: Presentation of differences in revenue from RTF and CTF due to increased grain price and the feed ration presented from the optimization model solution

	Grain Price + 10%		**Grain Price - 10%**	
	Profit	Feed ration	Profit	Feed Ration
Alt. 1	170 470 SEK	FR 1	118 486 SEK	FR 1
Alt. 2	191 914 SEK	FR 3	174 467 SEK	FR 3
Alt. 3	9 474 SEK	FR 1	- 1 267 SEK	FR 1

In Table 10 the difference in profits, Equation (23), are presented. The results from this analysis show that the profits of a CTF grass system are affected substantially by the grain price and the relation to cereals as an alternative crop. When adjusting the feed costs in the feed rations to changes in grain price the potential price correlations with protein feed stuffs are taken into account. A report from the Swedish Board of Agriculture (2011) examining the competiveness on the Swedish feed stuffs market found no significant correlation between Swedish grain prices and international trading prices for soya. Consequently, the prices for protein feed concentrate is not adjusted when grain prices increase or decrease in this part of the sensitivity analysis. For all alternatives except one CTF still remians profitable regardless of a 10 % fluctuation in the grain prices. In general an increase in grain prices result in an increase in the profitability of converting to the CTF system.

5.4.2 Interest rate on machinery

The cost of capital for the machinery in this study is based on an annuity factor, where the depreciation is accounted for through the economic life-time. When using this method results are affected by the interest rate. When the machinery economic life-time exceeds 10 years the relevance of the interest rate increases. For this study a fixed ten year nominal interest rate of 4.10% (www, Landshypotek, 2014) is assumed. Recent inflation reports from the Swedish central bank states 0,0 % inflation for July 2014 (www, riksbanken, 2014). Using these figures in the Fischer Equation (18) provides a real interest rate equal to the nominal interest rate. Lagerkvist (1999) states that the real interest rate for Swedish farmers for the first half of 1990's ranges from 5,37% to 7,91%. With regard to the current financial situation in Sweden, compared to the early 1990's, the rage from 4,1% to 6,1% in this sensitivity analysis may be considered as representative for the current financial state in Sweden. In this part of the sensitivity analysis the results are analysed if interest rates are increased by 1 or 2 percentage units.

Table 11: Summary of profits with regard to adjusted interest rates for machinery.

Intesrest rate +1% & +2%				
	Alt. 1 (FR 1&2)	Alt. 2 (Fr 1 & 3)	Alt. 3 (FR 1 & 4)	Fixed MC
0%	144 728 SEK	177 315 SEK	4 284 SEK	1 161 985 SEK
1%	134 380 SEK	166 967 SEK	- 6 063 SEK	1 266 255 SEK
2%	123 816 SEK	156 403 SEK	- 16 628 SEK	1 372 811 SEK

Table 11 displays the difference in profits resulting from the adjusted interest rates. In general profits decrease with higher interest rates. The explanation is that CTF system is more capital intensive. However for alternative 3, comparing feed rations one and four, a minor profit has now turned to loss. Alternative 3 has proven to be a less desirable alterative revealing losses associated with CTF in all the sensitivity analyses. For alternative one and two the profits are lower but CTF still remains profitable.

6 Analysis and discussion

This chapter presents an analysis of the empirical results with respect to the research questions posed in chapter one on the basis of the modelling framework in chapter two. This analysis involves a reunification with the problem statement and objectives for this research project structured to first; compare the results and second; a presentation of relevant factors likely to affect the result. Finally, this analysis concludes a methodology discussion.

6.1 Comparison of results

Form the results, comparing the three alternatives; it is evident that the yield response from reduced field traffic induced by CTF is the most important factor affecting profitability when converting to controlled traffic on grass ley. Comparing alternative 1, 2 and 3 we clearly note that alternative three, high quality silage but no yield increase, displays only a fractional increase in profits due to CTF. One of the anticipated advantages of reducing field traffic is the possibility to grow a more clover rich silage with both higher energy and protein contents. With regard to previous studies (Frame, 1982; Hansen, 1996; Rasmussen and Møller, 1981) it seems to be a likely outcome. However, regarding the economic advantages, an increase in clover content without an overall yield increase does not provide sufficient economic motivation for the introduction of CTF. This tendency is accentuated in the sensitivity analysis where alternative three reveals that CTF is not profitable in three out of four simulations. In alternative two on the other hand, where 25 % higher protein content goes along with a 13% yield increase the calculation model show an increase in profits by 177 315 SEK. The higher intake of silage used in this alternative is a key factor and this is an effect of higher proportion of clover (10%) (pers. Comm Spörndly, R., 2014).

Although, to the best of my knowledge, no other studies have been conducted comparing economic benefits due to CTF in grass ley, other studies that target arable farming reveals similar results where farm profits tend to increase due to CTF. Kingwell and Fuchsbichler (2011) conducted a study in Australia where the dry climate enhances the benefits of CTF. This study reveals that the farm profit increase by 51% to 67% due to CTF. Alvemar and Johansson (2013) target economic benefits due to CTF for arable crops in Sweden. This study may be more representative given the geographical region compared to Kingwell and Fuchsbichler (2011). Alvemar and Johansson (2013) reveals a potential increase in farm profit due to CTF of 702 SEK/ha for a 500 hectare farm operating at 8 meter CTF module width. Compared to this study, targeting CTF in grass ley, the potential profit due to CTF amounts to 482 SEK/ha and 591 SEK/ha for alternative one and two respectively.

Given a comparison of the results it is worth to mention that the alternative feed rations (FR 2,3 and 4) intended to enhance the value of increased yield or silage quality only proved to be economically motivated for alternative two (FR 3). Alternative two, including both yield and clover content increase is clearly an interesting option. Otherwise feed ration 1 (FR 1) with the lowest silage share is found in the optimized solutions. This result relates directly to the alternative use of land where the benefit of making land available for economically favourable cash crops exceeds the value of reducing grain and protein concentrate share in the feed ration.

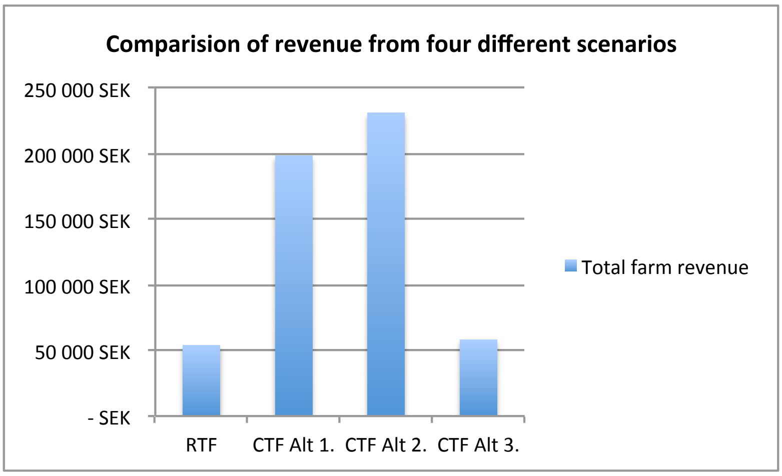


Figure 15: Comparison of farm revenues for RTF and CTF based the three alternatives

In Figure 15 the optimal values from the different yield outcome alternatives are summarized. Alternative one and two where, a 12% yield increase is assumed, increases the total farm revenue. However for alternative four where silage quality is assumed to be higher but yields stay at the same level as in the RTF case does not provide a significant increase in revenue.

6.1.1 Marginal value of silage energy and protein contents

To measure the value of improved silage yield and quality, for the different alternatives the marginal value, λ for the silage energy and protein contents, expressed as SEK/MJ measured in MJ/kgDM and SEK/AAT measured as AAT in g/kgDM is calculated. The marginal value is calculated using Equation (10) and (11) by changing the constraint to produce 1000 or more units. Consequently the model forces increase of production by 1000 units of MJ or AAT. By doing these for both MJ and AAT the marginal value of 1000 units of MJ and AAT each is calculated. The values are presented in Table 12.

Table 12: Marginal values of energy and protein for RTF and the three CTF alternatives

Marginal value (λ) of silage energy (MJ) and protein (AAT) content		
	SEK/MJ-MJ/kgDM	SEK/AAT - AAT/g/kgDM
RTF	0,1966	0,0372
CTF alt. 1	0,1632	0,0245
CTF alt. 2	0*	0,0243
CTF alt. 3	0,176	0,0264

The marginal values for energy and protein in the grass silage decrease as the grass yields and quality increase due to CTF, Figure 16. For CTF alternative two*, 13% yield increase and 10% clover increase, the system already produces a surplus of energy, thereby the marginal value amount to 0. For CTF alternative three the marginal values are still less that RTF but the assumption of similar grass yield to RTF increase the marginal value for energy protein in the silage. This implies that the implicit cost of producing energy and protein through ley decreases when the CTF system is introduced.

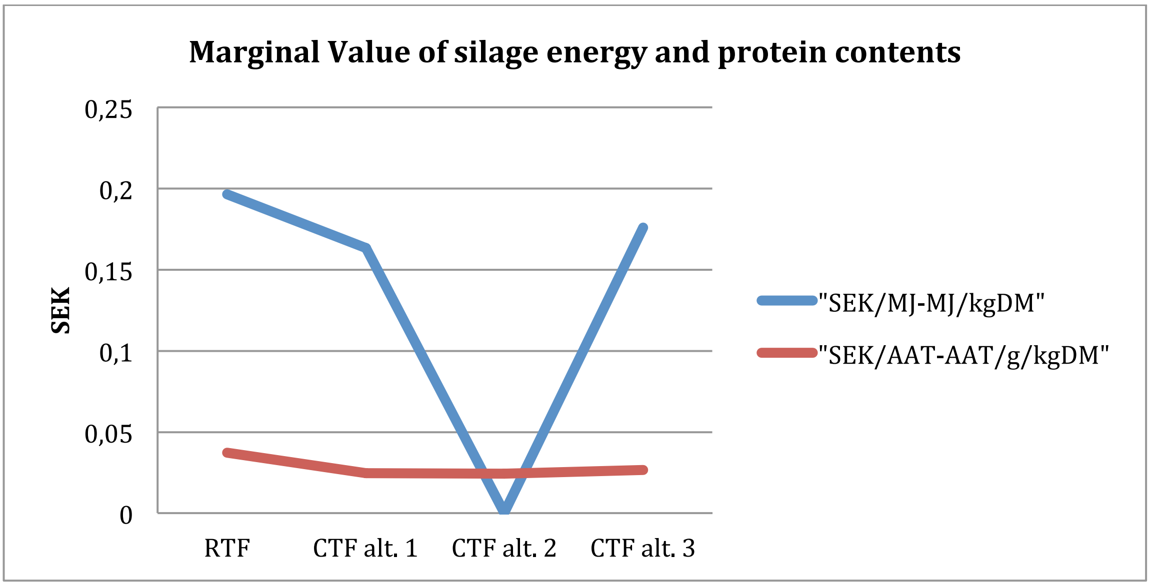


Figure 16: Changes to marginal value of silage energy and protein contents due to CTF

The marginal values for energy and protein in the silage produced follows the opposite pattern as the total farm revenues (Figure 15) where an increase in profits decreases the marginal value for silage energy and protein.

6.2 Possible factors which may affect the outcome of CTF

There are several interlinked factors affecting the profit of converting to CTF for grass silage production. The magnitude of the investments associated with CTF depends on the existing machinery system and the desired module width. The module width affects the tracked area and hence the yield outcome due to the non-trafficked soils and the return on investment.

Machinery cost

The machinery cost increases by adopting CTF. Adopting a larger CTF module width will induce larger machinery investments but the trafficked area decreases providing larger non-trafficked areas. With regards to the existing machinery system several machinery systems can be adopted minimizing the investment cost. As aforementioned in chapter 4 the 12-meter mower used in the calculations for this particular study is available in three different options. There are two cheaper alternatives, than the one used for this study, without collectors and without both collectors and conditioner. These alternatives may change the forage quality due to prolonged drying and soil contamination. Without the conditioner the drying period after cutting is prolonged affecting the silage dry matter content, especially if harvested in wet conditions. The lack of collectors will inevitably induce the necessity for raking, increasing the risk of soil contamination in the silage. These changes in forage quality cannot be evaluated in this thesis. Therefore the potential economic value of a CTF system using these machines is yet unknown. However it may be worth noticing that the two alternatives of this mower would induce a machinery cost per hectare (excl. fuel) of 4462 SEK/ha and 4547 SEK/ha compared to the original values for RTF of 4336 SEK/ha and for CTF 4736 SEK/ha. The figures include adjustment for tractor power requirements.

Module width and tracked area

The increase of module width as mentioned earlier decreases the tracked area and should then provide a potential to further increase yields due to the larger non-trafficed area. Large module widths require in general larger investments. However, there are alternatives suitable to adopt as a first step in the conversion to a controlled traffic system. An alterative is to use a six meter mower in a 12 meter system, this alternative is adopted by Jörgen Sønderby, Danish dairy farmer, who states that this system has produced a 10 % yield increase of the organic grass ley (pers. Comm, Sønderby, J., 2014). The tracked area for this system is 31 % providing a 9 % yield increase using Equation (22) and the yield data from Hansen (1996). Poul Sørensen, Danish dairy farmer uses an 18-meter CTF system on his dairy farm with 300 cows providing a large area of non-trafficked fields. To solve issues of large machinery investments for such a system when only growing 90 hectares of grass ley the farm uses a machinery contractor for the silage harvest. (pers. Comm, Sørensen, P.,2014) When discussing tracked area it is important to bear in mind that tracked area calculation often refer to theoretical square fields. The field shape affects the tracked area. However CTF might bring positive effects when providing a well considered driving pattern to random shape fields.

Yield outcome, DM yield and clover

The results from this study show that if a profit is to be made by converting to CTF the yields must increase. Even though there are multiple studies showing yield increases from no traffic machinery systems the expected yield increase must be regarded as an uncertain factor when converting to CTF.

6.3 Methods discussion

The choice of method and delimitations for this study most certainly affect the results and thereby quality, generalizability and validity of this study. In theoretical research, such as this project, the credibility in terms of connection to the real world must always be questioned and evaluated. In this section some alternative approaches to the research problem and their expected effects on the results will be presented.

The calculation model
To calculate the total farm revenue a mixed integer programming model is used. However there are other possible approaches for this. By using the agriwise software farm planning tool the total farm revenue can be calculated by simply adding the machinery and feed costs to the gross margin calculations and summarizing the total revenue from the different units of production. However, this method would not take into account the alternative value of land, comparing feed ration silage share to the value of additional land area available for cash crops. If this is to be regarded using this method several additional steps in the calculation process has to be made. Hence the use of a mixed integer programming optimization model.

Case study design
For this study a fictitious case farm is used. However, another possible approach would be to study the profitability of farms using CTF for their silage production. To the best of my knowledge as of today only one farm in Sweden uses the system. However interesting, such a study would not provide a generalizable result since the profitability of one company is likely to be affected by more than one specific factor such as CTF. Looking abroad for eligible objects of study there are several objects of interest in Denmark. However in Denmark there seems to be a difference in organization where farmers tend to use contractors for their entire silage harvest. This difference in structure should also affect the generalizability of results in a Swedish context. By examining the research questions, one could argue that an approach of studying specific companies e.g. research question one regarding the investment cost for a CTF system would probably give a rather specific answer per company included in the study. A company case study would also have to make sure the comparisons regard the same years since prices my change. In theory, if a case study should provide similar results two identical farms with RTF and CTF would have to be found.

Qualitative method
An examination of qualitative approaches instead of the mixed method used in this study reveals that there are alternatives. By interview farmers using CTF and farmers interested in moving form RTF it would perhaps be possible to find other issues than economic factors to why only a few farmers use the system. In addition it would be interesting to know how the farmers using CTF have managed to solve such issues. The results from such a study would indeed be interesting but may not provide the answer to the research questions in this study. However the results in this study may increase the interest for CTF.

The following chapter presents the conclusions for this study.

7 Conclusions

The aim of this study is to research the profitably of CTF management system for silage production in grass leys. In this chapter the research questions are answered given the information obtained from the results of this study. The research questions this study intends to answer, presented in chapter 1.3, are:

1. What is the investment cost for a CTF system?
2. What factors are decisive for the profitability of this investment?
3. What are the total differences in farm profit margin between RTF and CTF?

The results from this study showed that:

1. The replacement value for the total machinery system increased by 1 420 000 SEK for CTF which, increases the annual cost of capital by 120 308 SEK. However the variable machinery cost for the CTF system decreases compared to the RTF system.
2. The existing machinery can allow lower investment costs. However if there are sufficient increases in yield and clover content due to CTF this may justify the investment. A higher grain price enhances the profitability of the CTF investment but positive changes due to silage quality and yield increase are the main factors that support the CTF investment.
3. The differences for the three alternative results differ from increased profits of 4824 SEK to 177 315 SEK. The profit margin for RTF in this study is 0,5% which is relatively close to the recent government report, suggesting a zero profit margin for large dairy farms in Sweden (SOU, 2014). The introduction of CTF could increase the profit margin by 1,25% and 1,55% for alternative 1 and 2 presented in chapter 5.

This study shows that CTF is profitable in a large dairy farm context, for the western part of the GNS region, if reduced field traffic induce higher silage yields. If CTF also would provide conditions that support a higher clover content in a grass-clover ley the profitability of CTF increases. If CTF provides only a higher feed quality but not a yield increase CTF is marginally profitable. From these findings it is concluded that the profits attributable to higher silage yields are not only a product of reduced feed costs but mainly due to increase in land available for cash crops.

7.1 Future research.

In the future there might be more farms using CTF. If that would be the case the possibility to conduct a study using real farm data may enhance the validity and generalizability of the results. The use of real farm data would give more depth to the calculations of the potential economic benefits due to CTF. There are previous studies conducted focused on only arable farming, an interesting subject for future research might be to calculate potential profits due to CTF in silage and cereals production on one single farm. Another approach would be to conduct a study focused on organic production methods. In organic farming the agronomic benefits from CTF may increase the profitability of the system more than in conventional farming. The value of increase protein contents of silage could replace expensive organic protein feed stuffs. Consequently reducing the need for home grown legume protein crop such as faba beans possibly increasing total farm revenue. In the proposed future studies, there is a possibility to use the model developed in this to calculate the economic benefits due to CTF.

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Personal meeting, 5 July, 2014

Hans Larsson
Head of Market planning, Lantmännen maskin
E-mail correspondences 8 August 2014

Rolf Spörndly
Research Group Leader, Feed Science Division, Department of Animal Nutrition and Management, Swedish University of Agricultural Sciences (SLU)
Personal meeting 16 June and 19 August 2014

Jørgen Sønderby
Organic dairy farmer, Knepperhedegård, Bjerringbro, Denmark
Personal meeting 20 June 2014

Poul Sørensen
Dairy farmer, Fjerritslev, Denmark
Personal meeting 21 June 2014

Appendix 1: Bodil Frankow-Lindberg, 2014-05-26

Meeting with Bodil Frankow-Lindberg,
Professor Agricultural Cropping Systems, Department of Crop Production Ecology, Swedish University of Agricultural Sciences (SLU)
Date: 26 May 2014
Location: Uppsala
Attendants: Hans Alvemar and Bodil Frankow-Lindberg

During this meeting the use of field trial data from Hansen, 1996 were discussed. Bodil notes that the trials seems to be conducted with a correct method but the use of Alskie clover may be regarded as "out of date" with consideration to contemporary seed mixtures.

General topics regarding cultivation of grass-clover leys and methods to achieve desirable botanical composition were discussed, giving the author additional knowledge to the topic.

The difficulties in finding accurate figure for average silage yields were discussed and Bodil recommended the use of Henriksson, et al., 2012, which according to Bodil is an accurate source for average silage yields compared to the official statistics from the Swedish Board of Agriculture.

Appendix 2: Christer Johansson, 2014-07-26

Meeting with Christer Johansson
Energi och teknik rådgivare (Agricultural techincal advisor), LRF Konsult Linköping
Date: 5 July 2014
Location: Linköping
Attendants: Hans Alvemar and Christer Johansson

Christer Johansson is a technical advisor for farmers at LRF Konsult, Linköping specializing in grass leys and silage machinery. During this meeting the proposed machinery system for the RTF and CTF alternatives used in this study were presented and discussed. Based on Christer knowledge, from frequent farm visits in his line of work, we dissected the RTF system to make sure that it is representative for a typical large scale dairy farm.

Different alternatives to the proposed CTF system were discussed, the author presented pictures from his findings regarding grass harvest machinery at the agriculture exhibition Grass land 2014 in Denmark. A 12-meter CTF system for the silage harvest where determined. However, Christer raised some questions regarding the assumption that the farmer owns a self-propelled silage harvest. Christer suggest that the use of a machinery contractor should be taken into account.

When discussing the different option to machinery system the possible changes to silage quality are evaluated. However, this is very difficult to answer when using energy and protein parameters in the calculation model.

Appendix 3: Rolf Spörndly, 2014-06-16 and 2014-08-19

Meeting with Rolf Spörndly
Research Group Leader, Feed Science Division, Department of Animal Nutrition and Management, Swedish University of Agricultural Sciences (SLU)
Date: 16 June and 19 August 2014
Location: Uppsala
Attendants: Hans Alvemar and Rolf Spörndly

At the first meeting, in June, the feasibility of including changing feed ration values for this study were discussed. Several field trials were presented to Rolf with focus on how changes to energy and protein contents in silage should be evaluated from these trials. The author was presented to a calculation model for feed rations intended to use for this thesis.

At the time of the second, in August, meeting the possible yield quantity outcome of CTF has been determined. However, the literature review had found no energy and protein data form field trial with trafficked and non-trafficked soils. During this meeting the three alternative feed rations were determined with the basis of yield increased and assumed clover increase, based on previous research. Rolf designed adjusted feed rations for all of these alternative outcomes.

Appendix 4: Jørgen Sønderby, 2014-06-20

Meeting with Jørgen Sønderby
Organic dairy farmer, Knepperhedegård, Bjerringbro, Denmark
Date: 20 June 2014
Location: Bjerringbro
Attendats: Hans Alvemar, Hans Henrik Pedersen and Jørgen Sønderby

Jørgen Sønderby farms his land using a CTF system since 2006. The farm holds 265 dairy cows keep in an organic production system. The silage is produced of 200 hectares of grass-clover ley, the soils on Knepperhedegård are on average 15-20% clay content loams. In the crop rotation grass is altered with beans, and carrots, which expose the soils to very heavy machinery traffic. Form using CTF Jørgen has experience a 10% yield increase on his grass leys, he notes that the effects are most significant in sloping field where wheel slip during wet conditions previously were prevailing to regrowth. Another observation at Knepperhedegård is that weeds tend to establish in the traffic lanes. At the moment Jørgen uses a 12-meter CTF system with exception for the mower operating at 6 meter. The machinery system for grass harvests is:

- Mower 6 meter
- Tedder 12 meter
- Rake 12 meter
- Tractor pulled silage cutter wagon

The cultivation methods used between beans and carrots are: power harrow to 25 cm depth, ploughing and subsoil cultivation.

Appendix 5: Poul Sørensen, 2014-06-21

Meeting with Poul Sørensen
Dairy farmer, Fjerritslev, Denmark
Date: 21 June 2014
Location: Fjerritslev
Attendats: Hans Alvemar and Poul Sørensen

Poul Sørensen farms in Fjerritslev where he has 300 dairy cows and he grows 90 hectares of grass let, 90 hectares of maize and some cereals.

Poul has been farming with a CTF system since 2011. He does not state any yield increase figures but presents a very positive attitude to the system. Poul points out that CTF has reduces problems with deep tracks after slurry spreading on this sand based soils. Poul grows a 60/40 ryegrass white clover seed mix, field observation show great differences in clover content from the traffic lanes to the non-trafficked soils. According to Poul his grass leys ca. yield 6500 kg dry matter per year.

Poul uses a machinery contractor for his silage harvest. He has been involved in developing an 18-meter CTF system, which they use for the silage harvest providing large non-trafficked areas.

Appendix 6: Machinery summary, data sheet

Summary	
Fuel Price (SEK/l)	10,00 SEK
Real intrest rate	4,1%
Area tillalbe land (ha)	300
Salvage value after depreciation time	25%
RTF	
Tot. machinery cost (excl. fuel) SEK/ha	4 336 SEK
Fuel cost SEK/ha	1 089 SEK
Labour (h/ha)	6,64
CTF	
Tot. machinery cost (excl. fuel) SEK/ha	4 736 SEK
Fuel cost SEK/ha	1 042 SEK
Labour (h/ha)	5,68

Field operation annual average/ha	
Sprayer	2
Ferilizer	2
Slurry	1
Harrow	2
Roller	1

Grass ley management		
	RTF	CTF
Grass area	161,6	144
No. Years in ley	3	4
Cuts/years	3	3
Vallbrott?? Efter skörd?	2	2
Total cuts/year	2,67	2,75

RTF

Machine No.	Description	Replacement value	Depreciation time	Salvage value	PV of SV (SEK)	Annutiy factor	Cost of capital	Tractor - machine match	Capacity (ha/h)	Annual usage (h)	Maintenance cost	Maintenance SEK/ha	Fuel. l/h	Fuel cost
1	Tractor 170 KW extra equiped	1 455 000,00 kr	14	363 750,00	207 249	0,09530	118904			542	19 030,94	63,00		
2	Tractor 100 kW std. equiped	750 000,00 kr	12	187 500,00	115 769	0,10717	67971			679	12 813,98	43,00		
3	Frontloader 6 t	740 000,00 kr	18	185 000,00	89 755	0,07964	51783			600	8 538,55			
4	Mower 6 m (2,8 front+3,2 rear)	400 000,00 kr	12	100 000,00	61 744	0,10717	36251	Tractor 170 KW extra equiped	5,1	84	22 176,64	74,00	35	29574
5	Rake 9-12 m side	500 000,00 kr	15	125 000,00	68 415	0,09057	39089	Tractor 100 kW std. equiped	6	72	7 715,38	26,00	20	14364
6	Self-propelled forage harvester	2 700 000,00 kr	12	675 000,00	416 769	0,10717	244697		5	86	11 065,04	37,00	63	54298
7	Slurry Tanker 18 m3, 24m Spreader	1 250 000,00 kr	14	312 500,00	178 049	0,09530	102152	Tractor 170 KW extra equiped	2	150	91 637,17	305,00	35	52500
8	Combine 6.3 m, 220 kW	2 350 000,00 kr	20	587 500,00	263 023	0,07423	154926		2	69	6 778,33	23,00	44	30448
9	Rapid 4 m, grass seed box	585 000,00 kr	12	146 250,00	90 300	0,10717	53018	Tractor 170 KW extra equiped	2,1	66	14 331,11	48,00	30	19771
10	Plogh 5 tractor mounted	240 000,00 kr	12	60 000,00	37 046	0,10717	21751	Tractor 100 kW std. equiped	1	138	12 550,21	42,00	25	34600
11	Harrow 8 meter	300 000,00 kr	14	75 000,00	42 732	0,09530	24516	Tractor 170 KW extra equiped	5	55	5 106,64	17,00	25	13840
12	Roller (crosskill)8.2 m	250 000,00 kr	14	62 500,00	35 610	0,09530	20430	Tractor 100 kW std. equiped	5	60	2 710,43	9,00	18	10800
13	Fertilizer spreader, 2500l 24 m	130 000,00 kr	12	32 500,00	20 067	0,10717	11782	Tractor 100 kW std. equiped	6	100	5 492,34	18,00	15	15000
14	Sprayer 1200 l, 24 m (contractor)	300 000,00 kr	10	75 000,00	50 183	0,12391	30954	Tractor 100 kW std. equiped	5,5	109	14 864,31	50,00	15	16364
15	Tipper 12 t + silage equipment	155 000,00 kr	25	38 750,00	14 191	0,06469	9109	Tractor 100 kW std. equiped		100	3 625,72	12,00	15	15000
16	Tipper 25 t + silage equipment	415 000,00 kr	25	103 750,00	37 994	0,06469	24389	Tractor 170 KW extra equiped		100	9 707,57	32,00	20	20000
17	GPS	300 000,00 kr	10	75 000,00	50 183	0,12391	30954			1	10 000,00	33,00		
	SUM	**12 820 000 SEK**		**3 205 000 SEK**			**1 042 677 SEK**			**1977**	**258 144 SEK**	**832 SEK**		**326 559 SEK**

CTF

Machine No.	Description	Replacement value	Depreciation time	Salvage value	PV of SV (SEK)	Annutiy factor	Cost of capital	Tractor - machine match	Capacity (ha/h)	Annual usage (h)	Maintenance cost	Maintenance SEK/ha	Fuel. l/h	Fuel cost
1	Tractor 220 kW extra equiped	1 835 000,00 kr	14	458 750,00	261 376	0,09530	149959			420	15 148,61	50,00		
2	Tractor 110 kW, std. equiped	835 000,00 kr	12	208 750,00	128 890	0,10717	75675			572	11 636,65	39,00		
3	Frontloader 6 t	740 000,00 kr	18	185 000,00	89 755	0,07964	51783			600	8 538,55			
4	Mower 12 m	1 210 000,00 kr	12	302 500,00	186 774	0,10717	109660	Tractor 220 kW extra equiped	12	33	13 959,73	47,00	37	12210
5	Rake 12-15 m, center	575 000,00 kr	15	143 750,00	78 677	0,09057	44953	Tractor 110 kW, std. equiped	7	57	6 352,27	21,00	20	11314
6	Self-propelled forage harvester	2 700 000,00 kr	12	675 000,00	416 769	0,10717	244697		5	79	9 665,17	32,00	63	49896
7	Slurry Tanker 18 m3, 24m Spreader	1 250 000,00 kr	14	312 500,00	178 049	0,09530	102152	Tractor 220 kW extra equiped	2	150	91 637,17	305,00	35	52500
8	Combine 6.3 m, 220 kW	2 350 000,00 kr	20	587 500,00	263 023	0,07423	154926		2	78	8 209,27	27,00	44	34320
9	Rapid 4 m, grass seed box	585 000,00 kr	12	146 250,00	90 300	0,10717	53018	Tractor 220 kW extra equiped	2,1	74	16 744,21	56,00	30	22286
10	Plogh 5 tractor mounted	240 000,00 kr	12	60 000,00	37 046	0,10717	21751	Tractor 110 kW, std. equiped	1	156	14 406,58	48,00	25	39000
11	Harrow 8 meter	300 000,00 kr	14	75 000,00	42 732	0,09530	24516	Tractor 220 kW extra equiped	5	62	6 038,37	20,00	25	15600
12	Roller 12 m	320 000,00 kr	19	80 000,00	37 284	0,07679	21709	Tractor 110 kW, std. equiped	6	50	2 737,24	9,00	18	9000
13	Fertilizer spreader, 2500l 24 m	130 000,00 kr	12	32 500,00	20 067	0,10717	11782	Tractor 110 kW, std. equiped	6	100	5 492,34	18,00	15	15000
14	Sprayer 1200 l, 24 m (contractor)	300 000,00 kr	10	75 000,00	50 183	0,12391	30954	Tractor 110 kW, std. equiped	5,5	109	14 864,31	50,00	15	16364
15	Tipper 12 t + silage equipment	155 000,00 kr	25	38 750,00	14 191	0,06469	9109	Tractor 110 kW, std. equiped		100	3 625,72	12,00	15	15000
16	Tipper 25 t + silage equipment	415 000,00 kr	25	103 750,00	37 994	0,06469	24389	Tractor 220 kW extra equiped		100	9 707,57	32,00	20	20000
17	GPS	300 000,00 kr	10	75 000,00	50 183	0,12391	30954				20 000,00 kr	67,00		
	SUM	**14 240 000 SEK**		**3 560 000 SEK**			**1 161 985 SEK**			**1782**	**258 764 SEK**	**833 SEK**		**312 490 SEK**

Appendix 7: Screen picture of the optimization model for Alt. 1

			Oats Xj1	S-Barley Xj2	OSR Xj2	Winther Wheat Xj4	SRTF	SCTF	ICTF	IRTF	FR 1	FR 2	Cows Li		
Max π	201508	Control Variable	18,0	18,0	35,0	84,7	0,0	144,2	1,0	0,0	300,0	0,0	300,0		
		Gmj, cRTF, cCTF, CRTF, CCTF, Fri, Li	2048,5	2288,5	6423,5	5064,5	-6581,8	-6495,3	-1161985,1	-1042676,6	-7527,8	-7125,6	12756,0		
		Revenue or cost	36935,0	41262,4	224821,0	428926,3	0,0	-936912,8	-1161985,1	0,0	-2258339,0	0,0	3826800,0		
														<=>	
Area Ha (7)	300		1	1	1	1	1	1						<=	300
Number of Cows (8)	300												1	=	300
Feed (9)	0										1	1	-1	>=	0
MJ from silage (10)	-1,8626E-09						67200	75264			-36188,25	-38910,375		>=	0
AAT from silage (11)	-1,4901E-08						448000	501760			-241255	-259402,5		>=	0
Max OSR (12)	35				1									<=	35
Nursecrop (13)	0		1	1			-0,33	-0,25						>=	0
Oats=Barley 50/50 (14)	0		1	-1										>=	0
Binary-ICTF=IRTF (15)	1								1	1				=	1
Fixed MC ICTF (16)	-155,754743							1	-300					<=	0
Fixed MC IRTF (17)	0						1			-300				<=	0

Appendix 8: Feed ration 1

Calculation of total quantity of feeds

Ration name:

Yield, kg ECM:	**9150**	**Roughage %: 55**	**Organic%:**	**0**	**Home grown %:**	**62**	**No of cows**	**1**	**Indoor period, days** 120

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**sin**	**sin**
ECM	*43*	*41*	*39*	*36*	*33*	*29*	*26*	*23*	*20*	*10*	*0*	*0*
kg DM silag	10	10	10	10	10	10	10	10	10	10	6	7
kg straw												
kg Grain	9	9	9	8	7	5,8	4,8	3,8	2,8	0	0	0,5
kg prot conc	7,5	6,7	5,6	5,2	4,8	4	3,6	3,2	2,8	1,5	0,8	1
Minerals							10	10	20	60	80	100
Kg DM	**24,4**	**23,7**	**22,7**	**21,5**	**20,3**	**18,5**	**17,3**	**16,1**	**14,9**	**11,4**	**6,8**	**8,4**
MJ/kg ts	12,2	12,1	12,1	12,0	11,9	11,8	11,7	11,6	11,4	10,8	10,7	10,8
AAT/MJ	8,0	8,0	7,8	7,8	7,8	7,7	7,6	7,6	7,5	7,2	7,2	7,2
PBV, g	277	221	145	143	141	117	115	114	112	94	50	50
% MJ	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**101**	**101**	**112**
% AAT	**105**	**105**	**103**	**102**	**102**	**101**	**100**	**100**	**100**	**96**	**96**	**107**
% cp	17	17	16	16	16	16	15	15	15	14	14	14
% rough.	**41**	**42**	**44**	**47**	**49**	**54**	**58**	**62**	**67**	**88**	**89**	**83**
% organic	0	0	0	0	0	0	0	0	0	0	0	0
% homegr.	51	52	54	56	58	62	65	68	72	88	89	85
% Ca	106	104	100	102	103	103	107	109	113	123	118	127
% P	107	106	104	103	103	100	102	101	102	101	111	116

	Sum per farm per year	**indoor per.**
	0	0
kg DM silage 2	3 447	1 133
kg straw	0	0
kg Grain	1 821	599
kg prot conc	1 424	468
	0	0
Minerals	9	3

Total/year	**Quantity**	**à SEK**	**Sum**	**DM**	**MJ /kg ts**	**AAT g/kg ts**	**PBV g/kg ts**	**cp g/kg ts**	**Ca g/kg ts**	**P g/kg ts**	**Rough %**	**Home grown %**	**Organic %**
ECM	9150	3,5	32025										
	0		0										
kg DM silag	3447	0	0	1	10,5	70	-1	120	6	2,7	100	100	0
kg straw	0	0,8	0	0,85	6,6	55	-54	40	3,3	1,1	100	100	0
kg Grain	1821	1,29	2349	0,87	13,1	94	-30	123	2,6	4	0	30	0
kg prot conc	1424	3,6	5128	0,87	13,6	145	80	305	11,2	5,6	0	0	0
	0		0	0,91									
Minerals	9	6	51	1					132	138	0	0	0

Total kg DM 6278

Feed cost other than forage, SEK/kg EC 0,82

Milk - Feed other than forage, SEK/cow per year: 24 497

Milk - Feed other than forage, SEK/cow and day: 67

Appendix 9: Feed ration 2

Calculation of total quantity of feeds

Ration name:

Yield, kg ECM: 9150 | **Roughage %:** 58 | **Organic%:** 0 | **Home grown %:** 65 | **No of cows** 1 | **Indoor period, days** 120

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**sin**	**sin**
ECM	*43*	*41*	*39*	*36*	*33*	*29*	*26*	*23*	*20*	*10*	*0*	*0*
kg DM silag	11	11	11	11	11	11	11	10,5	10,5	10,5	6	7
kg straw												
kg Grain	8,6	8,6	8,6	7,5	6,5	4,8	4	3,3	2,1	0	0	0,5
kg prot conc	7	6,1	5,1	4,9	4,6	4,2	3,6	3,3	3	1,3	0,8	1
Minerals							10	10	20	60	80	100
Kg DM	**24,6**	**23,8**	**22,9**	**21,8**	**20,7**	**18,8**	**17,6**	**16,3**	**15,0**	**11,7**	**6,8**	**8,4**
MJ/kg ts	12,1	12,0	11,9	11,9	11,8	11,7	11,6	11,5	11,3	10,7	10,7	10,8
AAT/MJ	8,0	7,9	7,7	7,7	7,7	7,7	7,6	7,6	7,6	7,2	7,2	7,2
PBV, g	252	189	120	134	140	156	135	133	143	80	50	50
% MJ	**100**	**100**	**100**	**100**	**101**	**100**	**100**	**100**	**100**	**103**	**101**	**112**
% AAT	**104**	**103**	**101**	**102**	**102**	**101**	**101**	**100**	**100**	**97**	**96**	**107**
% cp	17	16	16	16	16	16	15	15	15	14	14	14
% rough.	**45**	**46**	**48**	**50**	**53**	**58**	**62**	**65**	**70**	**90**	**89**	**83**
% organic	0	0	0	0	0	0	0	0	0	0	0	0
% homegr.	54	56	58	59	61	65	68	70	74	90	89	85
% Ca	106	104	101	103	106	109	111	112	117	125	118	127
% P	106	104	103	103	103	101	102	101	102	102	111	116

	Sum per farm per year	**indoor per.**
	0	0
kg DM silage 2	3 706	1 218
kg straw	0	0
kg Grain	1 662	546
kg prot conc	1 369	450
	0	0
Minerals	9	3

Total/year	**Quantity**	**à SEK**	**Sum**	**DM**	**MJ /kg ts**	**AAT g/kg ts**	**PBV g/kg ts**	**cp g/kg ts**	**Ca g/kg ts**	**P g/kg ts**	**Rough %**	**Home grown %**	**Organic %**
ECM	9150	3,5	32025										
	0		0										
kg DM silag	3706	0	0	1	10,5	70	-1	120	6	2,7	100	100	0
kg straw	0	0,8	0	0,85	6,6	55	-54	40	3,3	1,1	100	100	0
kg Grain	1662	1,29	2144	0,87	13,1	94	-30	123	2,6	4	0	30	0
kg prot conc	1369	3,6	4930	0,87	13,6	145	80	305	11,2	5,6	0	0	0
	0		0	0,91									
Minerals	9	6	51	1					132	138	0	0	0

Total kg DM 6352

Feed cost other than forage, SEK/kg EC 0,78

Milk - Feed other than forage, SEK/cow per year: 24 899

Milk - Feed other than forage, SEK/cow and day: 68

Appendix 10: Feed ration 3

Calculation of total quantity of feeds

Ration name:

Yield, kg ECM: 9150 **Roughage %: 59** **Organic%:** 0 **Home grown %:** 66 **No of cows** 1 **Indoor period, days** 120

Month	1	2	3	4	5	6	7	8	9	10	sin	sin
ECM	*43*	*41*	*39*	*36*	*33*	*29*	*26*	*23*	*20*	*10*	*0*	*0*
kg DM silag	11	11	11	11	11	11	11	11	11	11	6	7
kg straw												
kg Grain	8,9	8,8	8,8	7,7	6,6	4,9	4,1	3,2	2,3	0,5	0	0,5
kg prot conc	6,8	6	5	4,7	4,4	4,1	3,5	3	2,5	0,7	0,8	1
Minerals							10	10	20	60	80	100
Kg DM	**24,7**	**23,9**	**23,0**	**21,8**	**20,6**	**18,8**	**17,6**	**16,4**	**15,2**	**12,1**	**6,8**	**8,4**
MJ/kg ts	12,0	12,0	11,9	11,8	11,7	11,6	11,5	11,4	11,2	10,6	10,6	10,7
AAT/MJ	8,0	7,9	7,7	7,7	7,7	7,7	7,6	7,6	7,5	7,0	7,2	7,3
PBV, g	571	518	448	456	464	487	467	455	444	366	236	267
% MJ	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**105**	**100**	**111**
% AAT	**104**	**103**	**101**	**101**	**102**	**101**	**100**	**100**	**99**	**97**	**96**	**107**
% cp	18	18	17	17	17	17	17	17	17	16	16	16
% rough.	**45**	**46**	**48**	**50**	**53**	**58**	**62**	**67**	**72**	**91**	**89**	**83**
% organic	0	0	0	0	0	0	0	0	0	0	0	0
% homegr.	54	56	58	60	62	65	68	72	76	92	89	85
% Ca	105	103	100	102	104	108	110	112	116	122	118	127
% P	106	105	103	102	102	100	101	100	101	103	111	116

	Sum per farm per year	indoor per.
	0	0
kg DM silage 2	3 752	1 233
kg straw	0	0
kg Grain	1 717	565
kg prot conc	1 296	426
	0	0
Minerals	9	3

Total/year	Quantity	à SEK	Sum	DM	MJ /kg ts	AAT g/kg ts	PBV g/kg ts	cp g/kg ts	Ca g/kg ts	P g/kg ts	Rough %	Home grown %	Organic %
ECM	9150	3,5	32025										
	0		0										
kg DM silag	3752	0	0	1	10,4	70	30	150	6	2,7	100	100	0
kg straw	0	0,8	0	0,85	6,6	55	-54	40	3,3	1,1	100	100	0
kg Grain	1717	1,29	2215	0,87	13,1	94	-30	123	2,6	4	0	30	0
kg prot conc	1296	3,6	4667	0,87	13,6	145	80	305	11,2	5,6	0	0	0
	0		0	0,91									
Minerals	9	6	51	1					132	138	0	0	0

Total kg DM 6382

Feed cost other than forage, SEK/kg EC 0,76

Milk - Feed other than forage, SEK/cow per year: 25 092

Milk - Feed other than forage, SEK/cow and day: 69

Appendix 11: Feed ration 4

Calculation of total quantity of feeds

Ration name:

Yield, kg ECM: 9150 | **Roughage %:** 64 | **Organic%:** 0 | **Home grown %:** 70 | **No of cows** 1 | **Indoor period, days** 120

Month	1	2	3	4	5	6	7	8	9	10	sin	sin	tot.
ECM	*43*	*41*	*39*	*36*	*33*	*29*	*26*	*23*	*20*	*10*	*0*	*0*	300
kg DM silag	12	12	12	12	12	12	12	12	12	11,5	5	6	
kg straw											1	1	
kg Grain	8	7,6	7	6,4	5,4	4,5	3,3	2,1	1	0,6	0	0,5	
kg prot conc	6,1	5,6	5,3	4,6	4,2	3,4	3,2	3	2,5	0,2	0,8	1	
Minerals							10	10	20	60	80	100	
Kg DM	**24,3**	**23,5**	**22,7**	**21,6**	**20,4**	**18,9**	**17,7**	**16,4**	**15,1**	**12,3**	**6,6**	**8,3**	
MJ/kg ts	12,3	12,2	12,2	12,1	12,1	12,0	11,9	11,8	11,6	11,3	10,7	10,9	
AAT/MJ	7,7	7,6	7,6	7,5	7,5	7,4	7,3	7,3	7,2	6,5	7,1	7,1	
PBV, g	528	503	498	465	463	431	449	466	460	297	140	167	
% MJ	**100**	**100**	**101**	**101**	**102**	**103**	**103**	**104**	**103**	**113**	**99**	**111**	
% AAT	**101**	**101**	**101**	**100**	**100**	**100**	**100**	**100**	**98**	**97**	**93**	**105**	
% cp	18	17	17	17	17	17	17	17	17	15	15	15	
% rough.	**49**	**51**	**53**	**56**	**59**	**64**	**68**	**73**	**80**	**94**	**88**	**83**	
% organic	0	0	0	0	0	0	0	0	0	0	0	0	
% homegr.	58	60	61	63	66	70	73	76	81	95	88	85	
% Ca	103	103	104	104	105	106	111	116	119	120	111	121	
% P	101	101	100	99	98	97	99	98	98	101	105	110	

	Sum per farm per year	**indoor per.**
	0	0
kg DM silage 2	3 980	1 309
kg straw	61	20
kg Grain	1 415	465
kg prot conc	1 217	400
	0	0
Minerals	9	3

Total/year	**Quantity**	**à SEK**	**Sum**	**DM**	**MJ /kg ts**	**AAT g/kg ts**	**PBV g/kg ts**	**cp g/kg ts**	**Ca g/kg ts**	**P g/kg ts**	**Rough %**	**Home grown %**	**Organic %**
ECM	9150	3,5	32025										
	0		0										
kg DM silag	3980	0	0	1	11,2	72	26	150	6	2,7	100	100	0
kg straw	61	0,8	49	0,85	6,6	55	-54	40	3,3	1,1	100	100	0
kg Grain	1415	1,29	1826	0,87	13,1	94	-30	123	2,6	4	0	30	0
kg prot conc	1217	3,6	4381	0,87	13,6	145	80	305	11,2	5,6	0	0	0
	0		0	0,91									
Minerals	9	6	51	1					132	138	0	0	0

Total kg DM 6331

Feed cost other than forage, SEK/kg E(0,69

Milk - Feed other than forage, SEK/cow per year: 25 718

Milk - Feed other than forage, SEK/cow and day: 70